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Geophysical, Geotechnical and Water Quality Assessment of Gosa Dumpsite in Abuja, Nigeria: Implications for the Future Development of a Sanitary Landfill

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Abstract

Geophysical, geotechnical and water quality investigations of Gosa dumpsite in Abuja, Nigeria were performed to unravel the feasibility of upgrading it to a modern sanitary landfill. Nineteen vertical electrical soundings were carried out to geoelectrically characterized the site. In addition, eight soil and nine water samples were analyzed to determine their geotechnical and physiochemical properties as well as their usability. The inversion of VES-DC data indicate 3-4 geoelectric layers. Geotechnically, the soils are classified as well graded clayey-sand to silty-sand with permeability between 5.1×10^{-7} m/s and 1.1×10^{-6} m/s, which makes the groundwater prone to leachate pollution. The physicochemical parameter of the water are generally below the WHO recommended value. It could be inferred that only the northern part of the area possess the required geophysical and geotechnical characteristics for upgrade to a sanitary landfill. The high concentration of radioactive elements in the water revealed that the present dumping activities has negatively impacted the groundwater quality.

Keywords: *Geophysical; Geotechnical and groundwater; Sanitary landfill; Nigeria.*

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]. The use of waste disposal by landfill is a very common practice, and the ever increasing demand for waste management makes them a very vital part of human existence. Preferred options of solid waste management are waste reduction at source and re-use [2]. However, disposal of solid waste in sanitary landfills is now increasingly gaining acceptance in many nations of the world [3]. This can be attributed to the fact that landfills serves as a final repository even for waste managed with other waste disposal techniques. Several researchers including Thompson and Zandi [4], Rushbrook [5], and Carra and Cossu [6] have documented that solid waste disposal in landfills are still the most economic form of disposal in the vast majority of cases. Thus, landfills will continue to be the most attractive disposal method for solid waste. Depending on location, about 95% of the solid wastes generated worldwide are disposed in landfills [7-8]. Since the implementation of early landfills, steps have been taken to improve their designs and management in order to reduce the impact of solid waste on environment and groundwater resources. Though, the same measures have been used worldwide, underdeveloped and developing countries are still struggling with the final disposal of their solid waste.

Landfills in the form of open and uncontrolled dumpsites are the most common waste disposal systems in many cities and towns in Nigeria. Open dumps are the oldest and most common way of disposing off solid wastes, although in recent years, thousands have been closed and many are still being used. Most of these waste landfills are unsuitably designed and managed as a result of capital investment, hence allowing for environmental pollution in those areas where they are located. Recently, the impact of leachate on groundwater and other water resources have attracted a lot of attention because of its overwhelming environmental significance. Landfill leachates are complex; heavy metal components are undoubtedly the most harmful because of their persistence and toxicity [9]. Most heavy metals in sanitary landfills, which have anti-seepage protection measures, are retained in the waste in a complex form [10]. The leachate from irregular landfills links directly to groundwater, and pollutes the groundwater as well as the hosting or local soil. Presence of heavy and trace metals in drinking water as a consequence of groundwater contamination by leachates is also a major health and environmental problem in Nigeria. Certain toxic heavy metals like lead, mercury, cadmium, minerals and man-made synthetic chemicals present in wastes may contribute to environmental degradation that leads to poor health, disease or death [11]. Waste has been recognized as one of the major problems confronting governments and city planners in Nigeria, thereby posing a serious threat to environmental quality and human health [12].

The quantity and generation rate of solid wastes in Nigeria have increased at an alarming rate over the years with lack of efficient and modern technology for the management of the wastes [13]. Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced [14]. The rapid population increase due to urbanization in Abuja metropolitan areas (i.e. Gosa village) have caused difficulties for the state and local environmental protection agencies in providing an effective and efficient municipal solid waste management [15]. Presently, there is no sanitary landfill in the rapidly growing city of Abuja (Federal Capital of Nigeria). The waste collected from the city are disposed in designated dumpsite which include Mpape (closed), Ajata (operational), Kubwa (closed) and Gosa (operational). These dumpsites are characterized by indiscriminate dumping on ground surface and persistent burning of waste. Waste picking is common at the Gosa dumpsite, which is usually an urban phenomenon [16]. Gosa dumpsite is located in Gosa village, Abuja, Nigeria. The management of municipal solid waste has become a major environmental problem, especially for fast growing cities like the current federal capital; FCT Abuja, with generation amount increasing on yearly basis [17]. Leachate movement from waste sites or landfills pose a high risk to groundwater resource if not adequately managed. Control of heavy metals in leachates has therefore become the focus of landfill management. A suitable solid waste sanitary landfill site should be characterized by proper hydrological, geological and environmental conditions. For these reasons, waste sanitary landfills must be specially designed, constructed and managed to keep them safe during operation. In order to achieve safer disposal of municipal solid waste in Abuja and its environs, the Abuja Environmental Protection Board [18] propose to upgrade the Gosa dumpsite to a modern sanitary landfill. Modern landfills are highly engineered containment systems, designed to minimize the impact of solid waste (refuse, trash, and garbage) on the environment and human health [19]. In modern landfills, the waste is contained by a liner system [18]. The primary purpose of the liner system is to isolate the landfill contents from the environment and therefore, to protect the soil and ground water from pollution originating in the landfill. However, no single geophysical tool can effectively determine the characteristics of a landfill. Integration of geophysical, geotechnical and physiochemical analytical methods provides an important tool in the evaluation and characterization of contaminants or landfills. Pursuant to the above, this study was undertaken to investigate the technical feasibility of upgrading the Gosa dumpsite to a modern sanitary landfill using integrated geotechnical, geophysical and groundwater quality assessment.

2. Geology of the area

Abuja is underlain by crystalline basement rocks and the rocks include different textures of granites, coarse to fine, consisting essentially of biotite, feldspars and quartz [20]. The rocks in the study area comprises of migmatite gneiss, granodiorite, porhyroblastic gneiss, Pan African granite, granite gneiss and amphibolites (Figure 1). Generally, the North-North East (NNE) and South-SouthWest (SSW) of the FCT are made of gneiss, migmatites and granites

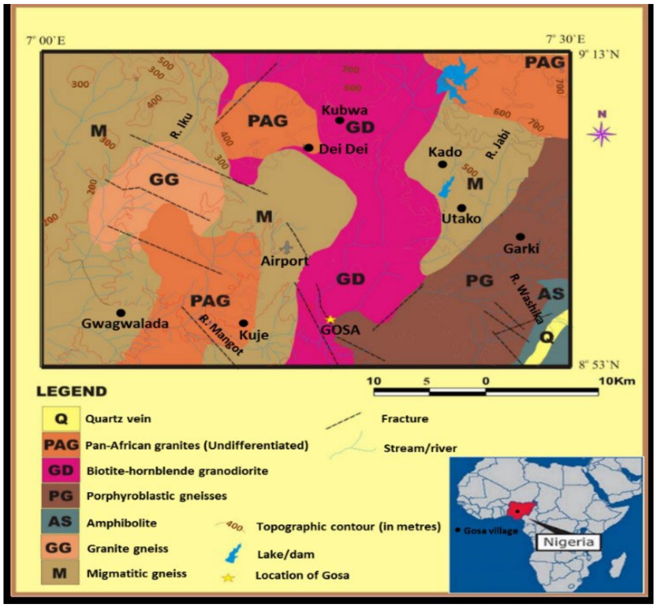

Figure 1. Geological map of the study area [3]

which characterize the Northern Nigeria [21]. All these rocks have been affected and deformed by the Pan-African thermotectonic event [22]. The rocks are highly fractured and jointed showing essentially two fracture patterns, NE-SW and NW-SE [23]. These fractures induce structural control on the drainage of Abuja. The out crop of schist belt is found along the Eastern margin of the area and this belt broadens as one moves south wards and maximum size is found to the South Eastern region of the FCT [21]. Minor Cretaceous deposits of Nupe sandstones occur in the southern part of FCT between Kwali and Abaji, extending to Rubochi [23]. The rocks in the study are have reddish micaceous sandy clay to clay materials, often capped by laterite.

3. Materials and methods

3.1. Geophysical investigation

An allied Omega terameter was used to carry out vertical electrical sounding (VES) geophysical survey along five traverses that cut across the study area (Figure 3). Schlumberger array was employed along the NE-SW traverses. A total of nineteen VES stations were used to investigate the area. Sixteen VES stations fall within the study area, while three VES stations (VES 5, VES 16 and VES 19) were taken outside the boundary of the area to extend investigation beyond the dumpsite. The VES data were processed using the software IP2Win developed by Alexey Bobachev, Moscow State University, Russia.

3.2. Geotechnical investigation

Eight samples comprising of two undisturbed and six disturbed samples were analysed geotechnically. The two undisturbed samples were recovered from two boreholes drilled during Standard Penetrometer Test (SPT), while the six disturbed samples were recovered from six trial/test pit dug manually. The test pits were dug to depths of 1.0 m and sampling done at 1.0 m. About 40 kg of disturbed soil samples were taken at each test pit. The soil samples recovered from the two boreholes (BH1 and BH2) and the six test or trial pits (T1-T6) were analysed to obtain required geotechnical parameter in landfill characterization. Preliminary geotechnical classification and identification tests such as water content, bulk density, specific gravity, grain size distribution, Atterberg consistency limits, specific gravity, permeability and compaction test were carried out on the 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.

3.3. Groundwater quality assessment

A total of nine water samples were collected from hand-dug wells, boreholes, springs and river in the study area. A clean 1.0 litre plastic container was filled with water sample from each sampling location after rinsing it with the same water sample in each case. The filled plastics were immediately capped tight to prevent the trapping and/or absorption of atmospheric oxygen. The samples were adequately labelled, refrigerated and sent to the laboratory to prevent cationic adsorption on the wall of the container during storage. Physicochemical analysis of the water samples were performed at Center for Energy Research and Development

(CERD), Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. Cationic and anionic analyses were carried out using Atomic Adsorption Spectrometry (AAS) in order to determine the concentration of Cd^{2+}, Cr^{2+}, Fe^{2+}, Cu^{2+}, Pb^{2+}, Ni^{2+}, Zn^{2+}, As^{3+}, K^{+}, Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, NO_3^{-}, HCO_3^{-}, CO_3^{2-}, PO_4^{2-} and SO_4^{2-}. In addition, physical parameters like pH, colour, temperature, total dissolved solid (TDS), turbidity, electrical conductivities, total hardness and total alkalinity were also determined.

4. Results and discussion

4.1. Geophysical assessment

The results of geophysical investigation is summarized in Table 1. The 2D pseudosection for the VES data along traverses 1-5 is shown in Figure 2.

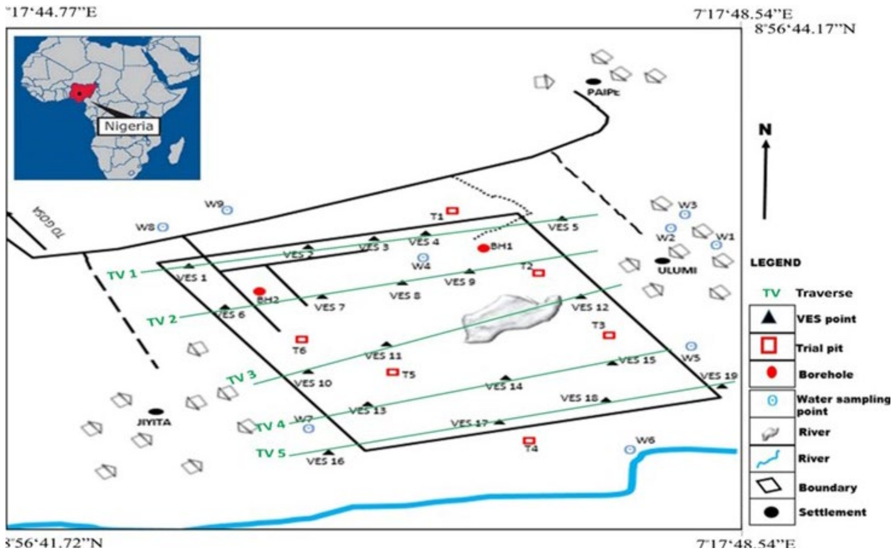

Figure 2. Map showing the study area as well as the VES, borehole, trial pits and groundwater sampling points

Table 1. Summary of the geophysical characteristics of the study area

Traverse	VES Station	No of Layers	Apparent Resistivity (Ωm)	Thickness (m)	Depth to Basement (m)
1	1	4	796/1883/903/4455	1.45/8.38/17.4/…	27.2
	2	4	120/522/685/1000	1.18/6.57/16.6/…	24.4
	3	4	74.2/415/755/2663	1.19/4.92/15.9/…	22.0
	4	4	742/1474/590/3026	1.28/5.17/13.4/…	19.8
	5	4	916/3871/1579/4780	1.47/11.8/8.38/…	21.6
2	6	4	613/3190/1018/4249	1.0/6.99/15.7/…	23.7
	7	4	461/850/554/5652	1.88/7.72/11.7/…	21.3
	8	4	231/1503/554/4080	1.13/8.09/12.0/…	21.2
	9	4	490/1699/922/6790	1.13/2.79/15.3/…	19.2
3	10	3	5426/2040/8849	2.31/15.2/…	17.5
	11	3	356/478/1000	0.5/6.05/…	6.6
	12	3	686/416/1570	2.17/4.76/…	6.9
4	13	4	2945/408/1818/4455	1.08/4.92/8.72	14.7
	14	3	1519/3334/7682	2.1/3.49/…	5.6
	15	3	2659/1279/7483	1.02/3.51/…	4.5
5	16	3	752/2353/5599	2.17/3.94	6.1
	17	3	3799/1264/6453	0.79/6.58	7.4
	18	3	1000/2259/5427	1.18/4.08	5.3
	19	3	110/736/5934	0.13/7.0/…	7.1

Four geologic layers were delineated at VES 1-VES 9 and VES 13, whereas, three geologic layer were delineated at VES 10, and VES 12-VES 19. These four layers correspond to lateritic top soil, laterites/clayey sand, weathered basement and fresh basement, respectively. The weathered basement thinned out at VES 10 and VES 12-VES 19 where outcrop of the basement occurred as low lying hill. The resistivity value of the lateritic top soil varies from 110 Ωm at VES 19 to 5426 Ωm at VES 10, while its thickness varies from 0.5 m - 2.31 m at VES 10 and VES 11. The second layer has resistivity value ranging from 408 Ωm at VES 13 to 3871 Ωm at VES 5. In addition, the thickness of the second layer varies from 2.79 m at VES 9 to 15.2 m at VES 10. This layer is clayey and therefore more significant in providing material barrier/seal in the proposed sanitary landfill. The 2D resistivity pseudo sections (Figure 3) show that this layer thinned out towards the south of the study area. Furthermore, depth to basement also becomes shallower southerly from a maximum of 27.2 at VES 1 to a minimum of 4.5 m at VES 15. Therefore, the required clay/clayey material required as landfill liner is more abundant in the Northern part of the study area. The third layer is the weathered basement, which directly overlies the fresh basement. Its resistivity value varies from 416 Ωm at VES 12 to 3334 Ωm at VES 14, whereas its thickness varies from 3.49 m at VES 14 to 17.4 m at VES 1. The last layer corresponds to the basement and its resistivity value varies from 1000 Ωm at VES 2 and VES 11 to 8849 Ωm at VES 10. The relatively high resistivity values are possibly due to reworking of the soil surface or presence of compacted lateritic hard pan.

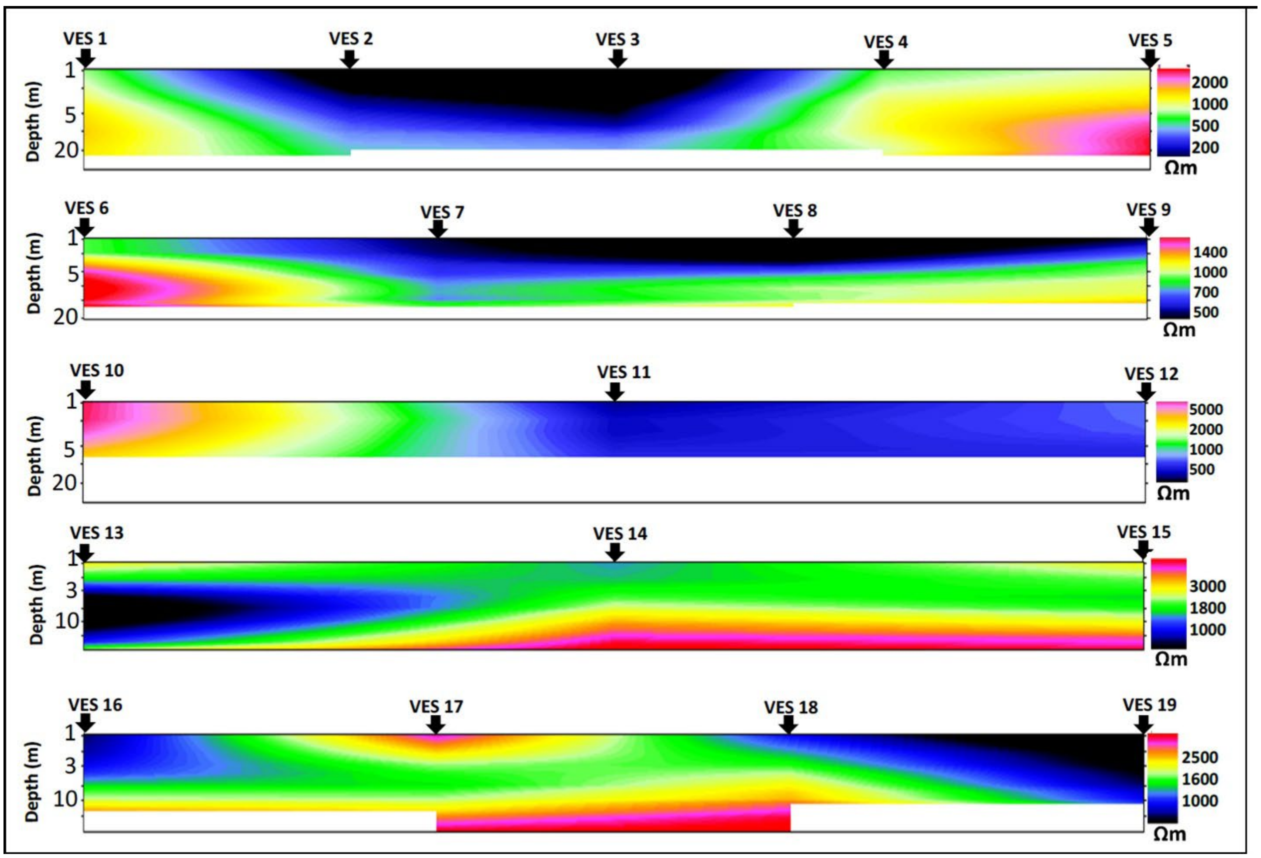

Figure 3. 2D resistivity pseudosection along traverse 1 (VES 1-5), traverse 2 (VES 6-9), traverse 3 (VES 10-12), traverse 4 (VES 13-15) and traverse 5 (VES 16-19)

4.2. Geotechnical assessment

The results of geotechnical analysis is summarized in Table 2. The geotechnical requirements for soil to be used as landfill liners as recommended and confirmed by Ige et al.[24] is presented in Table 3.

Table 2. Summary of results obtained from geotechnical analysis of the samples

Sample	WC (%)	BD (kg/m^3)	SG	USC	Atterberg Limit	Compaction Test		Permeability, k (m/sec)
						Standard	Modified	
T1	1.3	1.28	2.55	SC-SM	LL= 39%; PL= 21%; Ip = 21%; FI= ; TI= AC=0.33 ; SL=	OMC = 16 %; MDD =1.8g/cm^3	OMC = 14 %; MDD =1.83g/cm^3	4.892 x 10^{-7}
T2	2.8	1.26	2.64	SC-SM	LL= 35%; PL= 21%; Ip =14% ; FI=22 ; TI=0.64; AC=0.28 ; SL=	OMC =16.5 %; MDD =1.73g/cm^3	OMC = 16 %; MDD =1.78g/cm^3	4.467 x 10^{-7}
T3	0.6	1.66	2.60	SP		OMC = 10 %; MDD =1.8g/cm^3	OMC = 9 %; MDD =1.83g/cm^3	1.361 x 10^{-6}
T4	3.7	1.38	2.66	SC-SM	LL=30% ; PL=18% ; Ip =21% ; FI= ; TI= AC= 0.33; SL=	OMC = 15.5 %; MDD =1.8g/cm^3	OMC = 14.5%; MDD =1.85g/cm^3	6.080 x 10^{-7}
T5	2.1	1.65	2.65	SC-SM	LL=30% ; PL=17%; Ip =13% ; FI= 25; TI= 0.5; AC=0.6 ; SL=	OMC =12 %; MDD =1.79g/cm^3	OMC = 11 %; MDD =1.82g/cm^3	1.101 x 10^{-6}
T6	5.9	1.35	2.60	SC-SM	LL= 34%; PL=23% ; Ip =11% ; FI= 25; TI= 0.6; AC=0.2 ; SL=	OMC = 16 %; MDD =1.7g/cm^3	OMC = 14 %; MDD =1.76g/cm^3	5.142 x 10^{-7}
BH1	14.6	1.82	2.55	SC	LL= 24%; PL=16% ; Ip = 7%; FI= ; TI= AC= ; SL=	OMC = ; MDD =	OMC = ; MDD =	
BH2	11	1.85	2.64	SC	LL=28% ; PL=17% ; Ip = 11%; FI= ; TI= AC= ; SL=	OMC = ; MDD =	OMC = ; MDD =	

WC = Moisture content; BD = Bulk density; S.G = Specific gravity; USC = Unified Soil Classification; SP = Poorly graded sand; SC = Well graded clayed-sand; SM = Silty-sand; LL = Liquid limit; PL = Plastic limit; Ip = Plastic index; FI = Flow index; TI = Toughness index; AC = Activity of clay; OMC = Optimum moisture content; MDD = Maximum dry density.

The result of specific gravity mainly indicate values ranging from 2.50 up to 2.69. Based on the classification scheme of Bowles [25], it could be inferred that the soil samples are composed mainly of sand, silt and clay. In addition, based on specific gravity of common minerals given by Das [26], it can be inferred that the dominant minerals in samples are kaolinite and quartz. Kaolinite is non-expansive clay and is generally good for liner materials in dams and landfills. Grain size analysis of soil samples T1, T2, T3, T4 and T6 shows abundance of gravel, sand, silt and are as follows: T1 (0 % Gravel, 50 % sand, 30 % silt, 20 % clay); T2 (25 % Gravel, 45 % sand, 23 % silt, 7 % clay); T3 (10 % Gravel, 90 % sand, 0 % silt, 0 % clay); T4 (10 % Gravel, 60 % sand, 19 % silt, 11 % clay); T5 (25 % Gravel, 57 % sand, 13 % silt, 5 % clay); and T6 (1.2 % Gravel, 48.8 % sand, 36 % silt, 14 % clay).

The grain size analysis shows that the samples are composed predominantly of sand size particles with some amount of silt and clay. The only exception is sample T3 which is composed almost entirely (90 %) of sand size particles had no silt. All the soil samples (except sample T3) are classified as clayed-sand to silty sand (SC-SM) base on Unified soil classification. Sample T3 is classified as poorly graded sand (SP) which implies that all the grain sizes are not well represented. The percentage of sand predominates, follow by silt and sand respectively. The bored samples (BH1 and BH2) can be classified as clayed-sand lateritic soil with dominant percentage of clay (14-30 %). The largest grain size in soil samples is 16 mm and thus satisfies the grain size requirement of ≤ 63mm suggested by ONORMS[34] and the values of between 30 mm and 50 mm suggested by Daniel (1993). The percentage of fines contained in the soils are T1 = 50 %, T2 = 30 %, T3 = 0 %, T4 = 30 %, T5 = 18 %, T6 = 50 %, BH1 = 29-30 %, BH2 = 30 %. The values of the percentage of fines also satisfy the required ≥ 15 %. All the studied samples have gravel percentages less than the recommendation. This shows that the soil samples (except T3) are cohesive soil with very little porosity, which is desirable for liner materials.

Table 3. Comparison of geotechnical criteria by different researchers with this study

Parameters	Author(s)	Recommendations	This study
Grain size	Oelzschner [30] Bagchi [31] ONORMS [32] Daniel [33]; Rowe *et al.*, [34]	Clay fraction < 20 % Largest grain size ≤ 63mm Silt/clay fraction ≥ 15 % Largest grain size < 25mm, %Gravel < 30, % fine ≥ 30 %	Clay = 5 – 30 % Largest grain size = 16mm 20 – 50 % fines ≤ 10 % gravel
Atterberg consistency limits	Daniel [33]; Rowe *et al.*, [34] Seymour and Peacock [35] Oelzschner [30]	LL ≥ 30%, IP ≥ 15 % LL ≥ 30%, IP ≥ 10 % LL ≥ 30%, IP ≥ 15 % LL ≥ 25%, IP ≥ 15 % LL ≥ 30%, IP ≥ 15 % Inorganic clay of low-medium plasticity (CL-CI) and Ac of < 1.25	LL = 22 – 39 %, IP = 5.4 - 18.4 % Ac = 0.2 - 0.6
Moisture content-density relationship	ONORMS [32] Taha and Kabir [29]	MDD ≥ 1.71 t/m^3 MDD ≥ 1.71 t/m^3	SP = 1.7 - 1.80 g/cm^3 MP = 1.7683 g/cm^3
Permeability	Murphy and Garwell [36] Mark [37] Joyce [38] Fred and Anne [39]	≤ 1×10^{-9} m/s ≤ 1×10^{-9} m/s ≤ 1×10^{-8} m/s ≤ 1×10^{-9} m/s	5.1×10^{-7} m/s - 1.1×10^{-6} m/s

The results of the Atterberg consistency limits for samples T1 - T6 (excluding T3) and the bored samples BH1 - BH2 shows that the liquid limits, flow index and toughness index range from 25-39%, 3.7-29.1 and 0.3-0.6, respectively. Plot on the plasticity chart shows that samples T1, T2, T4, T5 and T6 are dominantly of low plasticity (PI: 10-20%), whereas the bored samples (BH1-BH2) are of low to intermediate plasticity (PI < 10 %). Plot on the plasticity chart also confirmed that the excavated samples are composed of inorganic clay of medium plasticity, while the bored samples are of inorganic clay of low plasticity. The clay activity (AC) of soil sample T1, T2, T4, T5 and T6 are 0.33, 0.28, 0.35, 0.6 and 0.2, respectively. Therefore, the samples are composed of inactive clays (Ac < 0.75) (non-swelling clay minerals) such as kaolinite, muscovite. Plot of the soil samples on the Casagrande plasticity chart shows that sample BH1 and BH 2 are inorganic clay of low plasticity (CL), whereas T1-T6 are inorganic clay of intermediate plasticity (CI). The results obtained for clay activity of the soil samples reveals that clay activity in the range of 0.20-0.6, which also support or confirm the dominance of kaolinite clay type. Therefore, the soil samples are recommended for use as landfill liners.

Compaction test was carried out to determine the response of the soil samples to compaction effort. It evaluates the ease with which the soil samples from the area can be improved by compaction. Improvement by compaction is necessary to obtain low hydraulic conductivity, which is desirable in landfill barrier. The soil samples were compacted using both standard proctor and modified proctor methods. Summary of results compaction test of the soil samples are presented in Table 2. The results of the permeability test of sample T1-T6 shows that the permeability values range between 5.1×10^{-7} m/s and 1.1×10^{-6} m/s. The samples needed to be improved by the addition of little amount of clay to meet up to 1×10^{-8} m/s recommended by Ige *et al.* [1]. The maximum dry density (MDD) range from 1.7 g/cm^3 up to 1.80 g/cm^3 for samples compacted at both standard and modified proctor. This range satisfy the minimum requirement of 1.7 g/m^3 proposed by Ige *et al.* [1] for samples under standard proctor. The MDD values under modified proctor range from 1.76 g/cm^3 to 1.83 g/cm^3 much better than 1.45 g/cm^3 (standard proctor) and 1.64 g/cm^3 (modified proctor) specified by Taha and Kabir [29] for soils produced from basement complex rocks to be usable as liners in landfill.

4.3. Groundwater quality assessment

The results of the physicochemical analysis of groundwater samples and the drinking water quality standard, as recommended by World Health Organization (WHO) is summarized in Table 4. The result shows that the pH values for the samples range from 8.1 – 9.4, which is higher than the 6.5 – 8.5 pH values recommended by WHO for drinking water. The colour of drinking water does not have direct implication on human health, nonetheless it may affect the acceptability and aesthetic value of the water [27]. Based on WHO recommendation, the colour of drinking water should be less than 15 TCU (True colour unit). The colour range for water samples in the study area range from 1 – 90 TCU. Water samples 1, 2, 3, 4, 6, and 8 have colour range of less than 15 TCU, but water samples 5, 7 and 9 have colour units of 90, 25 and 23, respectively and are therefore not suitable for drinking. The palatability of water with total dissolved solids (TDS) level of less than about 600mg/L is generally consider to be good. Drinking water becomes significantly and increasing unpalatable as TDS level become greater than 1000 mg/L [28]. TDS in drinking water originate from natural sources, sewage, urban runoff and industrial waste water. All the water samples have TDS value below 600 - 1000 mg/L, which is the WHO recommended value. Turbidity is an important indicator of possible presence of contaminants. Turbidity in water is caused by suspended particles or colloidal matters that obstruct light transmission through the water [27]. The WHO recommended turbidity of small water supply to be at least less than 5 NTU (Nephelometric turbidity unit). The turbidity of water samples 1, 2, 3, 5, 6 and 8 are below the WHO [27-28] recommended value. However, water samples 5, 7, and 9 have turbidity of 74.64 NTU, 8.31 NTU and 7.43 NTU, respectively, which are above the WHO [27] recommended value.

According to the Standard Organization of Nigeria (SON) [29], the acceptability threshold value for drinking water conductivity is ≤ 1000 µS/cm. The conductivity of water samples range from 722.56–1855.02 µS/cm. Water samples 3, 8, and 9 have electrical conductivities of approximately 1199 µS/cm, 1855 µS/cm and 1766 µS/cm, respectively. These values are higher than the SON [28] recommended value, hence the water is unfit for drinking. Furthermore, the most significant water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity [24]. Very high electrical conductivity can lead physiological drought in plants. Todd [26] classified water having electrical conductivity between 750 –2000 µS/cm as permissible for irrigation. Thus, the water in the study area is permissible for irrigation purpose. Hardness is the traditional measure of the capacity of water to react with soap, hard water requiring considerably more soap to produce lather [27]. It is usually predominantly caused by the presence of dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations. Hardness in drinking water affects its acceptability (taste) and a taste threshold of 100–300 mg/L is established for calcium. In addition, water with hardness above 200 mg/L may cause scale deposition in distribution and storage systems. High soap consumption and scum formation are major negative impact of hardness in water. Total hardness of water samples vary from 40–232 mg/L of $CaCO_3$. Therefore, all the water samples from the study area have total hardness within the WHO recommended value. Total Alkalinity is important factor in the prevent ion of water quality problem associated with corrosion of iron pipes (either cast or ductile) use in distribution system. The corrosion of ion in distribution system usually result in degraded water quality commonly called "red water". Successful control of ion corrosion has been achieved by adjusting the pH to the range 6.8 – 7.3, hardness and alkalinity to at least 40 mg/L (as calcium carbonate). However, the annual mean of alkalinity of water sample from the area is 45.50 mg/L $CaCO_3$ and thus satisfy the WHO [27] recommended value of total alkalinity of at least 40 mg/L (as $CaCO_3$) for the prevention of "red water".

Table 4. Summary of physiochemical parameter in the studied samples and WHO Standard [27-28].

Measured Parameter	Min.	Max.	Mean	Std. Deviation	WHO (2011) Standard	
					Health-based Guideline Value	Acceptability Threshold/ Optimum Value
pH	8.10	9.40	8.72	0.40		6.5-8.5
Colour (Pt/Co Units) Raw	1.00	90.00	17.67	28.66		< 15 TCU
Temperature (°C)	37.80	39.30	38.28	0.44		
Total Dissolved Solid (mg/l)	244.84	398.33	319.72	55.85		1000
Turbidity (NTU)	1.17	74.64	11.40	23.86		< 5 NTU
Electrical Conductivities (µS/cm)	722.56	1855.02	1106.39	422.18		1000
Total Hardness (mg/l $CaCO_3$)	40.00	232.00	127.11	60.82		100-300
Total Alkalinity (mg/l $CaCO_3$)	32.00	302.00	130.67	87.61		At least 40
Cd^{2+} (mg/l)	0.001	0.017	0.009	0.005	0.003	
Cr^{2+} (mg/l)	0.004	0.023	0.015	0.007	0.05	
Fe^{2+}(mg/l)	0.003	0.029	0.018	0.009		
Cu^{2+}(mg/l)	0.003	0.128	0.059	0.045	2	
Pb^{2+}(mg/l)	0.000	0.018	0.008	0.006	0.01	
Ni^{2+}(mg/l)	0.002	0.140	0.073	0.050	0.07	
Zn^{2+}(mg/l)	0.004	0.161	0.084	0.054	3	
As^{3+} (mg/l)	0.000	0.020	0.009	0.007	0.01	
K^{+}(mg/l)	0.054	0.322	0.184	0.091		
Na^{+}(mg/l)	0.084	0.721	0.364	0.239		200
Ca^{2+}(mg/l)	0.052	0.131	0.096	0.027		
Mg^{2+}(mg/l)	0.013	0.089	0.057	0.032		
Cl^{-} (mg/l)	15.50	23.01	20.39	2.81		200 – 300
NO_3^{-} (mg/l)	3.28	12.27	8.77	3.31		
HCO_3^{-} (mg/l)	36.00	238.00	115.22	60.31		
CO_3^{2-} (mg/l)	8.00	64.00	44.00	26.53		
PO_4^{2-}(mg/l)	0.21	1.52	0.74	0.49		
SO_4^{2-} (mg/l)	14.43	31.19	20.95	5.85		

In epidemiological studies, an association has been found between exposure to chromium (VI) by the inhalation route and lung cancer [27]. The WHO recommended maximum value for chromium in drinking water is 0.05 mg/L. The chromium concentration in water range from 0.004–0.023 mg/L. Therefore, all the water samples from the study area are free from chromium contamination. Copper is both an essential nutrient and a drinking-water contaminant [28]. Studies are ongoing on the long-term effects of copper on sensitive populations, such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis. The WHO [27] recommended maximum value for copper in drinking water is 2 mg/L. The copper concentration in water samples range from 0.003–0.128 mg/L. Therefore, all the water samples are free from copper contamination. Exposure to lead is associated with a wide range of effects, including various neurodevelopmental effects, mortality (mainly due to cardiovascular diseases), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes [28]. The amount of lead dissolved from the plumbing system depends on several factors, including pH, temperature, hardness and standing time of water, with soft, acidic water being the most plumbosolvent. The WHO recommended maximum value for lead in drinking water is 0.010 mg/L. The lead concentration in water samples range from 0.001–0.018 mg/L. Samples 6, 8 and 9 have arsenic concentration of 0.011 mg/L, 0.015 mg/L and 0.018 mg/L, respectively and are therefore lead-contaminated. Smoking and occupational exposure are the two main sources of Nickel in the population while water is generally a minor contributor to the total daily oral intake. Allergic contact dermatitis is the most prevalent effect of nickel in the general population [27]. The International Agency for Research on Cancer (IARC) documented that inhaled nickel compounds are carcinogenic to humans (Group 1) and that metallic nickel is possibly carcinogenic (Group 2B). The WHO recommended maximum value for nickel in drinking water is 0.070 mg/L. The Nickel concentration in the water samples range from 0.002–0.140 mg/L. Samples 5, 6, 7, 8 and 9 have nickel concentration of 0.101 mg/L, 0.096 mg/L, 0.094 mg/L, 0.0127 mg/L and 0.140 mg/L, respectively and are therefore nickel-contaminated. Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. However, drinking-water containing zinc at levels above 3 mg/L may not be acceptable to consumers [27]. The WHO recommended maximum value for zinc in drinking water is 3 mg/L. The zinc concentration in water samples range from 0.004 – 0.161 mg/L. Hence, all the water samples from the area are free from zinc contamination.

The International Programme on Chemical Safety (IPCS) reported that long-term exposure to arsenic in drinking-water is causally related to increased risks of cancer in the skin, lungs, bladder and kidney [27]. The WHO recommended maximum value for arsenic in drinking water is 0.010 mg/L. Arsenic concentration in the water samples range from 0.001 – 0.020 mg/L. Samples 5, 8 and 9 have arsenic concentration of 0.012 mg/L, 0.017 mg/L and 0.020 mg/L, respectively and are therefore arsenic-contaminated. Source of calcium in underground water is usually weathering of parent rock materials especially in limestone region. Calcium ion is a major cause of hardness in drinking water and thus affects the acceptability and aesthetic value of water. The taste threshold for the calcium ion is in the range of 100 – 300 mg/L, depending on the associated anion [27]. The collected water samples have calcium concentration ranging from 0.052 – 0.131 mg/L and thus satisfy the WHO taste threshold value. Magnesium ions contribute to hardness in water and the presence of magnesium ion in drinking water is prevalent in gypsum region. Drinking-water in which both magnesium and sulphate are present at high concentrations can have a laxative effect, although data suggest that consumers adapt to these levels as exposures continue [28]. The water samples have magnesium ion concentration ranging from 0.013–0.089 mg/L and thus satisfy the WHO recommendation [27].

The main source of human exposure to chlorine is the addition of salt to food, and the intake from this source is usually greatly in excess of that from drinking-water [27]. Other source of chloride in drinking-water include sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion. No health-based guideline value is proposed for chloride in drinking-water. However, chloride concentrations in excess of about 250 mg/L can give rise to detectable taste in water and excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water [27]. This can lead to increased concentrations of metals in the supply. The range of concentration of chloride in water sample is between 15.50–23.01 mg/L. These values falls below the WHO recommended maximum value range of 200–300mg/L and thus safe and acceptable for drinking. Nitrate (NO_3^-) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is a part of the nitrogen cycle. Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks [27]. In the case of bottle-fed infants, drinking-water can be the major external source of exposure to nitrate and nitrite. A guideline value of 50 mg/L for nitrate ion is established by WHO to protect against methaemoglobinaemia in bottle-fed infants. Absorption of nitrate ingested from vegetables, meat or water is rapid and in excess of 90 %, and final excretion is in the urine. Contaminated private wells have been associated with most cases of methaemoglobinaemia. In the present study, nitrate ion concentration in the water samples range between 3.28–12.27 mg/L. This values satisfy the WHO recommendation of maximum of 50 mg/L for nitrate ion. Natural sources and industrial waste water are the main sources of sulphate in groundwater. The existing data do not identify a level of sulphate in drinking-water that is likely to cause adverse human health effects [27]. Therefore, health-based guideline value has not been derived for sulphate. However, a laxative effect may occur at concentrations of 1000–1200 mg/L. The presence of sulphate in drinking-water may also cause noticeable taste and may contribute to the corrosion of distribution systems. Taste thresholds have been found to range from 250 mg/L for sodium sulphate to 1000 mg/L for calcium sulphate ion. It is generally considered that taste impairment is minimal at levels below 250 mg/L of sulphate. In the study area, water samples collected have sulphate concentration, which ranges from 14.43–31.19 mg/L and thus satisfy the WHO recommended maximum value. Based on the results from the geophysical, geotechnical and groundwater quality assessment, suitable and non-suitable areas for the proposed sanitary landfill have been unravel (Figure 4).

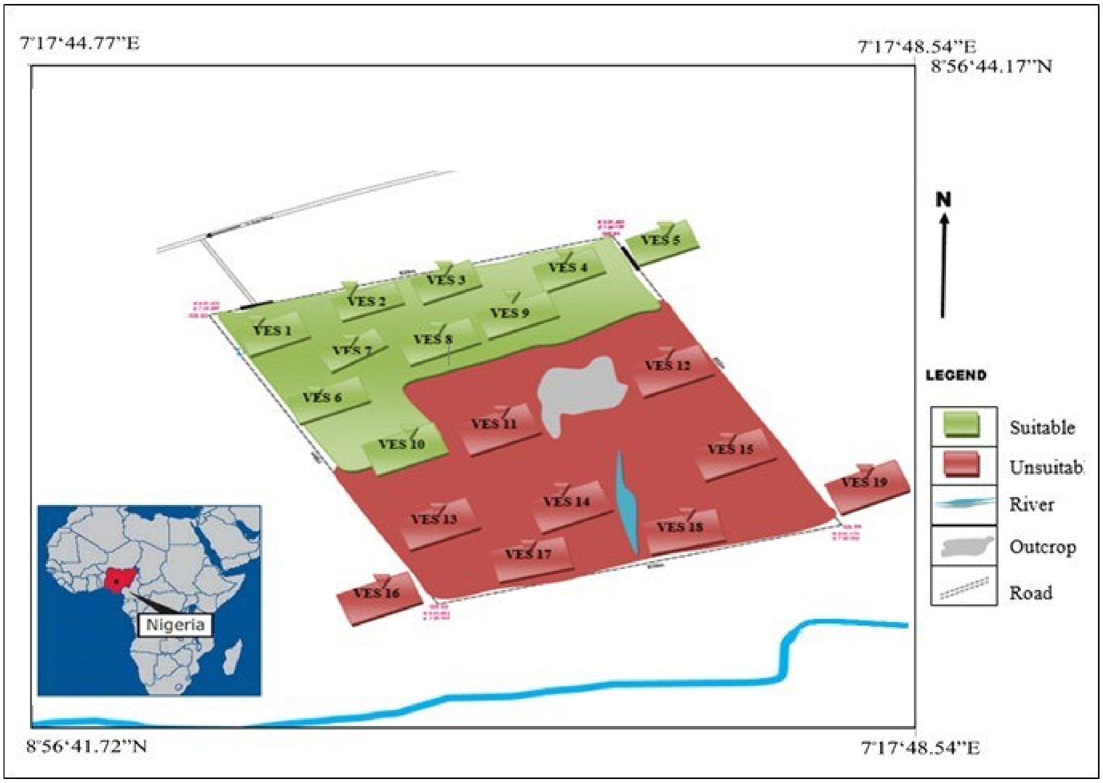

Figure 4. Schematic diagram showing suitable and non-suitable areas for the proposed sanitary landfill

5. Conclusions

The suitability of the soil as landfill liners have been evaluated based on geophysical and geotechnical parameters. Most of studied soils satisfy the recommended values of each parameter and are considered suitable for use as landfill liner. The results of the geophysical and geotechnical assessments indicate that the soils in the northern part of the area satisfy the recommended values of each parameter and are considered suitable for siting the sanitary landfill. In addition, this soil is preferred to their southern counter part due to the presence of thick layer of clay as well as the absence of fractures and shear zones which may increase the risk of groundwater pollution. Geotechnical analysis also revealed that the soil samples obtained from the northern part of the area are less permeable, thus they can act as seals in sanitary landfill. The generated suitability map indicate that approximately 45% of the landmass is suitable for sanitary landfill construction. Assessment of baseline groundwater quality shows that physicochemical parameter of the water samples are generally below the values recommended by World Health Organization (WHO). However, the high concentration of Nickel (Ni^{2+}), Lead (Pb^{2+}) and Arsenic (As^{3+}) in most of the water samples point to the fact that present dumping activities on the site has negatively impacted the groundwater quality in the area. Hence, the consumption of the water over a long period of time would be harmful to both humans' health and animals.

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