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Assessment of acid soils for sanitary landfill in Khana Local Government Area of Rivers State, South – South, Nigeria

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Abstract

Open dumping of refuse is the order of the day and the collective method for discarding municipal solid waste, and the inefficient way of handling waste coupled with poor planning of landfill has resulted to environmental pollution and land degradation. Sanitary landfills are therefore necessary for the appropriate disposal of municipal waste. Thus, this study was carried out to assess the soils of Beeri in Khana Local Government Area for sanitary landfill. Three soil map units (pedons) based on vegetation, toposequence and drainage were identified and delineated in the study area. A modal soil profile of 2 m × 2 m × 2 m dimensions was dug in the identified soil map units, and the genetic horizons were labeled and sampled for laboratory analysis. Results obtained revealed that sand fractions varied from 804 g/kg in horizon-B of pedon 2 to 924 g/kg in pedon 1; silt content varied between 14 g/kg in horizon-AB of pedon 3 to 24 g/kg in B-horizon of pedons 1 and 2; and clay content decreased from 172 g/kg in B-horizon of pedon 2 to 52 g/kg in pedon 1. Bulk density decreased from 0.935 gcm^{-3} in horizon-Ah of pedon 1 to 1.4550 gcm^{-3} in B-horizon of pedon 2. Soil pH ranged from strongly acidic 4.89 in AB-horizon of pedon 2 to slightly acidic 5.47 in Bw-horizon of pedon 1. Effective cation exchange capacity decreased from10.86 $cmolkg^{-1}$ in pedon 2 to 2.84 cmol/kg in pedon 3. Soil suitability assessment of the study area indicated that the soils were not suitable (N) for the construction and operation of sanitary landfill as a result of defects in soil texture, high sand and low clay contents, porosity, and low ECEC. Therefore, it is necessary to make efforts to improve texture, bulk density, porosity, and ECEC through appropriate management practices so that the physical and chemical properties of the soil can be improved to a moderate to high level of suitability for sanitary landfill.

INTRODUCTION

One of the serious issues associated with population explosion in Nigeria is the generation and accumulation of solid wastes, especially in communities or environment where there is little or no service provider in charge of proper waste management and disposal (Adesemuyi et al., 2021). The collection and disposal of solid wastes are the responsibility of the public waste agency, and this agency is lacking in most communities, as such, it poses a very big health and environmental challenges to such communities. The generation of solid waste has become an increasing environmental and public health problem everywhere in the world, particularly in the developing countries (Kurakalva et al., 2016). Moreover, due to population explosion and urbanization, some of the municipal borders and vacant lands has been developed as residential area, resulting in the lack of land for appropriate disposal of waste. Thus, the effect of pollution due to improper management of solid waste collection and disposal system now poses a serious threat to life in some urban centers and cities.

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Accordingly, it is necessary to provide a well-organized waste management system as a result of the increase in waste generation and the associated environmental pollution and health hazards. In Nigeria, an open dumpsite is a serious environmental health challenge due to its resultant pollution effect on the environment. Effective management of municipal solid waste (MSW) is a major challenge to local authorities and planners due to the rapid industrialization, population increase, and land scarcity (Khan et al., 2018). Despite the population explosion and urbanization resulting in an increasing solid waste generation, the method of waste disposal mostly used is the use of sanitary landfill (Khodaparas et al., 2018). This system of solid waste management and disposal has some drawbacks as the leachates from landfill leach down the water table, contaminating the soils and ground water, especially in an area with low water table. The ability of the soils to absorb solid waste effluent effectively is a role of the soil particle size (type of clay), porosity and the soil depth to the water table. Adequate information about a soil system in terms of their physical, chemical and microbiological properties are very important in the design of an effective and efficient landfill system to reduce some of the environmental hazards associated with toxic solid waste generated in our environment. Soil suitability assessment is the matching of the specific soil requirement of the land use based on the properties of the soils (Peter et al., 2022). Most of soil assessment studies are for agricultural production based on their inherent characteristics, but in this case, the soil assessment is solely for sanitary landfill system to enhance an efficient and effective waste disposal system in our environment. Sanitary landfill is one of the methods of waste disposal where municipal wastes are placed and allowed to decay in a soil environment. Landfill is also known as a hip dump for the disposal of waste materials. Landfill is one of the most common forms of waste disposal, although they are as the systematic burial of the waste materials to enhanced proper putrefaction. In Nigeria, open throwing away system is the common method for the discarding of municipal solid waste (MSW). Consequently, due to poor planning of landfill, it has several ecological pollution and soil degradation problems. Therefore, the sole aim of this study was to evaluate the suitability of selected acid soils in Khana Local Government Area for the construction of sanitary landfills.

MATERIALS AND METHODS

This study was carried out in Beeri community, Khana Local Government Area of Rivers State within three identifiable soil map units based on vegetation, drainage pattern, topography or physiography, soil texture, toposequence or topography, and slope aspects. It occupies approximately 300.5 hectares of land located within latitude 04.68838 and 04.66826 and longitude 007.42315 and 007.42362 with an elevation of 11 meters above the sea level near the east-west road. The study area has in average annual rainfall between 2,000–2,500 mm with two distinct seasons (dry and rainy seasons) (Peter and Ayolagha, 2012; Peter and Umweni, 2021). The rainy season typically endures from late March to October, while the dry season spans from November to early March; however, this pattern has been significantly altered by climate change. During some years, portions of the dry season might be characterized by dustiness and cold, attributable to the northeasterly winds that induce the harmattan. The soils in the research region are well-drained and originate from coastal plain sand of marine deltaic deposits, generally referred to as Ogoni sands (Peter and Oweremadu, 2015; Peter et al., 2021; Peter and Umweni, 2021). The flora of the study area consists of a rainforest ecosystem characterized by abundant deciduous trees and sporadic stunted species, including Iroko (*Chlorophora* spp.) and Mahogany (*Khaya* spp.). The vegetation consists of a multistoried high tropical rainforest, distinguished by a variety of tree species that has been significantly altered by land degradation, rampant deforestation, and continuous agricultural practices (Peter and Umweni, 2021). They are green in the rainy season with fresh leaves and secondary grasses such as *Panicum maximum* and *Penesetum purpureum* (Peter and Oweremadu, 2015; Peter and Aaron, 2019; Peter et al., 2022a; Peter et al., 2022b).

Field studies

Field study was carried out in Beeri community within three identifiable soil map units based on vegetation, drainage pattern, topography or physiography, soil texture, toposequence or topograph and slope aspects. Three soil map units were identified, and the geographical coordinates of each profile point were taken using a handheld Global Position System (GPS). A modal soil profile pit was developed for each soil map unit based on

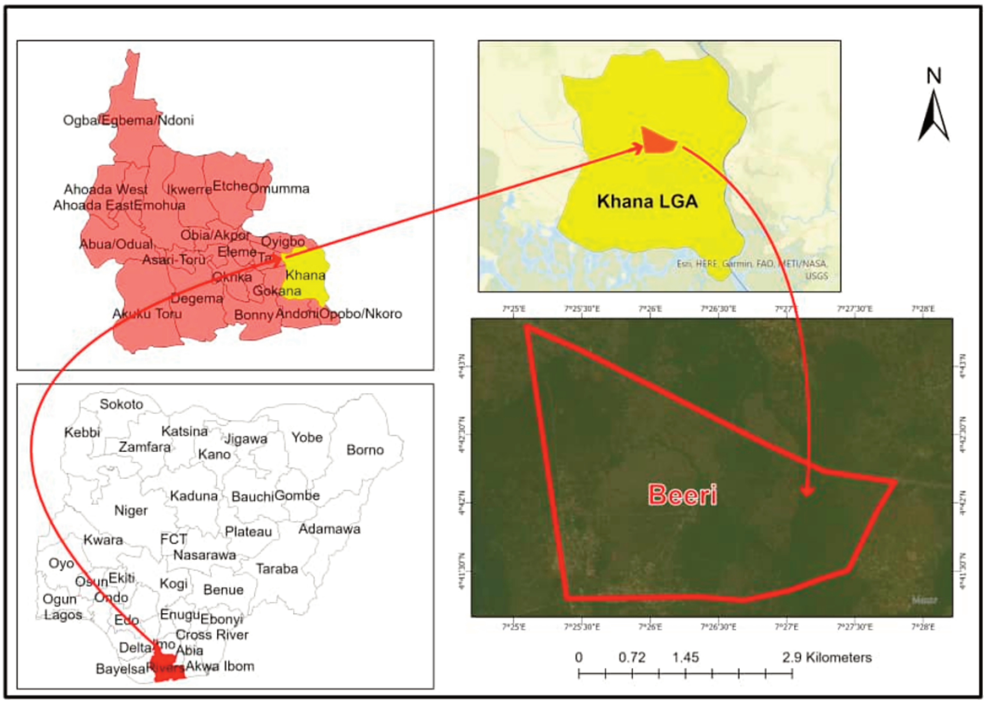

Figure 1. Map of the study area (Beeri)

observed soil color, drainage, and consistency, and was documented according to the USDA Soil Survey Staff (2020) requirements. The soil profile pits and their surroundings were characterized in situ, and soil samples were obtained from each discernible profile horizon, from bottom to top, to avoid contamination. These samples were transported to the Soil Science Laboratory, where they were air-dried, crushed with a mortar and pestle to pass through a 2 mm mesh sieve, and labeled accordingly for laboratory analysis. Core samples were obtained using cylindrical samplers, and soil colors were assessed in situ employing the Munsell color chart.

Land suitability evaluation (LSE)

The parametric methods, where numbers in percentage were given to describe the degree of suitability (Peter and Umweni, 2020; Peter and Umweni, 2021), were used to assess the suitability of the soils for sanitary landfill. The soil properties of the study area, including soil texture, porosity, permeability, and drainage, were evaluated in relation to land use attributes for sanitary landfill. Each soil property related to the potential for sanitary landfill was scored in a numerical value ranging from 1 to 100, with 100 indicating the highest suitability and values of 40 or below indicating the lowest suitability. This was conducted based on the extent to which the land qualities satisfy the criteria for a sanitary landfill. The results of all the relevant soil properties were integrated into several aggregate suitability as expressed in the following equation.

$$S = A \times \sqrt{\frac{8}{100}} \times \frac{C}{100} \times \frac{D}{100} \times \frac{D}{100} \times \frac{E}{100} \times \ldots = 3 \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Remarks: S = aggregate suitability, A = overall lowest score, and B, C, D, F = the lowest score for other soil properties.

Laboratory analysis

The following physical characteristics of the soils were determined. Particle size distribution was determined using the hydrometer method as described by Wang et al. (2022). Soil texture (percentage of sand, silt, and clay) was assessed using Textural triangle. Bulk density was assessed via cylindrical core techniques (Liu et al., 2020). Total Porosity was calculated with the values of the bulk density using the method outlined by Ukabiala et al. (2022). Soil color was determined using the Munsell Color Chart (Ferrando, 2021). Soil pH of the soil was determined by using glass electrode pH meter as described by Zhou et al. (2022). Organic carbon was determined by the dichromate wet oxidation methods of He et al. (2022). The ratio of organic matter in the soil was quantified as the proportion of the mass of

Table 1. Land use requirements for sanitary landfill

Soil properties	HS (S1) (100–95)	MoS (S2) (95–84)	Mar. S (S3) (84–40)	NS (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 ($m^3\ m^{-3}$)	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	6–69, 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

Remarks: HS = highly suitable, MoS = moderately suitable, Mar. S = marginally suitable, NS = not suitable, 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.

organic matter relative to the quantity of dry soil solids. Total nitrogen was determined by the macro-Kjeldahl digestion distillation method (Bremner and Mulvaney, 1982). One gram of soil was disintegrated with concentrated H_2SO_4. The digestion product was broken down with acid. Available phosphorus was determined using Bray and Kurtz (1945) No 1 as adopted by Juo (2011). The soil P was first extracted by agitating the soil with solution containing 0.3N NH_4 and 0.025N HCL. The quantity of phosphorus in the extract was determined using a colorimetric technique. The percentage transmittance (absorbance) of prepared samples was measured on the spectrophotometer at a wavelength of 660nm. Electrical conductivity was measured using an electrical conductivity meter. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were all determined using the ammonium acetate saturation method by Zhao et al. (2020). The effective cation exchange capacity (ECEC) was determined by summing total exchangeable bases and total exchangeable acidity, while the percentage base saturation was derived by representing total exchangeable bases as a proportion of cation exchange capacity. Exchangeable acidity was determined using the EDTA Titration method (Zhao et al., 2020).

RESULTS AND DISCUSSION

Morphological properties of the soils

The morphological properties of the soils are presented in Table 2. There were soil color variations when moist ranging from 7.5YR (very dark grey) to 10YR (grayish brown) that was the Hue in pedon 1. Soil colors in pedon 2 were 7.5YR 4/6 (strong brown) and 5YR5/8 (yellowish red) in the superficial soils and the subsoil layers, respectively. Pedon 3 had soil color variations of 10YR 5/2 (greyish brown) to 10YR 4/2 (dark grey brown). The very dark coloration at soil horizon surface is an indication of the present of organic matter, while the greying condition might be as a result of the saturation of water in the soils over time. The soil texture mostly ranged from sand to sandy loam in the surface and subsurface soils of pedons 1 and 3, but that of pedon 2 exhibited sandy loam in both layers. The sandy texture of the soils could be attributed to the parent materials and formation mode (Peter et al., 2022). The soils of pedon 2 and 3 had both single-grained and subangular blocky structures, while in pedon 1, all soils had single-grained structures. The consistence of the soils was predominantly friable, loose, non-sticky and non-plastic due to low clay content of the soils (Peter and Umweni, 2020). Pedon 1 soils were poorly drained, while pedon 2 and 3 soils were well drained. The poor drainage condition of soils in pedon 1 was as a result of low soil depth to water of the location.

Physical properties of the soils

The physical properties of the soils of the study area are presented in Tables 3. Sand fraction had a value of 924 gkg^{-1} at both the surface and beneath horizon in pedon 1. Silt and clay varied from 14–24 gkg^{-1} and 52–62 gkg^{-1} in the surface and subsurface soils, respectively. Generally, sand particles ranged

Table 2. Morphological properties of the soil of the study area

Pedon deg.	Horizon depth	Colour (moist)	TC	Structure	Consistence	Drainage	Boundary	Root
Pedon 1								
Ah	0–20	7.5YR 3/1 VDG	S	Granular	PD	Diffused	Mrts	Loose
AB	20–58	10YR 4/2 DGB	S	Granular	PD	Diffused	Frts	Loose
BW	58–112	10YR 5/2 GB	S	Granular	PD	Clear	Nrts	Friable
Pedon 2								
AB	0–25	7.5YR 4/6 SB	Ls	Sbk	WD	Clear	Mrts	Non sticky
B	25–90	5YR 5/8 YR	Sl	Sbk	WD	Clear	Nrts	Slightly sticky
Pedon 3								
AB	0–23	10YR 5/2 GB	S	Sbk	WD	Clear	Frts	Non sticky
BW	23–90	10YR 4/2 DGB	S	Sbk	WD		Nrts	Slightly sticky

Remarks: VDG = very dark brown, DGB =, dark grey brown, SB = strong brown, YR = yellowish red, GB = greyish brown, DGB= dark greyish brown, sbk = subangular blocky, PD = poorly drained, WD = well drained.

Table 3. Physical properties of the soil of the study area

Horizon design	Depth (cm)	Particle size distribution (g/kg)			Textural class (gcm^2)	Bulk density (gcm^2)	TP (%)
		Sand	Silt	Clay			
Pedon 1							
Ah	0–20	924	24	52	Sandy	0.9350	64.70
AB	20–58	924	14	62	Sandy	1.3204	50.18
Bw	58–112	924	24	52	Sandy	1.3452	98.52
Pedon 2							
Ah	0–25	844	24	132	Sandy loam	0.9548	63.97
B	25–90	804	24	172	Sandy loamy	1.4550	451
Pedon 3							
Ah	0–23	914	14	72	Sandy	1.3041	50.79
Bw	23–90	904	14	82	Sandy	1.3487	41.19

from 804–924 gkg^{-1}, silt particles increased from 14–24 gkg^{-1}, and clay particles decreased from 172–52 gkg^{-1}. The soil texture classes of sand and sandy loam are more abundant on the surface and below the surface of the soil in pedons 1, 2 and 3. The sandy nature is attributed to the parent material, the sedimentary rock and coastal plain sands from which the soils are formed (Peter et al., 2022). The values of the soil bulk density increased from 0.935 to 1.4550 gcm^{-3}; while the values of total porosity increased from 41.19–98%. The high bulk density observed in the soils might also be attributed to low clay content of the soils. This collaborated with the findings of Ukabiala et al. (2022), who reported that low amount of clay of some soil units resulted in higher bulk density, lower total porosity, and high Ksat values.

Chemical properties of the soils

Table 4 elucidates the chemical features of the soils. The values of pH in H_2O were generally higher (acidic to slightly acidic) and varied between 5.28 and 5.47 (pedon 1) in the surface and subsurface horizons, 4.89–4.90 (pedon 2) and 5.34–5.39 (pedon 3). The values of organic carbon and Av. P were 0.21–0.94 gkg^{-1} and 1.52–8.77 mg kg^{-1}, respectively. Calcium (Ca) varied across the different horizon from 1.4–3.5 $cmolkg^{-1}$ in pedon 1, while in pedons 2 and 3, it varied from 1.4–1.6 $cmolkg^{-1}$ and 1.6–3 $cmolkg^{-1}$ respectively. Magnesium (Mg) ranged from 0.4–1.2 $cmolkg^{-1}$, 0.2–6.4 $cmolkg^{-1}$ and 0.2–0.8 $cmolkg^{-1}$ in all the pedons. Sodium (Na) varied from 0.060–0.043 $cmolkg^{-1}$, 0.043–0.27 $cmolkg^{-1}$, and 0.043–0.068 $cmolkg^{-1}$. Potassium (K) decreased from 0.184–0.820 $cmolkg^{-1}$ in pedon 1 and increased from 0.102–0.128 $cmolkg^{-1}$ and 0.087$cmolkg^{-1}$ in pedons 2 and 3. Cation exchange capacity (CEC) ranged from 3.24–4.85 $cmolkg^{-1}$ in pedon 1, while in pedons 2 and 3, it increased from 0.74-8.39 $cmolkg^{-1}$ and 2.56–4.06 $cmolkg^{-1}$, respectively. Effective cation exchange capacity (ECEC) value varied from 3.889–7.383 $cmolkg^{-1}$, 3.315–10.868 $cmolkg^{-1}$ and 2.836–5.81 $cmolkg^{-1}$ in pedons 1, 2 and 3, respectively.

Table 4. Chemical properties of the soil of the study area

Pedon designation	Horizon depth	pH (H_2O)	OC gkg	Om g/kg	AIV.P mg/kg	Ca	Mg	k	Na	EA	EH	TEA	CEC	ECEC	BS
									→ cmol/kg ←						%
Ah	0–20	5.28	2.14	3.69	8.77	2.6	0.4	0.18	0.06	0.24	2.96	3.2	3.24	6.44	50
AB	20–58	5.41	0.56	1.08	6.31	1.4	1.0	0.19	0.06	-	1.26	1.26	2.65	3.19	67
BW	58–112	5.47	0.39	0.68	8.77	3.52	1.2	0.09	0.04	-	1.80	1.8	4.85	6.65	72
AB	0–25	4.89	0.94	1.69	8.77	0.4	0.2	0.10	0.04	0.5	2.07	2.07	0.74	3.31	22
B	25–90	4.90	0.21	0.36	7.36	1.6	6.4	0.12	0.27	-	2.47	2.47	8.39	10.86	77
AB	0–23	5.34	0.57	0.97	6.67	1.6	0.8	0.09	0.07	-	0.28	0.28	2.56	2.84	90
BW	23–90	5.39	0.64	1.10	10.52	3	0.2	0.82	0.04	-	11.48	1.48	4.06	5.54	73

Table 5. Suitability class scores of the soils Beeri for sanitary landfill

Land quality	Pedon 1	Pedon 2	Pedon 3
Texture (t)	N (24)	S2 (85)	N (24)
Sand (S) (gkg^{-1})	N (24)	S3 (60)	N (24)
Silt (Si) (gkg^{-1})	S3 (60)	S3 (60)	S3 (60)
Clay (Cl) (gkg^{-1})	N (24)	S2 (85)	N (24)
Bulk Density (b) (gcm^{-3})	S1(95)	S1 (95)	S2 (85)
Porosity (p) ($m^3\ m^{-3}$)	N (24)	N (24)	N (24)
Hydraulic conductivity (h) (cmhr)	-	-	-
Permeability (m) (m^2)	-	-	-
Soil reaction (r)	S1 (95)	S2 (85)	S1 (95)
ECEC (c) ($cmol/kg^{-1}$)	S3 (60)	N (24)	N (24)
Flooding (f)	S2 (85)	S1 (95)	S1 (95)
Drainage (d)	S3 (60)	S1 (95)	S1 (95)
Aggregate suitability	N (24)	N (24)	N (24)
Limiting factors	Tscp	Pe	Tscpe

Remarks: Aggregate suitability class scores: S1 = 75–100, S2 = 50–74, S3 = 23–49; N = 0–24.

Suitability assessment of the soils of the study area for sanitary landfill

The evaluation of soil suitability for sanitary landfill (Table 5) was conducted by correlating key site features for sanitary landfill (Table 1) with the land use requirements for sanitary landfill. The values of several soil properties shown in Table 1 were used as thresholds for the development of a sanitary landfill. The sand (topsoil) in pedons 1 and 3 suggests that the research site is now unsuitable N (24) for sanitary landfill operations, whereas the loamy sand texture indicates intermediate suitability S2 (85) for sanitary landfill constructions. This is in line with the findings of Ukabiala et al. (2022), reporting that sandy loamy texture soils are suitable for sanitary landfill construction because a more sandy-textured soils are highly permeable and allow unrestricted infiltration of the leachates and hazardous pollutants to the ground water, especially in area with low soil depths to the water table, making it unsafe. It is also stated that soils with high sand (>700 gkg^{-1}) and low clay contents (<170 gkg^{-1}) are more prone to leaching and pollutant leaching potentials. Bulk density of 0.935 and 0.9548 gcm^{-3} placed pedons 1 and 2 in the suitability class 1 (highly suitable) for sanitary landfill. The bulk density of 1.3041 gcm^{-3} also placed pedon 3 in the suitability class S2 (moderately suitable). Soil porosity of 50.79–64.7% placed the soils of the study are in the not suitable (N) class for sanitary landfill. This is because they are less retentive, therefore, unable to reduce infiltration of leachates and other harmful contaminants into the ground water. ECEC value of pedon 1 (6.44 $cmolkg^{-1}$) also placed the soils as marginally suitable (S3). Pedons 2 and 3, with ECEC of 3.31 and 2.84 $cmolkg^{-1}$, respectively are categorized into not suitable (N). The low ECEC also placed the soils of the study area as not suitable (N) for sanitary landfill because ECEC play very vital role in sanitary landfill as it controls both the adsorption and chemical rainfall phenomenon in soils. Thus, high ECEC is the best for sanitary landfill constructions.

Consequently, the soils of the study area (pedons 1, 2 and 3) are not suitable for sanitary landfill due to limitations in texture, sand and clay content, and porosity in pedon 1. Pedon 2 had limitations in porosity and ECEC, while pedon 3 had limitations texture, sand and clay content, porosity, and ECEC.

CONCLUSIONS

This research aimed to evaluate the suitability of soils in Beeri, Nyokhana District, Khana Local Government Area, Rivers State, Nigeria, for sanitary landfill purposes. The soils range from sandy loam to sand from the surface layers to the subsoil. The soil exhibited acidity, characterized by little organic carbon and effective cation exchange capacity (ECEC). The base saturation was greater at the surface than to the subsurface. The soils were currently not suitable (N) for sanitary landfill based on certain limitations, such as soil texture, sand and clay content, and porosity (poor drainage pattern) in pedon 1 and 3 and porosity and ECEC in pedon 2. Thus, if these soils must be used for sanitary landfill, it is suggested that a proper soil and water management practices for sanitary landfill should be adopted. Additionally, initiatives to enhance texture, bulk density, porosity, and ECEC through appropriate management techniques, including the incorporation of specific organic materials and inorganic fertilizers, are necessary to improve their physical and chemical properties, potentially classifying them as moderately to highly suitable for sanitary landfill.

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