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Geotechnical and Water Quality Studies of the Kogi State Designated Waste Dumpsite, Southwestern, Nigeria

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Abstract

The recent increase in population and industrialization in Lokoja, Southwestern Nigeria has led to a corresponding increase in the quantity of waste generated and consequences on the quality of the environment. Thus, this research investigated the geotechnical and water quality attributes of a designated waste dumpsite at the Felele area for its suitability on a waste disposal site. Fifteen soil samples were obtained from the trial pits and boreholes for geotechnical analysis while ten water samples were taken within and outside the dumpsite for possible presence of heavy metals contamination. The control water samples showed no evidence of pollution while the leachate possessed a high concentration of physical parameters beyond the WHO and NAFDAC recommended permissible limits. Geotechnically, the samples are essentially sandy and gravelly with low clay content. The high permeability values ($1.40\times10^{-5} – 9.46\times10^{-7}$m/s), large grain sizes, poor compaction properties and proximity to the highway make the site unsuitable for the development of sanitary landfills.

Keywords: *Landfill, water sample, Geotechnical, Water quality, soil sample*

Introduction

Environmental pollution and degradation as a result of urbanization and technological development are the problems currently facing many nations of the world (Daramola and Ibem, 2010; Hardoy et al., 2013). Nigeria is a nation that exemplifies municipal solid waste management problems in conjunction with population growth. It is the most populous country in Africa with over 140million people (NPC, 2007) and over the last 50 years has had the third largest urban growth rate in the world at 5.51% annually (Odewumi, 2002). In Nigeria, about 5900kg of municipal solid waste is generated per industry per day and 30kg per person per day as of 1995 with 75% of municipal solid waste (MSW) disposed of through open burning, 15% is disposed through into channels and rivers while 10% is thrown by the roadside (Osumah, 2019; Onipede and Bolaji, 2004). All these forms of disposal have direct and indirect effects (pollution) on the health and environment of man (Ajibade et al., 2021). Incineration and land disposal of waste have been practiced for centuries in parts of the world (Makarichi et al., 2018; Barles, 2014).Due to industrial developments and the explosion of the urban population, huge amount of various types of waste such as solid, liquid and gaseous wasteare produced on daily basis and are deposited chaotically at various dumpsites in Nigeria.

Sanitary landfill method of waste disposal has been found to be an effective and reliable method that solves problems of environmental pollution in many parts of the world(Kamaruddin et al., 2017; Tian et al., 2013). Developing countries like Nigeria rarely practice this method of waste disposal because of a suspected lack of awareness, lack of technical know-how to properly engineer the sanitary landfill system, or mostly as a result of the inability to discover or prospect for localized materials for its construction(Mama et al., 2021; Baaki et al., 2017).Utilisation of available and naturally occurring materials for the construction of a sanitary landfill in any region will ultimately reduce the huge amount of money that is being spent by governments,non-governmental organizations (NGOs), and individuals to treat, control, or completely eradicate some of the environmental pollution-related diseases. It will also prevent further attack of leachate on the geotechnical properties (strength) of soils are the foundation that structures are constructed upon. Hence, lives, money, and properties will be prevented from wastage, thereby bringing down the current recorded global figure (82,196,000) of lives that are lost to environmental pollution- related diseases (Olayemi, 2007).This research work therefore attempts to investigate the viability of sanitary landfill construction around Felele dumpsite in Lokoja by considering all criteria for its development. This study will allow maximum utilization of prospected natural resources to enhance a healthier environment.

Study Location

The study area is located around Felele area in the capital city of Kogi state, along the Lokoja-Abuja express way. Lokoja is a city in Nigeria that lies at the confluence of the Niger and Benue rivers and is the administrative capital of Nigeria's Kogi state (Popoola et al., 2022). Lokoja is located between latitude $7^0 49'$ north ofthe equator and longitude $6^0 44'$ east of the Greenwich meridian and it's situated at an elevation of 53 meters above sea level (Alabi, 2009). It has developed into an urban centre attracting people from different parts of the country/world for greener pastures. This has therefore tremendously increased the population of the city. The city has grown into a full commercial and industrial status in the last ten years and there would have been a simultaneous increase in solid waste generation rate especially with the establishment of industries. The geology of Nigeria comprises both sedimentary basins and the basement complex as indicated in figure 1 below.

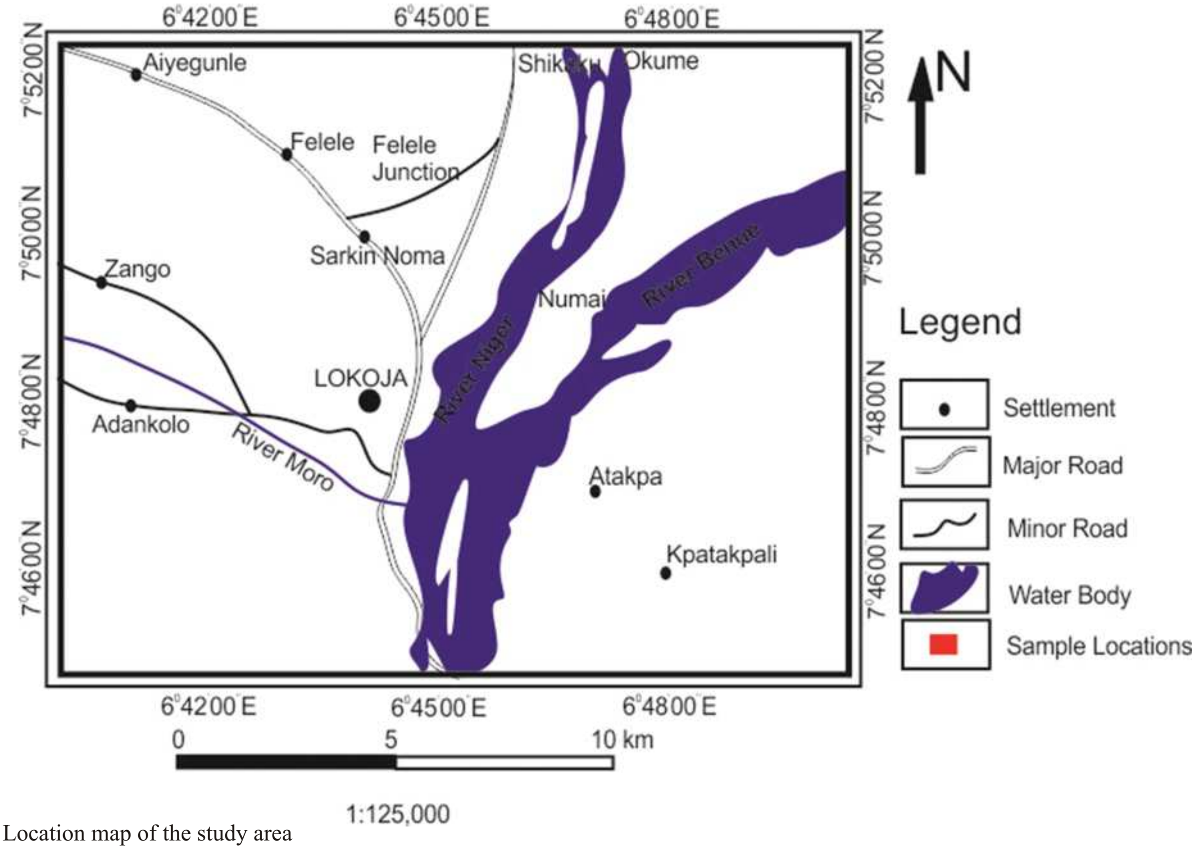

Fig. 1: Location map of the study area

Methodology

Soil Sampling

Soil samples were collected with the aid of a digger and shovel into sample sacks and labeled accordingly for easy identification. Soil samples are collected at a depth of 1 m below the ground surface from fifteen different locations inside the Felele dumping yard and are designated as pit 1 to pit 15 by excavating the ground surface. The soil samples were later moved to the laboratory for geotechnical analyses. Geotechnical analyses were carried out in the Civil Engineering Department Laboratory at the University of Ilorin, Ilorin, Nigeria.

Laboratory Analysis

The soils were analyzed for various soil properties. The soil properties analyzed are the grain size characteristics, the Atterberg consistency limits, compaction(standard and modify), specific gravity, the moisture–density relationships, and the coefficient of permeability. These tests will enable this research work to discuss and determine the suitability of the selected location for the proposed landfill site.Different analyses were carried out such as bulk and dry density determination, specific gravity determination, grain size distribution analysis, Atterberg consistency limits, compaction test, and coefficients of permeability (k).

Presentation of Results

Contaminated and Control Water Samples

The results of cation, anion, and trace metal concentration of both well water and leachate presented in Table 1.

Atterberg Consistency Test

The results of the Atterberg consistency test carried out are shown in Table 2and the plot of moisture content against the number of blows is represented in Figure 2.Table 3 shows the plasticity values of the soil samples.

Table 1: Summary of the water samples for contaminated and control samples from the study area

Parameter	Unit(s)	Contaminated	Control	Contaminated	Control	Contaminated	Control	Contaminated	Control	Contaminated	Control	WHO (2004)
Ph		6.8	7.2	6.8	6.70	7.4	7.0	6.9	7.0	7.2	6.8	6.5
Specific Conductivities	µS/cm	3980	330	3760	250.0	4030	310.0	4210	300	3772	350.0	1000
Total hardness	Mg/l	708	139	662	120.0	705	175.0	790	176	678	170	500
Permanent hardness	Mg/l	413	-	297	-	413	-	347	-	289	-	
Alkalinity	Mg/l	448	191	465	135.0	408	125	507	200	422	190	
Dissolved solids	Mg/l	2171	170	2120	120.0	2187	150	2370	200	2105	170	100
Suspended solids	Mg/l	82	-	102	-	73	-	101	-	96	-	
Chlorides	Mg/l	637	0.50	714	2.50	714	0.50	795	0.5	763	0.5	200
Sulphates	Mg/l	93	-	64	4.0	90	4.0	104	-	110	2.0	200
Ammonium	Mg/l	10.45	-	13.76	-	9.71	-	15.26	-	11.65	-	
Nitrates	Mg/l	4.95	0.70	7.41	0.50	5.68	0.90	6.93	0.90	5.6	0.6	10
Calcium	Mg/l	227	20.0	210	24.0	175	19.0	165	30.0	212	26.0	75.0
Magnesium	Mg/l	4.31	21.60	5.02	15.5	5.23	30.80	6.37	24.50	5.27	25.5	0.2
Sodium	Mg/l	364	6.30	297	5.70	327	7.30	395	7.00	451	8.20	200
Pottassium	Mg/l	48	4.00	54	5.60	50	4.20	64	4.00	62	3.80	10
Iron	Mg/l	0.085	-	0.089	-	0.076	-	0.07	-	0.097	-	0.3
Copper	Mg/l	0.00972	-	0.00855	-	0.00735	-	0.00786	-	0.0084	-	2.0
Zinc	Mg/l	0.219	-	0.210	-	0.185	-	0.205	-	0.198	-	5
Lead	Mg/l	0.00655	-	0.00783	-	0.00692	-	0.00647	-	0.00676	-	0.01
Cadmium	Mg/l	0.00471	-	0.00525	-	0.00465	-	0.0054	-	0.00485	-	0.003
Chromium	Mg/l	0.00512	-	0.00665	-	0.00512	-	0.00714	-	0.00835	-	0.050
Nickel	Mg/l	0.0882	-	0.0071	-	0.00963	-	0.00863	-	0.0083	-	0.020

Grain Size Analysis

Since the samples contained both finer (d <0.075mm) and coarser (d > 0.075mm) soil grains, both sieving and hydrometer analyses were carried out to determine the gradation of the soil as well as their compaction potential. The hydrometer analysis was imperative because the finer grains exceeded 5% of the total soil sample (Nyika et al., 2020). The grain size analysis results are shown in Table 4 while the grain size curve is shown in Figure 3.

Compaction Test

The result of the compaction test on seven samples is presented in Table 5 and plotted in Figure 4 below. The result showed that the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) ranged from 1.58 to – 1.90g/cm^3 and from 14.0 to – 18.0% respectively.

Permeability

The results of the permeability test carried out on fifteen soil samples are presented in Table 6.

Discussion and Interpretation of Results

Water Analysis Results

The pH of the leachates ranges from 6.8-7.2 with an average of 7.02mg/l (Figure 5a) which falls within the

Table 2: Summary of Moisture content, Bulk density, dry density, and specific gravity results for the samples

Sample ID	Moisture content (w)	Bulk density (ρ)	Dry density (ρ_d)	Specific gravity
TP 1	16.0	1.85	1.59	2.66
TP 2	13.1	1.85	1.46	2.53
TP 3	13.9	2.14	1.88	2.69
TP 4	8.65	1.82	1.68	2.63
TP 5	10.9	1.71	1.54	2.60
TP 6	11.95	1.81	1.61	2.52
TP 7	5.8	1.59	1.74	2.76
TP 8	6.45	1.85	1.68	2.71
TP 9	7.15	1.81	1.83	2.63
TP 10	15.95	2.13	1.59	2.68
TP 11	9.1	1.74	1.48	2.68
TP 12	15.0	1.71	1.52	2.58
TP 13	14.3	1.74	1.49	2.54
TP 14	17.1	1.61	1.67	2.51
TP 15	16.9	1.54	1.55	2.51

World Health Organization (WHO) standard, National Agency for Food Drug Administration and Control (NAFDAC) as well as the National Standard for Drinking and Water Quality (NSDWQ) recommended values for safe drinking water. The alkalinity of the waste water was extremely high (Figure 5b) compared to the acceptable limit of the World Health Organization. The values of total dissolved solids (TDS) were higher in all the wells ranging from (well 1) 2171mg/l to– (well 5) 2105mg/l with an average of

Table 3: Plasticity values of the soil samples

Sample ID	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Remark
TP 1	16.0	55.0	21.6	33.4	Suitable
TP 2	13.1	56.0	17.9	38.1	Suitable
TP 3	13.9	18.0	12.4	6.6	Poor
TP 4	8.65	n/d	n/d	n/d	-
TP 5	10.9	30.0	15.1	14.9	Poor
TP 6	11.95	47.0	24.7	22.3	Suitable
TP 7	5.8	33.0	17.0	16.0	Marginally Suitable
TP 8	6.45	n/d	n/d	n/d	-
TP 9	7.15	n/d	n/d	n/d	-
TP 10	15.95	26.0	14.0	12.0	Poor
TP 11	9.1	34.0	19	15	Poor
TP 12	15.0	53.0	20.7	32.3	Suitable
TP 13	14.3	51.0	21.3	29.7	Suitable
TP 14	17.1	50.0	27.2	22.8	Suitable
TP 15	16.9	n/d	n/d	n/d	-

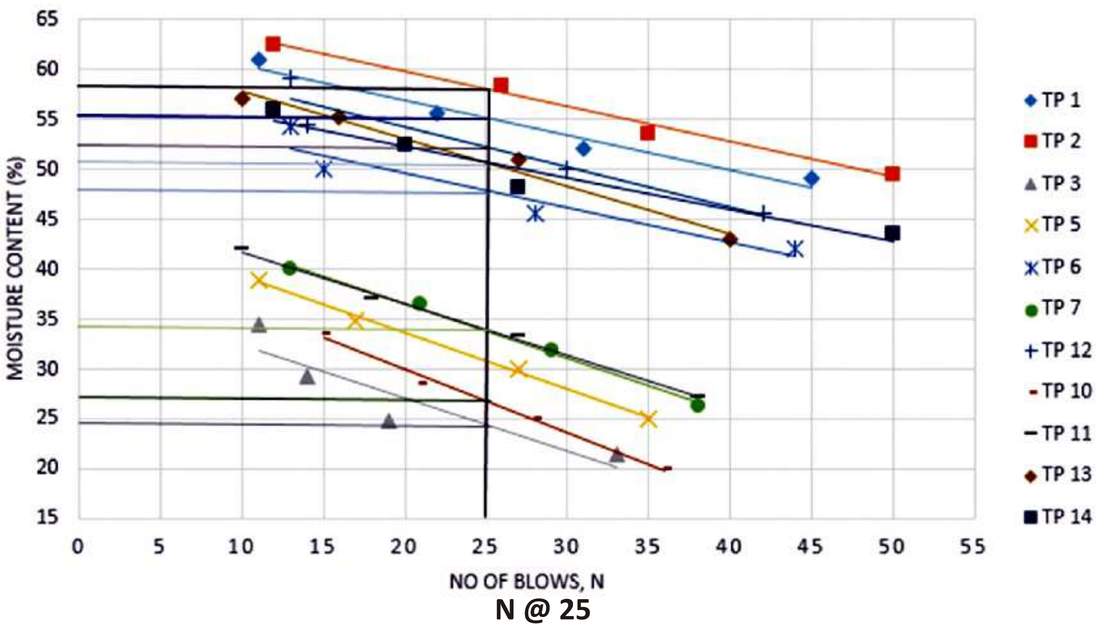

Fig. 2: Plot of Moisture Content against No of blows, N for the soil samples.

Table 4: Summary of the grain size analysis and soil classification

Sample ID	PI	% clay	% silt	% fine	% sand	% gravel	d10	d30	d60	Cu	Cc	Remark
TP 1	33.4	23	7	30	60	10	0.0008	0.06	0.5	625	9	Poor
TP 2	38.1	16	14	30	52	18	0.0015	0.006	0.5	333.3	0.048	Poor
TP 3	6.6	15	7	22	39	39	0.0013	0.3	2	1538.4	34.615	Poor
TP 4	n/d	2	10	12	73	15	0.009	0.14	0.62	68.8	3.512	Poor
TP 5	14.9	18	6	24	48	28	0.0014	0.08	1.5	1071.4	3.047	Poor
TP 6	22.3	32	18	50	24	26	0.0007	0.0019	0.4	571.4	0.013	Poor
TP 7	16.0	18	10	28	49	23	0.0013	0.8	1.2	923.1	410.256	Poor
TP 8	n/d	2	12	14	46	40	0.03	0.36	2.2	73.3	1.963	Good
TP 9	n/d	1	9	10	40	50	0.07	0.6	3	42.8	1.714	Good
TP 10	12.0	5	42	47	41	12	0.005	0.01	0.6	120	0.033	Poor
TP 11	15.6	18	4	22	48	30	0.0012	0.1	1.5	1250	5.556	Poor
TP 12	32.3	4	10	14	47	39	0.03	0.6	2	66.7	6	Poor
TP 13	29.7	25	9	34	30	36	0.0007	0.006	1.7	2428.6	0.030	Poor
TP 14	22.8	20	15	35	31	34	0.0013	0.007	1.8	1384.6	0.0209	Poor
TP 15	n/d	32	16	48	22	30	0.0007	0.0019	0.9	1285.7	0.0057	Poor

Key: SW & SM- Poorly Graded Sand, CL-Well Graded Sandysilt

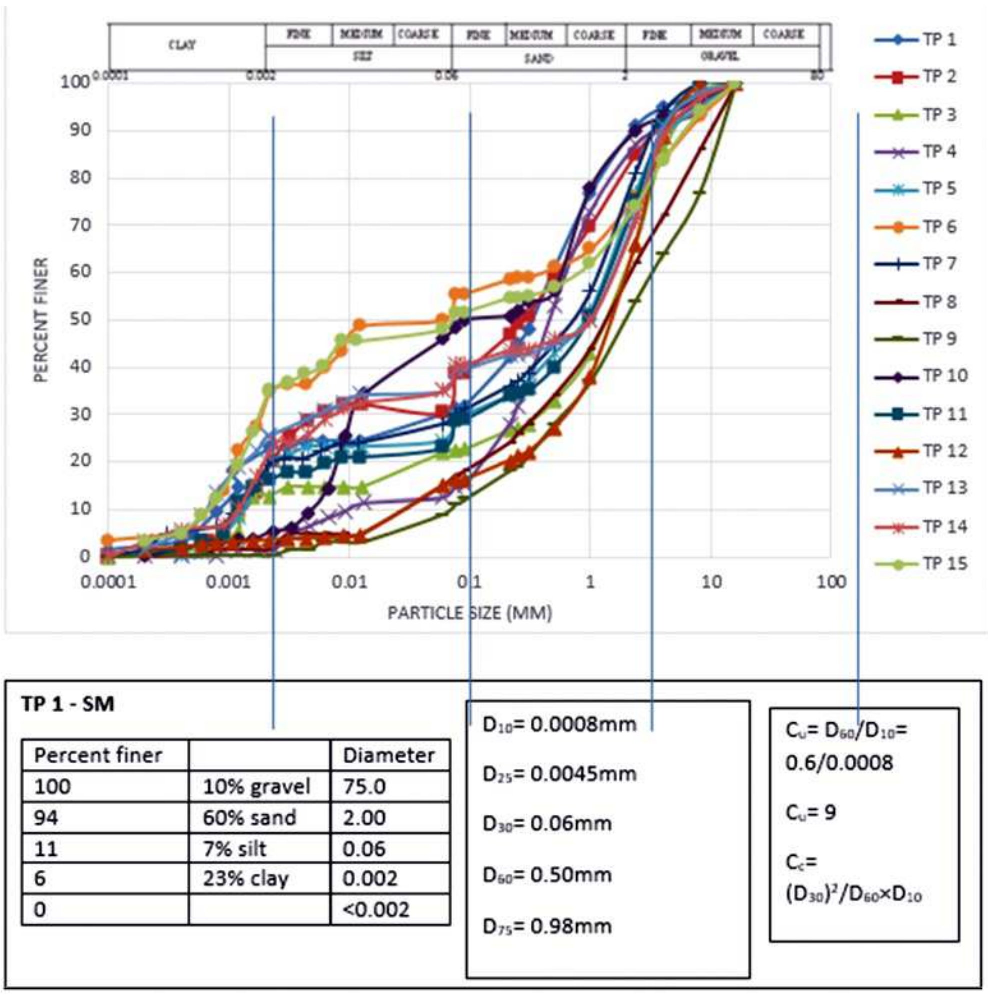

Fig. 3: Grain size distribution curves for the samples.

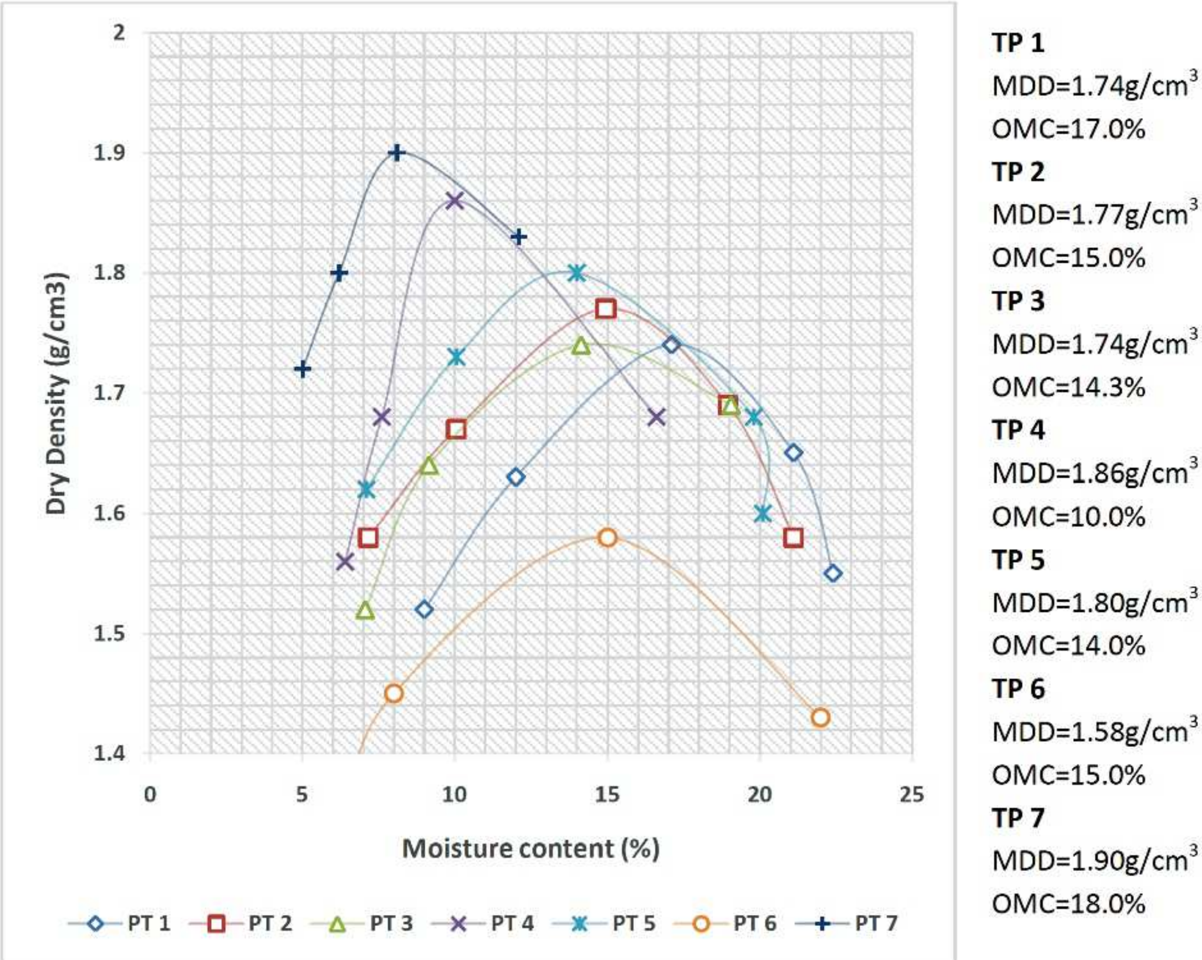

Fig. 4: Compaction curves showing the MDDs and the OMC of the samples

Table 5: Compaction test result and interpretation

Sample ID	MDD (g/cm^3)	OMC (%)	Remark
TP 1	1.73	17	Suitable
TP 2	1.77	15	Suitable
TP 3	1.73	14	Suitable
TP 4	1.86	10	Suitable
TP 5	1.80	14	Suitable
TP 6	1.58	15	Not Suitable
TP 7	1.90	18	Suitable

2191mg/l (Figure 5c) which was responsible for an increase in water hardness, the TDS values of all the samples were higher than permissible level since the threshold of acceptable aesthetic criteria for human drinking water is 100mg/l. The nitrate level in the leachate ranges between 6.1– 7.25mg/l (Figure 5d), these values are within the safe limits of WHO and Nigeria's standard for drinking water quality for nitrate (10mg/l). It is observed that though the nitrate concentration of the leachate is higher than that of the well water, both are still within permissible limits of relevant standards, particularly the WHO Standard. The concentration of chloride in the water samples taken from the surrounding wells ranges from 0.50 –to-2.50mg/l which are within the permissible limit while the leachate samples have chloride concentrations ranging from 637 to–739mg/l, these are extremely high when compared to the acceptable limit of WHO standard of 250mg/l. The sulphate concentration values ranges from 93mg/l to– 110mg/l with an average value of (92mg/l). These values are within the safe limit of WHO (WHO, 2004), NAFDAC, and Nigeria's standard for drinking water quality.

The results of the cations analysis of both well water and leachate revealed that calcium, sodium, and potassium concentrations in the well water are within WHO stipulated standards while that of the leachate is higher. Calcium concentration in the well water ranges from 19 to–26mg/l which is within the stipulated standard while the leachate calcium concentration ranges from 175 – 227mg/l which is above the WHO limit of 75mg/l. Also, the magnesium concentration of the well water ranges

Table 6: Coefficient of permeability for the samples and their interpretations

Sample ID	*K* (mm/sec)	*K* (m/sec)	Expected Drainage Condition	Interpretation
TP 1	3.09×10^{-4}	3.09×10^{-7}	Slightly High	Marginally Suitable
TP 2	1.90×10^{-4}	1.90×10^{-7}	Slightly High	Marginally Suitable
TP 3	3.53×10^{-3}	3.53×10^{-6}	High	Not Suitable
TP 4	1.40×10^{-2}	1.40×10^{-5}	High	Not Suitable
TP 5	6.34×10^{-3}	6.34×10^{-6}	High	Not Suitable
TP 6	9.46×10^{-4}	9.46×10^{-7}	Slightly High	Marginally Suitable
TP 7	4.50×10^{-2}	4.50×10^{-5}	High	Not Suitable
TP 8	7.10×10^{-2}	7.10×10^{-5}	High	Not Suitable
TP 9	4.20×10^{-2}	4.20×10^{-5}	High	Not Suitable
TP 10	3.64×10^{-3}	3.64×10^{-7}	Slightly High	Marginally Suitable
TP 11	3.47×10^{-3}	3.47×10^{-6}		Not Suitable
TP 12	7.66×10^{-4}	7.66×10^{-7}	Slightly High	Marginally Suitable
TP 13	6.53×10^{-4}	6.53×10^{-7}	Slightly High	Marginally Suitable
TP 14	2.14×10^{-4}	2.14×10^{-7}	Slightly High	Marginally Suitable
TP 15	2.41×10^{-3}	2.41×10^{-6}	High	Not Suitable

from 15.5 – 30.8mg/l while that of the leachate ranges from 4.31 – 6.37mg/l, both are beyond the WHO set limit of 0.2mg/l. It is important to mention that the magnesium concentration in the well water is higher than that of the leachate even though both are above permissible limits. In addition, the sodium concentration of the well water ranges from 5.7 to–8.2mg/l which falls within the permissible limit while the leachate concentration ranges from 297 to –451mg/l which is beyond the tolerable limit of 200mg/l. The potassium concentration in the well water ranges from 3.8 –to- 5.6mg/l which falls within the permissible limit while that of the leachate ranged from 48 to–64mg/l which is above the WHO permissible limit of 10mg/l.

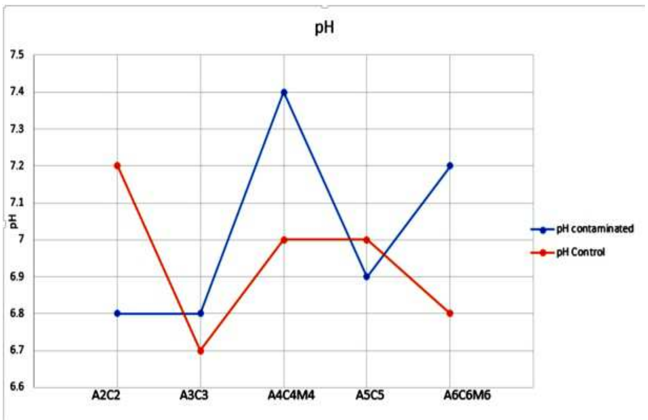

Fig. 5a: Graphs for pH water samples

Furthermore, the result of trace metal concentration of the leachate revealed that Fe, Mn, Pb, Cd, Zn, Cr, Ni, and Cu respectively were 0.0834, 0.1854, 0.00691, 0.00497, 1.017, 0.00648, 0.0244 and 0.008376mg/l

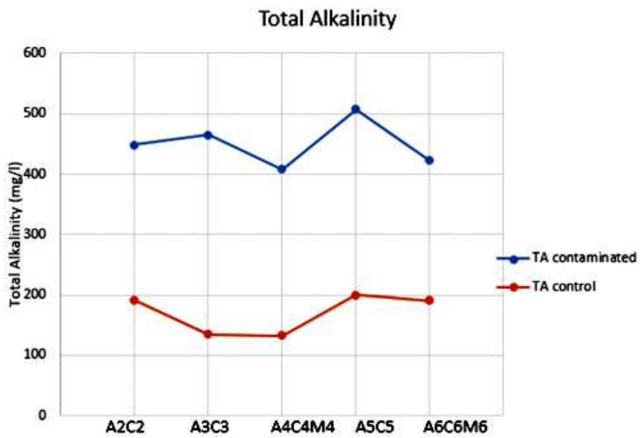

Fig. 5b: Graphs for Total Alkalinity for water samples

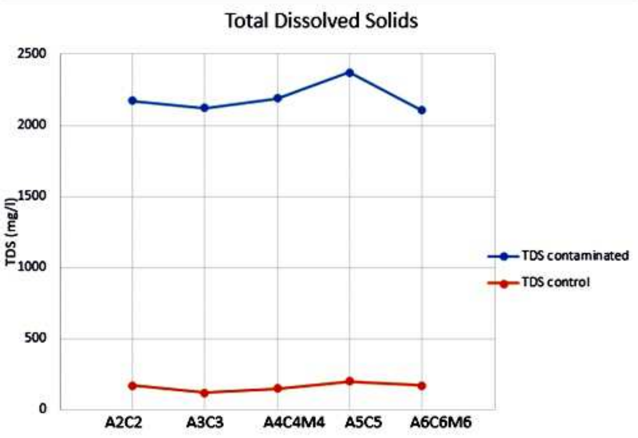

Fig. 5c: Graphs for Total Dissolved Solids for water samples

(table 1) which are within the WHO limits for drinking water quality except that of the Cadmium and Nickel which may in turn, pollute the groundwater in the area. The concentration of cadmium ranges from 0.0047 to–0.0054mg/l which is beyond the permissible limit of

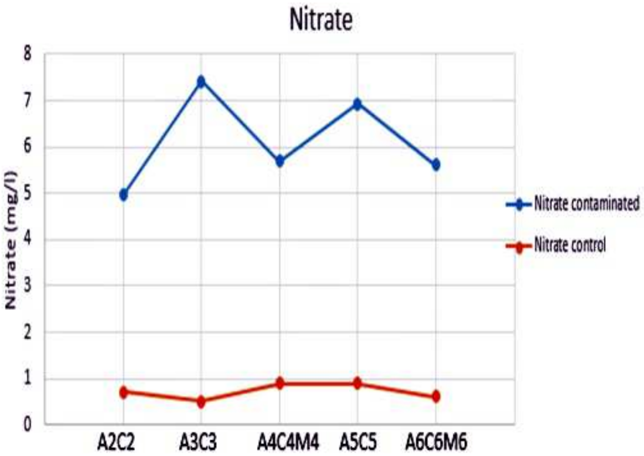

Fig. 5d: Graphs for Nitrate for water samples

0.003mg/l. This high concentration of cadmium and nickel is a pointer to the possible contamination of groundwater in the area in the future if they find any migratory pathway into the groundwater.

Geotechnical Results Interpretation

Specific Gravity

The results of the specific gravity analysis on the 15 soil samples are 2.66, 2.53, 2.69, 2.63, 2.60, 2.52, 2.76, 2.71, 2.63, 2.68, 2.68, 2.58, 2.54 and 2.51 respectively. Comparing these specific gravity values to some common soil types from Lambe (1969), all the soil can be generally described as sandy.

Atterbeg Consistency Limit Test Results Interpretation

Liquid limit, Plastic limit, and, Plasticity Index of the samples were carried out in the laboratory to determine the plastic behavior of the soil. Also, the tests assist in the classification of the samples when plotted on the Plasticity Chart. The plasticity chart (Figure 6) was used to classify the samples and all the samples fell above the A-line. Only one sample falls in the region of cohesionless soil, while others fall in the region of low to high plasticity. All the samples are below the U-line and above the A-line.Moreover, the results of Atterberg limits reveal the liquid limit (LL) ranges from 30-55%, the plastic limit (PL) is 12.4-27.2% and the plasticity index (PI= LL- PL) is 6.6-38.1%. Based on these data, the samples fall on Inorganic clay of medium to high plasticity (Karakan, 2022). The Atterberg consistency (degree of firmness) limits tests evaluate the relationship between moisture content and soil consistency. According to Amadi and Eberemu(2013), a lateritic clayey soil with a liquid limit (LL) ≥ 30% and a plasticity index (PI) ≥ 15% is recommended for use as landfill material. Clayey soils with a liquid limit (≥ 35%) and plasticity index of >15% are good for consideration asmineral seals (Won et al., 2021). Daniel (1993) suggested PI of 7% - 30% because of possible clodding by a higher percentage of PI. Taha and Kabir (2006) recommended a PI of <33% and PL of 35% for a granite-derived lateritic soil. Clayey soils with < 10% liquid limit and plasticity index of >65% liquid limit and >75% plasticity index will be difficult to compact on the field (Ash and Jagger, 2008).

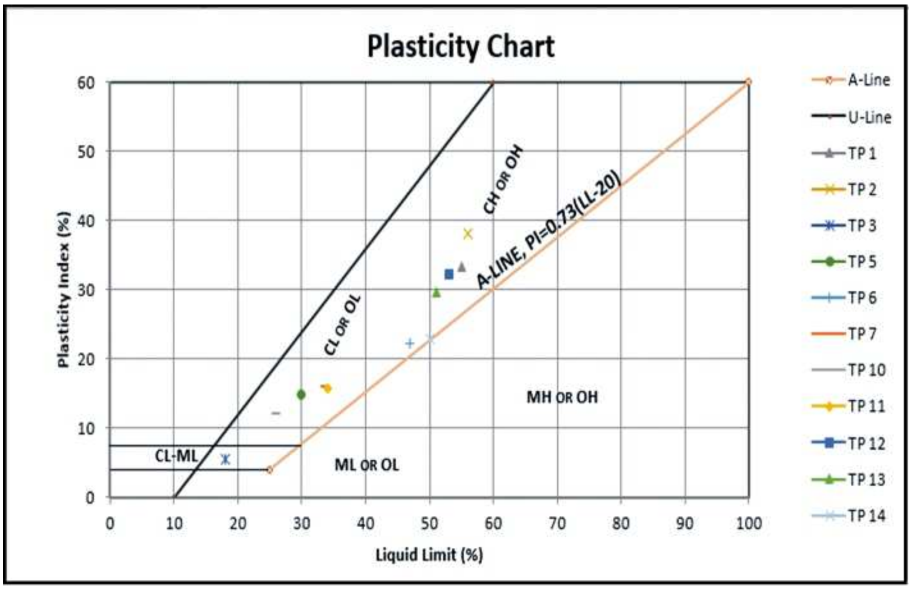

Fig. 6: Plasticity chart plot for fine-grained soil and fine fraction in coarse-grained soil.

Results of Grain Size Analyses

A good landfill material is expected to have good compaction properties which are dictated by the gradation of the soil materials. The relative gradation of the material based on their coefficient of uniformity and curvature is important in ascertaining their compaction potential. Based on the results of the grain size test (Table 4), only 2 samples out of a total of 15 samples representing 13% have clay content >30% (Daniel, 1993) suggesting that approximately 87% of the samples are probably unsuitable as landfill materials. Also, only two samples representing 13% of the samples have coefficients of uniformity and curvature >6 and 1.0 – 3.0 respectively in tandem with Wagner (1957) which posited that for sandy soil to be regarded as well-graded, the coefficient of uniformity must be greater or equal to 6 while the coefficient of curvature must fall between 1.0 – 3.0. Therefore, since only 2 samples representing 13% are well graded while 13 samples representing approximately 87% are poorly graded, the soil can be generally characterized as poorly graded and probably unsuitable as landfill materials.

Compaction Test Results Interpretation

In any engineering construction work particularly for sanitary landfill construction, compaction of soils is done to achieve soils with improved engineering properties. The process of compaction results in a soil mass free of large continuous inter- clods voids, increases its density and strength, and reduces its hydraulic conductivity (Benson and Daniels, 1990). Taha and Kabir (2006) recommended a maximum dry density greater than $1.70 g/cm^3$ for a material to be suitable for sanitary landfills. Only 1 sample representing 14% is therefore regarded as unsuitable for sanitary landfill while six samples representing 86% are regarded as suitable as landfill material.

Permeability Test Results Interpretation

The hydraulic conductivity value of the liner material is used as the principal indicator of its containment potential. Hydraulic conductivity behaviour of soil barrier is greatly influenced by the particle size distribution because the relative proportions of large and small particle sizes affect the size of voids conducting flow (Kabir and Taha, 2006). The coefficient of permeability is the key parameter affecting most soils to be useful as a barrier in landfills. Thus great attention is focused on ensuring a low permeability is achieved. Several investigators and waste management agencies have recommended $1x10^{-9}$ m/s as the minimum allowable value for soil to be useful for this purpose. On the suitability of soil as mineral seals in sanitary landfills, several recommendations have been proposed (USEPA, 1982; Oeltzschner, 1992; Jessberger, 1994, Seymour and Peacock, 1994; USEPA, 2005; Taha and Kabir, 2006). USEPA (1982) recommended that such soils should possess a *k*-value of $< 1 \times 10^{-7}$m/s; Oeltzschner (1992) suggested a *k*-value $<10^{-10}$m/s. Seymour and Peacock (1994) suggested a k-value of $1x10^{-10}$m/s. for the purpose of this work, USEPA (1982) recommendation of coefficient of permeability $<10^{-7}$ was adopted since it is the most conservative. Based on the results (Table 6), 7 samples representing 45% have a coefficient of permeability of 10^{-7}m/s interpreted to be marginally suitable while 8 samples representing approximately 55% are interpreted as non-suitable as barrier since their coefficient of permeability $>10^{-7}$m/s.

Conclusion

This study has shown that the well water showed no evidence of pollution but the leachate has contaminants concentration higher than WHO permissible limits especially for cadmium and nickel which could pose serious health hazards if find migratory pathway to the surrounding groundwater. Conversely, the grain size analysis revealed that 90% of the samples are poorly graded with large grain size pointing to soil with poor compaction properties. Also, the Atterberg limit test, compaction test, and permeability test all suggest that approximately 45% of the samples are suitable to marginally suitable while the remaining 55% are not suitable as landfill material. Therefore, the area may not be suitable for the location of a modern sanitary landfill unless some soil improvements are carried out. It is thereby concluded that;

I. The leachate's high concentration of TDS, EC, alkalinity, nitrate, nickel, and cadmium coupled with the poor geotechnical properties revealed that the area may not be suitable for the location of a modern sanitary landfill unless some form of soil improvement is carried out.

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