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Suitability Study of Subsurface Soil for Landfill Development in Makurdi-Nigeria

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ABSTRACT. Siutability study of subsurface soil was carried out in five categorized structure of makurdi municipality for the development of engineered landfill. Hydro-mechanical properties of subsurface soils relevant to landifill development were texture, porosity, hydraulic conductivity, soil moisture content, the bulk density, structure, consistency, temperature, colour and resistivity. Bouyoucoous Hydrometer method, principle of weighing the loss in mass of the test piece on drying to constant mass and hardness test of 'Agaraba' were methods used for particle size analysis, moisture content determination, compressive and hardness test respectively. Sand dominated the subsurface soil and was in the range of 80.4% - 83.4% with moderate percentage of cley 13.2% - 15.2%. Water holding capacity was between 3.0 and 5,0% as the porosity was in the range of 4.3 – 4.8%. The result of the bearing capacity indicated that site [A] has as 3211.00 KN/m3 and 4122.84KN/m3 outside and within the dumpsite respectively attesting to the highest value of compressive strenght due to trafic from compaction equipment. Factor at sites [D] and [E] approaches unity while [A] is 39% more strength than required and [B] and [C] 41% and 14% less strength than required.The determined liquid limits of the studied soils were all above 20 % and less than 90 % with mean value of 23.83%. Varying cohesion and angle of internal friction for all the dumpsites were observed with maximum cohesion as 17.61KN/m2 and friction angle of 21.8o at dumpsite [A].

Key words; Subsurface soil, hydro mechanical properties, Municipal solid waste and Engineered landfill

INTRODUCTION

1.1 Soil physical properties

The physical properties of subsurface soil at municipal solid waste (MSW) dump sites play significant roles in determining the rate at which leachate plume will infiltrate, migrate and contaminate the surface and subsurface environment (Obasi et al., 2015**)**. The physical parameters that readily come to mind are; texture, porosity, hydraulic conductivity, soil moisture content, and the bulk density of the soil. Their order of decreasing importance according to Nyle *et al*. (2009) are texture, structure, density, porosity, consistency, temperature, colour and resistivity. Most of these determine the aeration of the soil and the ability of water to infiltrate and to be held in the soil. The properties may vary through the depth of a soil profile.

Waste dumpsites with low sand fractions (<40%) are not suitable for waste landfilling (Ekundayo, 2003; Ogbonna, 2004; Ogbonna et al., 2006b) since they are rapidly permeable and could allow large quantities of leachates from the wastes to invade the deposited refuse and finally to the groundwater resource. David *et al.* (2014) in their study reported that waste dump sites with 64.8% sand and 65.8% silt did not also meet the textural requirement for refuse disposal because they have mean clay fractions greater than 31%. High clay fractions/concentrations greater than 31% encourage surface water flooding and pollution. The analysis of soil aggregation is important in a variety of applications including landfill development. The clumping of the soil textural components of sand, silt and clay forms aggregates and the further association of those aggregates into larger units forms soil structures called peds (Nimmo, 2004).

Temperature effects on soil can occur in the form of cracking due to both freeze-thaw cycles (Othman *et al*., 1994) and desiccation (Daniel, 1987) in addition to potential changes in shear strength, settlement, and hydraulic conductivity of liner soils. Doll (1997) demonstrated potential desiccation and cracking of bottom clay liners due to heat generated in overlying waste mass using numerical analysis. High temperatures increase degradation and aging and low temperatures decrease flexibility of geosynthetic liner materials in soil (Rigo and Cazzuffi 1991). Diffusive transport through liner materials increases with increasing temperatures (Rowe 1998). Even though temperature has significant effects on various landfill components, limited information exists on temperatures within wastes, liner systems, and surrounding subsurface. Soil temperature depends on the ratio of the energy absorbed to that lost (Snyder and Paw,2000). Fluctuations in soil temperature are much lower with increasing soil depth below 50 cm (20 in), soil temperature seldom changes and can be approximated by adding 1.8 °C (2 °F) to the mean annual air temperature however, a range between -20 to 60 °C was reported by Snyder and Paw,(2000).

1.2 Water Mechanics in Subsurface Soil

Water affects soil structure and stability when it is primarily concerned with sanitary landfill development. When a rain fall, the field is flooded, the air in the soil pore space is displaced by water. The field will drain under the force of gravity until it reaches what is called field capacity, at which point the smallest pores are filled with water and the largest with water and gases (Brehm, 2008). The total amount of water held when field capacity is reached is a function of the specific surface area of the soil particles. As a result, high clay and high organic soils have higher field capacities.

David *et al.* (2009) in another studies on the inorganic chemicals and microbial contaminants importance in groundwater resources in Port Harcourt Rivers State Nigeria observed high infiltration rate in all dumpsites except for East West Road where disposed refuse reduced infiltration because of high organic matter. Infiltration rates less than 0.9cm/min and greater than 4.0cm/min are recommended as unsuitable for sanitary landfilling of wastes (Bonarius, 1975).

David *et al.* (1998) in Kinematic wave model for water movement in MSW reported that landfill are highly heterogeneous in nature hence, the flow field is not uniform. The internal geometry of a landfill facilitates fast flow in restricted channels and voids. Furthermore, the field capacity is spatiatty variable, and some parts of the landfill therefore reach field capacity long before the entire landfill does. Water may be flowing in locally saturated regions, while the largest portion of the landfill may be well below field capacity. Channel flow, which is most significant in young deposits because of their coarser structure, has been observed in several investigations (Bengtsson *et al*. 1994). Because of stratification, a significant portion of the flow is taking place in the horizontal direction. These flow paths at different levels are connected by vertical shortcuts that lead to a network similar to the flow paths in fractured rocks or fissured media. On the basis of this flow pattern David *et al.,* (1998) conceptualized landfill as a dual-domain medium where channel domain defined by the flow path network constitutes only a fraction of the entire landfill. Gravity is assumed to be dominant here, and capillary force is considered to be negligible.

Open dumps in developing countries permit the mixture of precipitation with degradable organic matter from MSW to form leachate. Kjeldsen *et al.* (2002) reported that the major potential environmental impacts related to landfill leachate are pollution of groundwater and surface waters. Landfill leachate contains pollutants that can be categorized into dissolved organic matter, inorganic macrocomponents, heavy metals, and xenobiotic organic compounds. Tatsi and Zoubouli (2002) further stated that the composition of leachate varied widely, depending mainly upon hydro-mechanical characteristics of subsurface soil, their degree of stabilization and upon their seasonal production, representing the influence of different climatic conditions. This work seeks to look at the hydro-mechanical characteristics that influences leachate problem of subsurface soil at dumpsites in Makurdi.

METHODOLOGY

3.1 Sampling and analytical procedure

Five representative soil profile pits of depths, 0-60 cm were dug in each soil units within selected dumpsites. Field characterization of the profiles was carried out and the soil samples were obtained from the pedogenic horizons to avoid contamination. The temperature of each sample was taken in situ by immersing the bulb of the thermometer in the soil and the reading in degree Celsius (^oC) taken after one minute. The samples were preserved in polyethylene bags to the laboratory for physicochemical, mechanical and mineralogical analyses.

Soil samples were air-dried for 48hrs at ambient laboratory temperature, sieved with a 2mm mesh according to Allen *et al.* (1974) and subjected to laboratory analysis for determination of hydro-mechanical properties such as hydraulic conductivity, bulk density, porosity, moisture content as well as Friction angle, cohesion and specific gravity. Compressive strength, tensile strength and bearing capacity which are relevant to design of sanitary landfill as reported by Akpan *et al.* (2013) and Obasi et al.(2015) were evaluated.

[A] Particle Size Analysis.

Particle size density was analyzed using the Bouyoucoous Hydrometer method. Exactly 5g of sieved soil was weighed and transferred into a 250mL beaker, was stirred and allowed to stand overnight. Blank was analyzed in the same manner using 50mL of 5% calgon solution.

$$\textbf{\% silt = 100- \% sand - \% clay} \quad (1)$$

$$\textbf{\% clay} = \frac{(A-B)}{wt\ of\ soil}\ x\ 100 \quad (2)$$

A = Sample + temperature
B = Blank + temperature

[B] Determination of soil Moisture Content

The principle of weighing the loss in mass of the test piece on drying to constant mass was adopted to determine the soil moisture content. The test piece of approximately 30mm wide, 30mm long and 10mm thick was weighed to an accuracy of 0.01g and then dried in an oven at a temperature of 103 ± 2^oC in an environment of 33^oC temperature and 60% relative humidity.

[C] **Determination of the Hardness**

The hardness test of ‘Agaraba’ was carried out based on ASTM D1037 (1999) by applying a load of 100g on the specimen of minimum thickness of 10mm with a rectangular cross section and right angle corners on a Brinell hardness machine. The

Brinell hardness number of the top (*T*), middle (*M*) and bottom (*B*) locations for 'Agaraba' was determined by (ASTM 1999):

$$HB_{avg} = \frac{HBT+HBM+HBB}{3} \quad (3)$$

where:

HBavg = Average Brinell hardness number;
HBT = Brinell number of the top location;
HBM=Brinell number of the middle location; and
HBB=Brinell number of the bottom location.

[D] Determination of the Compressive Strength

The compressive strength of 'Agaraba' was evaluated using the specimen made parallel to the fiber direction. AC162 (2000) test technique was used for the evaluation of the compressive strength properties on a universal testing machine of capacity 100kN with a loading rate of 0.9 mm/min. The ultimate compressive strength for the top, middle and bottom locations of 'Agaraba' were determined by:

$$ultC = \frac{FultC}{A} \quad (4)$$

$$A = \{4[D^2 - (D-t)^2]\} \text{ and} \quad (5)$$

$$avg\ ultC = \frac{(ultCT+ultCM+ultCB}{3}, \quad (6)$$

where:

FultC = maximum load at which specimen failed when compressed (KN);
ultC = ultimate compressive strength of the material (MPa);
ultC T = ultimate compressive strength of the top position (MPa);
ultC M = ultimate compressive strength of the middle position (MPa);
ultC B = ultimate compressive strength of the bottom position (MPa);
avg ultC = average compressive strength of the material (MPa);
A = cross sectional area of the specimen (mm^2);
D = outer diameter of the specimen (mm); and
t = thickness of the specimen (mm);

[E] Determination of the Tensile Strength

The tensile test specimens were prepared to shape with the use of file and surface planer. A 1.5-mm thick metal plate was glued to the specimens in order to avoid slip during the test. The ultimate tensile strength for the top, middle and bottom locations of 'Agaraba' was determined by:

$$ultT = \frac{FultT}{A} \quad (7)$$

$$A = W \times t, \text{ and} \quad (8)$$

$$avg\ ultT = \frac{ultTT+ultTM+ultTB}{3} \quad (9)$$

where:

FultT = maximum load at which specimen failed at tension (kN);
ultT= ultimate tensile strength (MPa);
ultT T = ultimate tensile strength of the top position (MPa);
ultT M = ultimate tensile strength of the middle position (MPa);
ultT B = ultimate tensile strength of the bottom position (MPa);
avg ultT = average tensile strength of the material (MPa);
A = cross-sectional area of the gauge length (length of exposed portion of specimen) (mm^2);
W = width of the gauge length (mm); and
t = thickness of the gauge length (mm)

[F] Determination of the bearing capacity of sub surface soil

The evaluation of the ultimate bearing capacity of rough shallow foundations reported by (Das, 2007) was used in calculating the maximum allowable load a subsurface soil in sanitary landfill can sustain for foundations with a depth measured from the ground surface, equal to 3 to 4 times their width. According to Das and Sivakugan, (2007), Terzaghi developed a method for determining bearing capacity for the general shear failure case in 1943 with these equations taken into account soil cohesion, soil friction, embedment surcharge, and self-weight.

For square foundations:
$q_{ult} = 1.3c'N_c + \sigma'_{cD}N_q + 0.4\gamma'\text{B}N_\gamma$ (10)
For continuous foundations:
$q_{ult} = c'N_c + \sigma'_{cD}N_q + 0.5\gamma'\text{B}N_\gamma$ (11)
For circular foundations:
$q_{ult} = 1.3c'N_c + \sigma'_{cD}N_q + 0.3\gamma'\text{B}N_\gamma$(12)
Where;

$$N_q = \frac{e^{2\pi(0.75-\phi'/360)\tan\phi'}}{2\cos^2(45+\phi'/2)} \quad (13)$$

(29)

$$N_c = 5.7 \text{ for } \varphi' = 0 \quad (14)$$

$$N_c = \frac{N_q - 1}{\tan\phi'} \text{ for } \varphi' > 0 \quad (15)$$

$$N_\gamma = \frac{\tan\phi'}{2}\left(\frac{K_{p\gamma}}{\cos^2\phi'} - 1\right) \quad (16)$$

c' = effective cohesion.
σ_{zD}' = vertical effective stress at the depth the foundation is laid.
γ' = effective unit weight when saturated or the total unit weight when not fully saturated.
B = width or the diameter of the foundation.
φ' = effective internal angle of friction.
$K_{p\gamma}$ is obtained graphically. Simplifications have been made to eliminate the need for $K_{p\gamma}$. one such was done by Coduto as given below and it is accurate to within 10%.

RESULTS AND DISCUSSION

[A] Soil aggregation

The result of the soil aggregation and physical properties are presented in table 1. Sand dominated the subsurface soil and was in the range of 80.4% - 83.4% with moderate percentage of cley 13.2% - 15.2%. these proportion represents a good structure for landfill development as the infiltration characteristic is moderate according to Ekundayo (2003) and Ogbonna et al.(2006b). Water holding capacity was between 3.0 and 5,0% as the porosity was in the range of 4.3 – 4.8%.

Table 1; Physical properties of soil samples from dumpsites (0 – 60cm).

Parameter	[A]	[B]	[C]	[D]	[E]
Sand %	81.4	83.4	83.4	83.4	80.4
Silt %	3.4	3.8	3.4	1.4	3.4
Clay%	15.2	13.2	13.2	15.2	14.2
pH	7.2	6.8	6.3	6.7	6.8
Mc %	3.5	4 .0	4.5	3.8	4.0
WHC %	5.0	4.5	3.0	4.8	3.8
Porosity%	4.8	4.6	4.3	4.8	4.5

Table2; Mechanical characteristics of soil within dumpsites in Makurdi at 0 – 60cm depth.

	Sample location				
Property	[A]	[B]	[C]	[D]	[E]
MDD(g/m^3)	1.64	1.72	1.83	1.97	2.13
OMC(%)	14.54	14.15	14.12	13.78	13.48
LL(%)	24.04	23.53	23.65	24.14	23.51
PL(%)	15.20	15.94	16.61	18.68	16.67
PI(%)	16.8	16.28	15.28	13.68	14.92
K(m/s)	0.15	0.15	0.11	0.06	0.05
C(KN/m^2)	17.94	18.61	18.81	16.01	16.70
C_V	0.77	0.74	0.72	0.51	0.39
M_V(m^2/KN)	0.43	0.41	0.35	0.30	0.26
FI	20.00	23.00	25.00	27.00	16.00

qf(KN/m^3)	4122.84	3246.86	1825.30	1807.30	1912.63

Ttable 3; Mechanical characteristics of soil outside dumpsites in Makurdi at 30 – 60 cm depth.

	Sample location				
Properties	[A]	[B]	[C]	[D]	[E]
MDD(g/m^3)	1.94	2.03	2.12	2.25	2.40
OMC(%)	12.53	12.31	12.17	11.65	11.20
LL(%)	26.01	24.94	26.33	25.25	23.62
PL(%)	13.26	13.89	15.82	17.44	15.43
PI(%)	18.04	15.29	15.88	14.97	15.56
K(m/s)	0.07	0.06	0.04	0.03	0.02
C(KN/m^2)	13.38	13.48	14.60	16.27	16.61
C_V	0.26	0.25	0.23	0.23	0.21
M(m^2/KN)	1.10	0.90	0.85	0.47	0.32
F_I	5.52	6.02	6.40	7.00	7.32
qf(KN/m^3)	3211.00	2247.49	1031.60	1934.60	2233.51

Maximum dry density(MDD), Optimum moisture content(OMC), Liquid limit(LL), Plastic Limit(PL), Plasticity index(PI), Coefficient of permeability(K), Consolidation(C_V), Compressibility(M_V), Cohesion(C), Angle of internal friction(FI).and Bearing capacity (qf(KN/m^3)

[B] Consistency limit

The results of the consistency limits test are displayed in Tables 2 and Table 3. Liquid limit, Plastic limit and the Plasticity Index are the most useful indicators of engineering behaviour of soils. Declan and Paul (2003) stipulated that the liquid limit of soil liners should be less than 90 %. The determined liquid limits of the studied soils are all above 20 % and are less than 90 %. The values range from 23.62% to 26.33% which is above the 20 % stipulated minimum standard and less than the 90 % maximum limits. Thus the soils are expected to exhibit low hydraulic conductivity and are suitable for landfill development which has been supported by findings of Kabir and Taha, (2004), they reported that soils with high liquid limit generally have low hydraulic conductivity.

Physical appreciation from Figures 1 and 2 indicated similar mechanical behaviour at all sites both within and outside the the dumpsites. The MDD, K, Cv and Mv has very low values with high percentage of OM, LL, PI and C with moderate FI. Site [A] shows higher appreciation on the PI which is one of the most important criteria for selection of soil for landfill development. According to Kabir and Taha (2004), it is the key property in achieving low hydraulic conductivity in reducing leachate movement and the minimum value is. The high percentage of C proves that the subsurface soil in Makurdi can sustain adequate amount of MSW without failure.

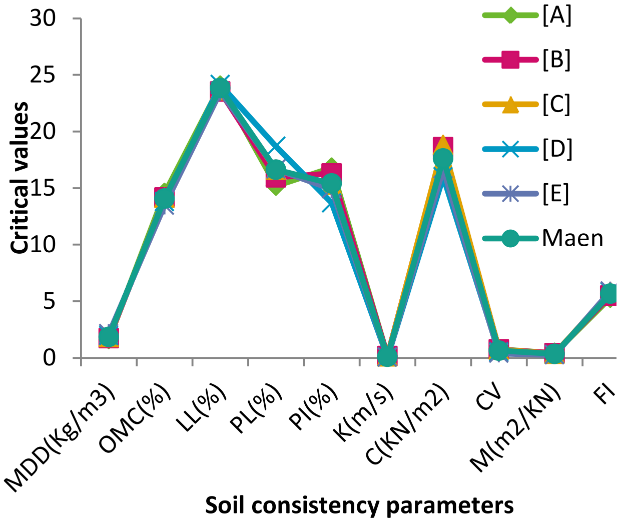

Figure 1; Mechanical behaviour of soil outside the dumpsites .

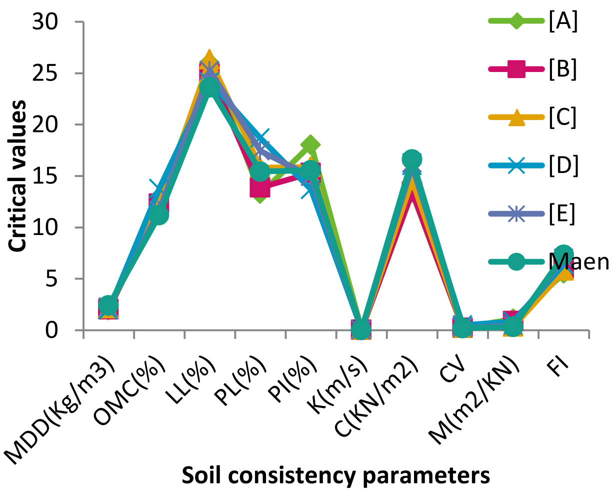

Figure 2; Mechanical behaviour of soil within the dumpsites.

[C] Compressive Strength

The results of the compressive strength test at consolidated pressures of 0-210 kN/m^2, compressive strengths of 186kN/m^2 - $360KN/m^2$ and moisture content of 40 – 100% were presented in the Mohr circle diagram of triaxial compression test. Varying cohesion (16.01-18.81) and angle of internal friction (20.0-28.0) for all the dumpsites as indices for the determination of bearing capacity and factor of safety for the design of the landfill were observed.

[D] Bearing Capacity

The maximum load that a sanitary landfill can carry is determine by the bearing capacity of the subsurface soil, The result of the bearing capacity from Table 1 and 2 indicated that site [A] has its value as 3211.00 KN/m^3 and 4122.84KN/m^3 outside and within the dumpsite respectively attesting to the highest value of compressive strenght due to trafic from compaction equipment.

Figuer 3 demonstrate the appreciation of the FS from one dumpsite to another. It presumes that the factor of safety is not the same everywhere along the slip plane of the dumpsites as the sites [D] and [E] approaches unity while [A] is 39% more strength than required and [B] and [C] 41% and 14% less strength than required. Comparing these results with the FS for MSW which is 1.65(65% above required strength), [A] stand as the best site for landfill development

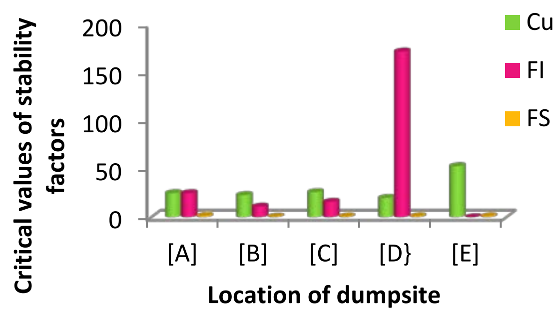

Figure 3; Limit-equilibrium analyses for dumpsite stability

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