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The Effect of Leachate Contaminant on the Geotechnical Properties of Lateritic Soils: A case study of lateritic soils around Ilorin in Kwara State, Nigeria

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Abstract

The way out of hitches in soil engineering requires a detailed knowledge of the geotechnical properties of soils, which are, perhaps, one of the most complex materials to be studied. This is partly because geotechnical properties of soils are affected by several factors including leachate-contaminant. The aim of the study is to determine the effects of the leachate-contaminant on soils' behavior when used for engineering purposes. In order to determine the effects of leachate contamination on geotechnical properties of lateritic soils, four portions of lateritic soil samples collected around Ilorin and artificially contaminated with 0%, 5%, 10% and 20% leachate and their respective geotechnical properties such as specific gravity, particle size distributions, consistency limits and compaction were determined. The geotechnical results show that leachate contamination proportionally increased with the Atterberg limits and permeability values for the contaminated soils, but decreases in compaction parameters. For compaction tests, maximum dry density decreased from 15.9 kN/m^3 in the control sample to 14.4 kN/m^3 in contaminated soil at 20 % leachate concentration. The co-efficient of permeability values for soils contaminated with 0 %, 5 %, 10 % and 20 % leachate are 1.6×10^{-6} cm/s, 1.8×10^{-6} cm/s, 2.3×10^{-6} cm/s and 2.8×10^{-6} cm/s, respectively. The coefficient of permeability values increased with increase in leachate content. It was observed that the addition of leachate has adverse reducing effects on the strength and hydraulic properties of the contaminated residual soil. The study revealed that the use of leachate-contaminated soils in geotechnical engineering works should be avoided because it is inimical to life, money and properties.

Keywords: *Leachate; Contaminated soil; Residual soil; Atterberg limits; Geotechnical properties.*

1. Introduction

Human population is increasing on daily basis, so is the corresponding quantity of waste contending for space with man and its effect impairing the quality of environment [1]. In recent time, the impact of leachate or impurities on groundwater and soil have attracted a lot of attention because of its overwhelming environmental significance. The leachate from irregular landfills links directly to groundwater, and pollutes the groundwater as well as the hosting or local soil. Lateritic soils constitute an important unit of soil in parts of Nigeria [2-3]. It is common and abundantly found as near surface material (below humus layer) within soil profile, especially in the southwestern Nigeria [4]. Lateritic soil, in its natural existence sometimes possess good engineering properties that have made it useful for engineering works like roads, dam, building bricks and barriers in sanitary landfills [5- 11]. Lately, due to increased urbanization and waste generation in Nigerian cities, this unit of soil layer has been turned to repository of solid and liquid waste by government agencies and individual. Leachate generation within the waste is encouraged by the process of the decay of organic component of the waste in the presence of chemically active water. According to Stevenson and Buttler [12], humic substances with functional group such as carboxyl, carbonyl and phenolic hydroxyl are produced from the decay of organic component.

The effects of different impurities on natural properties of lateritic soils have been studied by several researchers with various deductions [1, 13-14]. Sunil *et al*. [15] reported that the chemical and geotechnical properties of lateritic soils are altered by increasing content of pH, while Indrawan *et al.*[16] documented that increasing amount of coarse-grained materials increased the saturated permeability and reduced the shrinkage potential of residual soil. A number of other related studies were carried out in order to investigate the geotechnical behavior of oil contaminated soil [17]. Most of the report shows that oil contamination significantly reduced Atterberg limits, maximum dry density, permeability and strength properties of soils, which in turns affects their use for any engineering construction work. George and Beena [18] artificially contaminated soil with proportion of municipally generated leachate and discovered that permeability and shear strength increased, while consistency limits values reduced with increasing percentage of leachate. In cities of Nigeria, sources of wastes generation are on the increase and irrational disposal of these wastes on open or excavated lands/dumpsite creates source of soil pollution due to generation of leachate. These dumpsites, when closed or abandoned are commonly acquired by government agencies or individual for development of civil engineering works such as shopping complex or mall, bank and residential houses etc. The effects of leachate-soil interaction on the underlying soil at such sites in Nigeria have not been well investigated or documented. However, such interaction may weaken the strength of soil [19], thus limiting their application in civil engineering works or making the superstructure a potential death trap. Pursuant to the above, this study was undertaken to investigate the effects of leachate contamination on some geotechnical properties of lateritic soil around Ilorin in Kwara State, Nigeria (Figure 1).

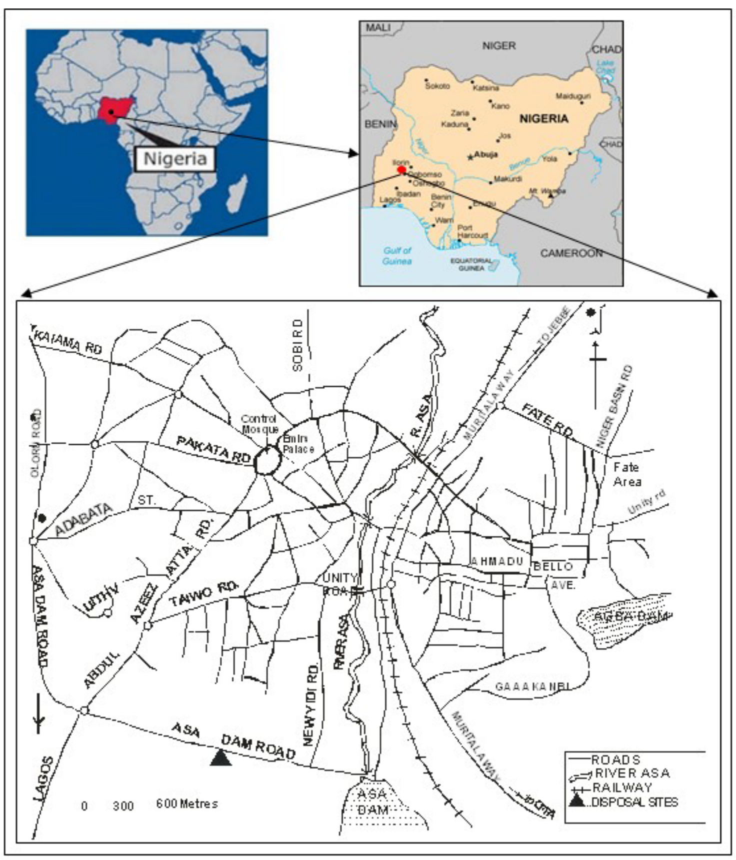

Figure 1. Map showing the study area and sampling site (modified after Ige *et al.* [8])

Geologically, the study area lies in the Precambrian Basement Complex area of southwestern Nigeria and is underlain by rock of metamorphic and igneous types [5]. The hydrologic setting of the area is typical of what is obtained in other Basement complex area; where the availability of water is a function of the presence of thick little clay overburden material and presence of water filled joints, fracture or faults within the fresh Basement rocks.

2. Materials and methods

The study was conducted within 1 year, between September 2020 and March 2021. About 5 kg of lateritic sample, derived from a granite-gneiss along Asa dam road, 500 m to Dangote Flour Mill (Figure 1) was collected for the purpose of preparing the leachate-contaminated samples. In order to ensure uniform conditions, sampling was limited to an area of one square meter within the same horizon. The samples were collected with the aid of digger, shovel and clean polythene bags at a depth of about 4m. At this depth, the sample is free from influence of plant roots, which may affect its properties. The sample was collected and stored in an airtight plastic container before being air dried at room temperature for 72 hours. The sample was pulverized into powdery state and air-dried for two weeks.

To prepare the leachate-contaminated soil, 10 liters of raw sample of leachate was collected from the base of over 20 years old waste dumpsite (at Amilegbe Bridge) in Ilorin, Nigeria. The dumpsite receives both hazardous and non-hazardous waste (domestic, industrial, hospital etc), which are the common waste generated in this part of the country [14]. The temperature, density and colour of the leachate are 21℃, 0.786 kg/l and darkish brown, respectively. A filter paper was placed on each face of the soil specimen to prevent the clogging of the perforated disks by the soil fines. After placing the bottom and top plate of the falling head permeameter, the nuts were fastened and assembled properly. The permeameter was then connected to a standpipe (when testing uncontaminated, soil the standpipe was filled with distilled water and during testing of contaminated soil, the standpipe was filled with leachate). The soil was saturated by allowing permeant (leachate) to flow continuously through the sample from the standpipe. Saturation of the soil sample was ensured under steady state flow conditions. The coefficient of permeability was calculated with the equation below:

$$k = \frac{2.303aL\left(log\left[{}^{h_1}/_{h_2}\right]\right)}{At}$$

where k = coefficient of permeability; a = cross sectional area of stand pipe (cm^2); L = height of soil sample (cm); A = cross sectional area of sample (cm^2); $h_1$and h_2 = initial and final height of permeant in stand pipe (cm) and t = time taken for drop from $h_1$to h_2 (sec).

The contaminated soil was divided into three parts, with each containing different proportions of leachate in order of 5%, 10% and 20% of dried weight. The contaminant was thoroughly mixed with soil and the mixture was permitted to cure in closed container at ambient temperature for 7 days. One uncontaminated sample was used as a control sample to monitor and establish the relationships between leachate contaminants and geotechnical properties of soils. Thereafter, preliminary geotechnical classification and identification tests such as particle size distribution analyses. Particle size distribution, specific gravity, dry and bulk densities, Atterberg consistency limits, compaction and coefficient of permeability tests were carried out on the four soil samples based on the British Standard (BSI 1377:1990). Each geotechnical test was performed twice on the same soil sample under the same condition in order to determine the reliability of the geotechnical test results.

3. Results

The basic geotechnical properties of the soil samples are presented in Table 1 and Figures 2-4. The grain size distributions result revealed 6% gravel, 47% sand and 47% fine (Table 1). The liquid limit, plastic limit and plasticity index values for uncontaminated soil with 0% leachate are 48.5%, 23.3% and 25.2%, respectively. The liquid limit, plastic limit and plasticity index values for the soil contaminated with 5 % leachate are 51.4%, 25.2%, and 26.2%, respectively. The liquid limit, plastic limit and plasticity index values for the soil contaminated with 10 % leachate are 56.3%, 28.4% and 27.9%, respectively. The liquid limit, plastic limit and plasticity index values for the soil contaminated with 20 % leachate are 61.7%, 33.4% and 28.3%, respectively. The specific gravity values increased from a maximum of 2.63 in sample contaminated with 20% leachate up to 2.67 in uncontaminated sample. On the contrary, the bulk density values ranged a minimum of 1.27 g/cm^3 in uncontaminated sample to a maximum of 1.83 g/cm^3 in sample contaminated with 20% leachate. For uncontaminated soil, the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are 20.3% and 15.9 KN/m^2, respectively; while the 5% leachate contaminated soil has OMC and MDD values of 20.8% and 15.6 KN/m^2, respectively (Figure 2). The OMC and MDD values for the 10% leachate contaminated soil are 22.0% and 15.5 KN/m^2, respectively, and 24.5% and 14.4 KN/m^2, respectively for the 20% leachate contaminated soil. The co-efficient of permeability values for soils contaminated with 0 %, 5 %, 10 % and 20 % leachate are 1.6×10^{-6} cm/s, 1.8×10^{-6} cm/s, 2.3×10^{-6} cm/s and 2.8×10^{-6} cm/s, respectively (Figure 4).

Table 1. Geotechnical characteristics of control and oil-contaminated soil samples.

Parameters	Control sample	Percentage of dry weight of base oil		
	0.0 %	5.0%	10.0%	20.0%
Atterberg limits Liquid limit	48.5	51.4	56.3	61.7
Plastic limit	23.3	25.2	28.4	33.4
Plasticity index	25.2	26.2	27.9	28.3
Specific Gravity	2.67	2.67	2.66	2.63
Density tests (g/cm^3)				
Bulk density	1.27	1.72	1.79	1.83
Dry density	1.25	1.18	1.18	1.20
Compaction tests				
Optimum moisture content (%)	20.3	20.8	22.0	24.5
Maximum dry density KN/m^2)	15.9	15.6	15.5	14.4
Grain size distribution of control sample	Gravel=6%	Sand = 47%,		Fine =47%

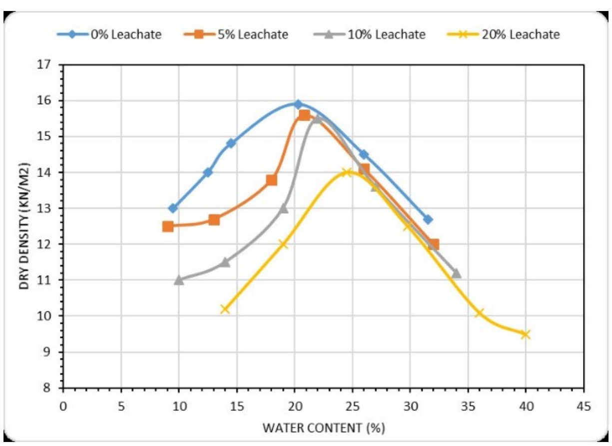

Figure 2. Compaction curves for lateritic soils with different leachate content

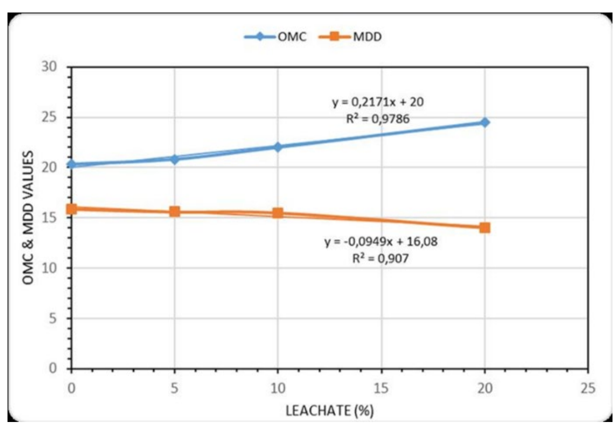

Figure 3. Relationship between compaction parameters and leachate content

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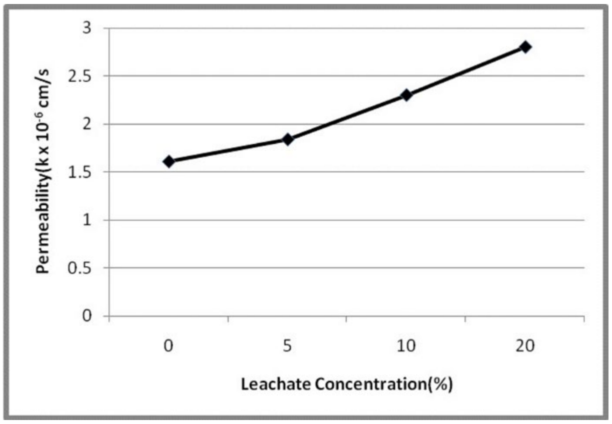

Figure 4. Variation in coefficient of permeability at different leachate content.

4. Discussion

The summary of results obtained from moisture content, liquid limit, plastic limit and plasticity index analyses are presented in Table 1. It is clear from that liquid limit, plastic limit and plasticity index increase with increase in leachate content. This trend may be due to polarized nature of the moisture content. The polarized water is attracted by negatively charged clay surface, thus influences the orientation of water around clay particles. Gillot [20] reported that clay soils with non-polarized fluid do not have plasticity properties. Crude oil-waste is a non-polarized fluid, as the oil is evenly mixed with the samples; it covers the grains and reduces water-soil interaction. This brings about increase in the consistency limits as the leachate content increases. The compaction is carried out to improve qualities of soils for suitability in engineering construction works. Light energy (standard proctor) of compaction was used to compact both control and artificially contaminated samples. By comparing the values of the optimum moisture content (OMC) and the maximum dry density (MDD) in the uncontaminated sample and contaminated samples, there was a noticeable departure in the values of OMC and MDD of uncontaminated and contaminated soils as the leachate content increases. OMC increases with increasing content of leachate, while MDD decreases as the leachate content increases. This result is consistent with other related studies by Shah *et al*. [21] on oil contaminated soils. The MDD values for contaminated soils showed a sharp and consistent departure from 15.9kN/m^2 obtained for control samples to 15.6-14.4kN/m^2 in contaminated soil as the proportion of leachate increases. These results are consistent with Shah *et al*. [21] study on oil-contaminated material. For the energy of compaction, the MDD consistently decrease with increase in leachate content while the OMC increases (Figure 3). These could be due to the lubricating effect of the presence of leachate, which prevents effective compaction. Also, the presence of leachate reduces the amount of water content needed to reach MDD. The results are similar to findings of Al-sanad *et al.* [3] who reported that at excess oil-waste content, the shape of the curve will be odd. The coefficient of permeability of any soil is dependent on several factors such as fluid velocity, pore-size distribution, grain size distribution, void ratio, roughness of mineral particles, and degree of saturation [22]. With the falling head permeability tests carried out on both contaminated and uncontaminated samples to compare the coefficient of permeability, there was increase in leachate concentration as the co-efficient of permeability of the contaminated soil increases (Figure 4). This increase in coefficient of permeability is attributed to chemical reaction between the leachate and the clay minerals. It is reported that strongly acidic and strongly basic liquids can dissolve clay minerals [23]. The dissolution of clay mineral particles by leachate increases the effective pore space and hence, the hydraulic conductivity increases. Sunil *et al.* [15] reported that the cementing agents in soils help to bind the finer particles together to form aggregates. However, strongly acidic conditions lead to the destruction of soil structure. Hence, as the particles are percolated by permeant, they clog pore spaces. Nevertheless, as dissolution progresses in the zones of clogging, particles will be removed and the hydraulic conductivity increases.

5. Conclusions

The effects of leachate contamination on some geotechnical properties have been investigated on lateritic soils with the index, compaction and permeability test performed in accordance with the BS standard. The Atterberg limits values of contaminated soils were higher than that of uncontaminated soil, while the maximum dry densities also dropped as leachate content increases above 5% in contaminated soils. Similar behavior was observed on compaction and co-efficient of permeability properties of the investigated soils. There was a noticeable departure in the values of OMC and MDD of control and contaminated soils as the leachate content increases. OMC increases with increasing content of leachate, while MDD decreases. The co-efficient of permeability values also increase in values with increasing percentage of leachate content in contaminated soils. The results showed that leachate contamination on soil has adverse influence on geotechnical properties of lateritic soil. Thus, use of old or abandoned open dumpsites civil engineering construction of superstructures should be discouraged and discontinued because of potential defects on soil strength, toxic consequences on lives, properties and eventual wastage of money.

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Competing interest

The authors have declared that no competing interest exists.

Data availability

All relevant data are within the paper and its supporting information files.

Significance statement

This study discovered that as the percentage or concentration of leachate contaminants increases in lateritic soil, the bulk density, Atterberg limits, permeability and OMC values increases, while there is decrease in MDD values, hence, reducing the strength and hydraulic properties of the soil which in turns affects their use for engineering construction work. This study can be beneficial government agencies or individual because it will serve as a guide and inform them to check leachate-contaminant in laterite soil before they use it for using for any engineering constructions works. Thus, it will in turn help in avoiding the potential death trap and losses that such soil possess.

Authors' contribution

Olusegun Omoniyi Ige conceived and supervised the work. Christopher Baiyegunhi wrote and revised the paper.

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