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ASSESSMENT OF SOILS FOR SANITARY LANDFILLS IN ABIA STATE, SOUTHEAST NIGERIA

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Abstract
Open dumping is the common procedure for final disposal of municipal solid waste (MSW) in Nigeria. Consequent upon poor planning of landfills, several environmental pollution and soil degradation problems often occur. Therefore, recognition of the MSW landfill is required to prevent environmental problems. The study was conducted to evaluate the suitability of selected soils of Abia State for the construction of sanitary landfills. Eight profile pits were excavated in different locations and the genetic horizons sampled for laboratory analyses of some selected soil properties. Results showed that the sand fraction ranged from 718 to 825gkg^{-1}, with a mean value of 762gkg^{-1} and the clay content ranged between 116 and 213gkg^{-1}, with a mean value of 174gkg^{-1}. Bulk density ranged from 1.17 to 1.48gcm^{-3}, with an average value of 1.40gcm^{-3}. Hydraulic conductivity ranged from 25.3 to 45.7cmhr^{-1}, with an average value of 38.cmhr^{-1}. Permeability ranged between 0.88 and 1.40cm^{2}, with a mean of 1.13 cm^{2}. Soil pH (H_2O) ranged from 4.35 to 5.38, with a mean value of 4.98. Effective cation exchange capacity ranged from 3.81- 17.17cmolkg^{-}1, with an average value of 6.83cmolkg^{-1}. The suitability assessment showed that the soils are fairly to marginally suitable for the construction and operation of sanitary landfills.

Keywords: Sanitary landfills, soil properties, evaluation

Introduction

Population increases have resulted in solid waste problems in communities where previously no service was provided, and where there has been little or no recognition of municipal responsibility. Municipalities with established solid waste collection and disposal services have found that community development implies new challenges. As growth presses to a municipality's borders and vacant land is developed, adequate solid waste disposal sites become less readily available. Therefore, the pollution effects of the improper management or disposal of solid wastes is fast becoming a threat to the quality of life, especially in the cities where most of these wastes are generated (Okpan, *et al*., 2017). In developing countries, it is necessary to develop efficient waste management systems due to increased waste production as a consequence of population growth.

Despite developments that have improved waste management systems, the disposal of solid waste in landfills is still the most commonly used method in developing countries (Donevska *et al*., 2013). Sanitary land filling is one of the best ways to decrease the volume of waste products (Wang *et al*., 2009). Nevertheless, lack of effective environmental laws and enough suitable land for landfill sites in most developing countries are major challenges to effective solid waste disposal (Okpan *et al*., 2017). Unfortunately, in most Nigerian cities, the primary method of waste disposal is still confined to pile-up and open dumping. An open dumpsite is an environmental hazard which causes natural resource (soil, water, air) degradation and environmental pollution (Guenon *et al*., 2013; Leon *et al*., 2014). Previous studies found that leachates from landfills contaminated groundwater (Nema *et al.,* 2009) and soil (Hernandez *et al*., 1997; Raman and Narayanan, 2008; Shaylor *et al*., 2009; Oo *et al*., 2013). The effects of pollution from improper waste management pose serious threats to human health (Brevik and Burgess, 2013; Brevik and Sauer, 2015).

The capacity of the soil to absorb effluent is determined mainly by the porosity of the soil, size of soil particle and the kind of clay in the soil (NRCS, 2000). Therefore, adequate information about the properties of the soil is required in the design of a working sanitary system in order to reduce the threats posed by some persistent and toxic wastes generated in our cities. Soil characterization provides valuable information in establishing the threshold values for sanitary landfill (Table 1). The overwhelming soil wastes generated in Abia State especially, Umuahia, the State capital need to be adequately managed to promote human and environmental health. The objective of the study was to evaluate the suitability of selected soils of Abia State for the construction of sanitary landfills.

Materials and Methods

Study area

The study area lies between latitudes 5° 25' and 5° 33'N and longitudes 7° 24' and 7° 35' E. Abia State has a hot humid tropical climate with mean annual rainfall ranging between 1900mm and 2500mm, and air temperature between 27°C and 32°C. The relative humidity is (70 – 80%), reaching a maximum of 90% during the rainy season (NRCRI, 2013). The original tropical forest of the study area has been almost completely replaced by secondary forest due to anthropogenic influence. The parent material of the study area is coastal plain sands underlain by Bende-Amaeke formation, which consists of sandstones and shales (Lekwa, 2002). The present land utilization types are agricultural, industrial and conservation.

Field work and soil analyses

The study was carried out in eight communities (representing eight mapping units) in the central senatorial district of Abia State namely: Amaoba-Ime, Amaeke-Ibeku, Ajata-Iyienyi, Amafor-Ihungwu, Umudike, Okwe, Olokoro and Ubakala. A modal soil profile pit was established in each community, horizonated based on the observed colour and consistence, and described according to the guidelines of Soil Survey Staff (2014) for morphological properties. The profiles were sampled (disturbed and undisturbed), and from bottom upward to avoid cross contamination. The disturbed soil samples used for analyses were air-dried, crushed gently and sieved with a 2mm diameter mesh size. The fraction that passed through the sieve were analysed in the laboratory for the physical and chemical soil quality parameters relevant to sanitary landfills. Particle size distribution was determined by hydrometer method (Gee and Or, 2002). Effective cation exchange capacity (ECEC) was determined by the summation method (buffered at pH 8.2) with all exchangeable cations including exchange acidity (Al^{3+} and H^{+}). Undisturbed soil core samples were oven-dried at 105°C to a constant weight and bulk density calculated using the equation:

$$\mathrm{Bd} = \frac{\mathrm{Mg}}{\mathrm{v}} \ldots.. (1)$$

Where: *Bd* = bulk density (mgm^{-3}); *Mg* = mass of oven-dried soil (g) and *V* = volume of the soil (m^3).

Total porosity was determined from bulk density value given that particle density is $2.65mgm^{-3}$ for mineral soils.

$$\mathrm{Pt} = 1 - (\frac{\mathrm{Bd}}{\mathrm{Pd}}) \times 100 \ldots.. (2)$$

Saturated hydraulic conductivity and permeability were determined using the method described by Udoh *et al*. (2009).

Suitability evaluation

The parametric method of FAO (1976) was used to assess the suitability evaluation of the soils for sanitary landfills. The land characteristics of the study area (Table 2) were matched with the land use requirements for sanitary landfill (Table 1). Each land characteristic, relevant to land use potential for sanitary landfills was allocated a numerical value, ranging from 100 (for the highest potential - suitable) to 40 or less (for the lowest potential – non suitable) based on the extent to which the land characteristic meets the requirements for the sanitary landfills. Then, all the scores of the relevant characteristics were combined into overall aggregate suitability, expressed thus:

$$\mathrm{S} = \mathrm{A} \mathrm{x} \sqrt{\frac{\mathrm{B}}{100} \mathrm{x} \frac{\mathrm{c}}{100} \mathrm{x} \frac{\mathrm{D}}{100} \mathrm{x} \frac{\mathrm{D}}{100} \mathrm{x} \frac{\mathrm{E}}{100}} \ldots\ldots 3$$

Where: S= Aggregate suitability, A = Overall lowest characteristic and B, C, D, F = the lowest characteristic ratings for other soil characteristics.

Results and Discussion

Important characteristics of the soils of the study area for sanitary landfill

Particle-size distribution showed high sand content across the study area. Mean sand fraction in each of the soil profiles across the sampling locations ranged from $718gkg^{-1}$ to $825gkg^{-1}$ (Table 2). The textural classification indicated loamy sand and sandy loam top soil, while the subsoil ranged from sandy loam to sandy clay loam. The generally high values of sand fraction at all the sampling locations reflect the coastal plain sands parent material of the soil (Lekwa, 2002 and Wilson, 2012) and partly to geological processes involving sorting of soil materials by biological activities (Malgwi *et al.,* 2000 and Akinbola *et al*., 2009). Conversely, the low distribution of clay (140 - $213gkg^{-1}$) and silt (35 – $106.7gkg^{-1}$) fractions in the all the soil profiles (Table 2) may have been responsible for the low value of ECEC. The values of the bulk density (1.17 - $1.48gcm^{-3}$) and total porosity (0.42 – 0.56) of the soils across the sampling locations indicate that the soils of area are fairly suitable for the operation of sanitary landfills. Similarly, the total porosity values varied between 0.42 and 0.56, with an average value of 0.47. Hydraulic conductivity values varied widely among the sampling locations. The values ranged between low ($25cmhr^{-1}$) and fairly rapid ($45cmhr^{-1}$). Permeability ranged from 0.88 to $1.43m^2$ with a mean of $1.13m^2$. Effective cation exchangeable capacity (ECEC) values were low (3.83 – $9.84cmolkg^{-1}$) across the study locations except

Amaeke-Ibeku which had a relatively moderate value ($17.17cmolkg^{-1}$). The low ECEC values may be attributed to the nature of the parent material from which the soils have developed (Fasina *et al.,* 2007). This is also corroborated by Nnaji *et al*., (2002), that low ECEC of a soil could also be consequent upon clay type content, high rainfall intensity and previous land use.

Suitability evaluation of the study area for sanitary landfill

The suitability evaluation of the study area for sanitary landfill (Table 3) was carried out by matching the relevant properties of the land for sanitary landfill (Table 2) with the land use requirements for sanitary landfill (Table 1). The values of soil parameters in Table 1 were used as threshold values for sanitary landfill construction suitability. The loamy sand top soil indicated by the particle size analysis in the sampling locations is highly suitable, while the sandy loam-sandy clay loam sub soil is fairly suitable for the construction and operation of sanitary landfill. NRCS (2000) and Ibia, *et al*. (2011) reported sandy loam textured soil as the most suitable soil for sanitary landfills, because more sandy-textured soils are highly permeable, thus, would allow unrestricted movement of leachates and pollutants to the groundwater. In the same vein, Nyles and Ray (1999) reported that soils with high sand (> $700mgkg^{-1}$) and low clay (< 170 $mgkg^{-1}$) contents have high pollutant leaching potentials. Consequently, the soils of Amaoba-Ime, Ameke-Ibeku, Umudike, Okwe, Olokoro and Ubakala are highly suitable, while Ajata-Iyienyi and Amafor-Ihingwu area fairly suitable for sanitary landfills (Table 3). However, the range of textures (loamy sand - sandy clay loam) down the profile across the study area is coarse enough to prevent water saturation and ponding and also fine enough to strain and attenuate pollutants, and prevent the contamination of groundwater (Ibia, *et al.,* 2011).

The values of the bulk density (1.17 - 1.54 $^{-3}$) and total porosity (0.42-0.56) of the soils across the sampling locations indicate that the soils of the area are within the fairly suitable values ($1.0\text{-}1.45mgm^{-3}$ bulk density and 0.41 – 0.56 porosity) for the operation of sanitary landfills (Table 1). NRCS (2000) reported that soils with high total porosity (>0.56) are not suitable for sanitary landfills because of rapid infiltration and risk of underground water pollution, whereas, soils with moderately low total porosity (0.2 - 0.56) are suitable because they are more retentive thus; prevent percolation of leachates and contamination of groundwater. The hydraulic conductivity values ($35\text{-}45cmhr^{-1}$) across the sampling locations have classified the soils highly suitable for sanitary landfills. Soil permeability values, ranging from 0.88 to $1.43m^2$ with a mean of $1.13m^2$, has also indicated that the soil of the study area highly suitable for the construction and operation of sanitary landfills. NCRS (*ibid*) reported that soils with permeability values less than $2.0m^2$ are suitable for sanitary landfills. This is because water movement through such soils would be moderate and consequently, will retard the movement of the leachate from landfills into the underlying layers where it may pollute ground water.

The ECEC values of the soil have placed Ameke-Ibeku as highly suitable, Amaobe-Ime and Amafor-Ihingwu as fairly suitable; and other locations as marginally suitable for sanitary landfill construction.

Generally, the aggregate suitability assessment revealed that no part of the study locations is highly suitable for the operation of sanitary landfill due to one limitation or the other. For instance, Ameke-Ime, Ameke-Ibeku and Amafor-Ihingwu would have been highly suitable for the construction of sanitary landfill, but bulk density, porosity, acidity and ECEC that are identified as constraints thus, are rated fairly suitable (S2). On the other hand, the extremely low values of ECEC have put Ajata-Iyienyi, Umudike, Okwe, Olokoro and Ubakala into marginal suitability class (S3). The ECEC is important in landfills, because it regulates both the adsorption and chemical precipitation phenomena in the soils. Thus, the higher the ECEC, the more the suitability rating of a soil (Ibia, *et al.,* 2011) (Table 1).

Conclusion

Eight sampling locations on the coastal plain sand across the study area were evaluated for the construction of sanitary landfill. The qualities of the land considered include; soil texture, bulk density, porosity, hydraulic conductivity, permeability, soil reaction and effective cation exchange capacity. The results revealed that Ameke-Ime, Ameke-Ibeku and Amafor-Ihingwu are fairly suitable for the construction of sanitary landfills, whereas, Ajata-Iyienyi, Umudike, Okwe, Olokoro and Ubakala are marginally suitable with ECEC as a major constraint for the establishment of sanitary landfills in Umuahia area of Abia State.

Table 1: Land use requirements for sanitary landfill

Soil Characteristics	Highly Suitable (S1) (100 – 95)	Fairly Suitable (S2) (94 – 85)	Marginally Suitable (S3) (84 – 40)	Non-suitable (N) (< 40)
Texture	Sandy loam	LS, SCL	Very Clayey, Sandy	Too clayey, too sandy
Sand (gkg^{-1})	600 - 700	710 - 800	500 – 590, 800 - 850	0 - 500, 850 - 1000
Silt (gkg^{-1})	70 - 90	30 - 60	20 – 30, 90 - 100	>100
Clay (gkg^{-1})	210 - 360	110 - 200	90 – 100, 370 - 390	0 - 90, 400 – 1000
Bulk Density (gcm^{-3})	0 - 0.9	1.0 - 1.45	1.45 – 1.6	>1.6
Porosity (m^3m^{-3})	0.2 - 0.4	0.41 - 0.56	0.17 - 0.19, 0.57 – 0.65	< 0.17, 0.65 - 1.00
Hydraulic conductivity ($cmhr^{-1}$)	35 - 45	46 - 59	60 – 69, 30 - 34	< 30, 70 - 100
Permeability (m^2)	1.0 - 1.3	1.4 - 2.0	> 2.0	> 2.0
Soil Reaction (pH)	5.1 – 7.0	4.0 - 5.0	< 3.9, > 7.0	< 3.9,> 7.0
ECEC ($cmolkg^{-1}$)	>10	7 - 9	5 - 6	< 5
Flooding	No flooding	Seasonal flooding	High Flooding	High Flooding
Drainage	Well Drained	Fairly well drained	Poorly drained	Poorly drained

Key: CL=Clay Loam; SL=Sandy Loam; LS= Loamy Sand; SCL= Sandy Clay Loam; S=Sand
Source: Fuller and Warrick, (1985); Ibia et al. (2011) - modified

Table 2: Some physical and chemical properties of the selected soils of Abia State for sanitary landfills

Location	Depth (cm)	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	Texture	BD mgm^{-3}	Total Porosity	HC $cmhr^{-1}$	Permeability cm^2	pH	ECEC $cmolkg^{-1}$	Drainage	Flooding
Amaoba-Ime	0-20	900.0	30.0	70.0	LS	1.60	0.40	55	2.00	5.40	11.61		
	20-62	830.0	40.0	130.0	SL	1.34	0.49	46	1.10	5.00	9.27	Well Drained	Nil
	62-125	800.0	40.0	160.0	SL	1.40	0.47	32	1.00	4.60	7.65		
	125-178	770.0	30.0	200.0	SCL	1.59	0.40	47	0.60	4.40	10.83		
Mean		**825.0**	**35.0**	**140.0**	**SL**	**1.48**	**0.44**	**45**	**1.18**	**4.85**	**9.84**		
Amaeke-Ibeku	0-16	800.0	110.0	90.0	LS	1.52	0.43	49	1.70	4.50	18.44	Well Drained	Nil
	16-58	800.0	80.0	120.0	SL	1.20	0.55	36	1.40	4.30	16.97		
	58-115	760.0	80.0	160.0	SL	1.30	0.51	40	1.50	4.40	14.62		
	115-183	650.0	100.0	250.0	SCL	1.54	0.42	42	0.40	4.20	18.64		
Mean		**752.5**	**92.5**	**155.0**	**SL**	**1.39**	**0.48**	**41.75**	**1.25**	**4..35**	**17.17**		
Ajata-Iyienyi	0-12	860.0	30.0	110.0	SL	1.20	0.55	48	1.20	5.20	5.95		
	12-28	840.0	20.0	140.0	SL	1.37	0.48	48	1.30	4.90	4.42	Well Drained	Nil
	28-92	700.0	80.0	220.0	SCL	1.64	0..38	32	0.60	4.80	4.85		
	92-170	590.0	30.0	380.0	SC	1.63	0.38	25	0.40	4.60	5.28		
Mean		**741.5**	**40.0**	**212.5**	**SCL**	**1.46**	**0.45**	**35**	**0.88**	**4.89**	**5.13**		

Table 2: Some physical and chemical properties of the selected soils of Abia State for sanitary landfills continue

Location	Depth (cm)	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	Texture	BD mgm^{-3}	Total Porosity	HC $cmhr^{-1}$	Permeability cm^2	pH	ECEC $cmolkg^{-1}$	Drainage	Flooding
Ihungwu	14-42	820.0	30.0	150.0	SL	1.46	0.45	48	1.20	5.50	5.48		
	42-85	690.0	80.0	230.0	SCL	1.62	0.39	29	0.80	5.30	6.57		
	85-185	620.0	50.0	350.0	SC	1.70	0.36	23	0.20	5.00	5.27		
Mean		**717.5**	**53.3**	**212.5**	**SCL**	**1.54**	**0.42**	**36**	**0.90**	**5.38**	**5.70**		
Umudike	0-16	890.0	50.0	60.0	LS	1.32	0.50	44.00	2.2	5.40	4.79	Well Drained	Nil
	16-38	800.0	40.0	160.0	SL	1.24	0.53	38.00	0.7	5.30	5.31		
	38-89	720.0	50.0	230.0	SCL	1.10	0.58	30.00	0.3	5.00	5.52		
	89-180	650.0	20.0	330.0	SCL	1.00	0.62	26.00	0.3	5.00	6.42		
Mean		**765.0**	**40.0**	**195.0**	**SL**	**1.17**	**0.56**	**34.50**	**0.88**	**5.18**	**5.51**		
Okwe	0-18	850.0	90.0	60.0	LS	1.17	0.56	49	1.6	5.50	5.55	Well Drained	Nil
	18-45	810.0	40.0	150.0	SL	1.22	0.54	39	1.3	5.40	4.62		
	45-88	670.0	20.0	310.0	SCL	1.49	0.44	26	1.0	5.10	5.83		
	88-171	690.0	40.0	270.0	SCL	1.47	0.45	27	0.4	4.70	4.91		
Mean		**755.0**	**47.5**	**197.5**	**SL**	**1.34**	**0.50**	**35.25**	**1.08**	**5.18**	**5.23**		
Olokoro	0-12	860.0	60.0	80.0	LS	1.41	0.47	49	1.9	5.10	6.52	Well Drained	Nil
	12-86	760.0	110.0	130.0	SL	1.36	0.31	40	1.2	5.20	7.62		
	86-170	710.0	150.0	140.0	SL	1.33	0.31	38	1.0	5.00	5.74		
Mean		**776.7**	**106.7**	**116.7**	**SL**	**1.36**	**0.49**	**42.33**	**1.37**	**5.10**	**6.63**		
Ubakala	0-20	880.0	30.0	90.0	LS	1.33	0.49	49	2.0	5.20	5.36	Well Drained	Nil
	20-59	730.0	100.0	170.0	SL	1.46	0.45	43	1.4	4.80	4.76		
	59-164	680.0	100.0	220.0	SCL	1.64	0.38	35	0.9	4.80	5.83		
Mean		**763.3**	**76.7**	**160.0**	**SL**	**1.48**	**0.44**	**42.33**	**1.43**	**4.93**	**5.32**		

Key: LS = Loamy sand, SL = Sandy loam, SCL = Sandy clay loam, BD = Bulk density, HC = Hydraulic conductivity, ECEC = Effective cation exchange capacity

Table 3: Suitability class scores of the soils of Abia State for sanitary landfill

Land Quality	Unit	Ameke Ime	Ameke Ibeku	Ajata Iyienyi	Amafor Ihingwu	Umudike	Okwe	Olokoro	Ubakala
Texture (t)		S1(95)	S1 (95)	S2(85)	S2(85)	S1(95)	S1(95)	S1(95)	S1(95)
Sand (S)	(gkg^{-1})	S2(85)	S2(85)	S2(85)	S2(85)	S2)85)	S2(85)	S2(85)	S2(85)
Silt (Si)	(gkg^{-1})	S2(85)	S1(95)	S2(85)	S2(85)	S2(85)	S2(85)	S2(85)	S1(95)
Clay (Cl)	(gkg^{-1})	S2(85)	S2(85)	S1(95)	S1(95)	S2(85)	S2(85)	S2(85)	S2(85)
Bulk Density(b)	(gcm^{-3})	S2(85)	S2(85)	S2(85)	S2(85)	S2(85)	S2(85)	S2(85)	S2(85)
Porosity(p)	m^3m^{-3}	S2(85)	S2(85)	S1(95)	S2(85)	S2(85)	S2(85)	S2(85)	S2(85)
Hydraulic Conductivity(h)	($cmhr^{-1}$)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)
Permeability(m)	(m^2)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S2(85)	S2(85)
Soil Reaction(r)		S2(85)	S2(85)	S2(85)	S1(95)	S1(95)	S1(95)	S1(95)	S2(85)
ECEC (e)	($cmolkg^{-1}$)	S2(85)	S1(95)	S3(60)	S2(85)	S3(60)	S3(60)	S3(60)	S3(60)
Flooding(f)		S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)
Drainage (d)		S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)	S1(95)
Aggregate Suitability		S2 (68)	S2 (68)	S3(47)	S2 (70)	S3 (47)	S3(47)	S3 (47)	S3 (47)
Limiting factors		**bpre**	**bpr**	**e**	**te**	**e**	**e**	**e**	**e**

Aggregate suitability class scores: S1 = 75 - 100; S2 = 50 - 74; S3 = 25 - 49; N = 0 - 24

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