

A REVIEW OF ENVIRONMENTAL AND GEOTECHNICAL FACTORS FOR AN ENGINEERED SANITARY LANDFILL DESIGN IN DELTA STATE NIGERIA

Nwaobi Emeka Emmanuel, Prof. Brendan Eje and Dr. Obianuju Abonyi

Department of Engineering Management Esut Business School Enugu State University of Science and
Technology

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Abstract: This study explored the critical environmental and geotechnical factors that influence the design of engineered sanitary landfills in Delta State, Nigeria. As the demand for sustainable waste management practices grows, understanding the unique challenges and opportunities within the local context is imperative. The study examines the environmental considerations, including climate, hydrogeology, and ecosystem impact, to ensure that the proposed landfill design aligns with ecological sustainability. Furthermore, the geotechnical aspects of the review focus on soil characteristics, slope stability, and foundation design, addressing the engineering challenges associated with constructing and maintaining a stable landfill structure. Delta State's geological and geotechnical conditions are analyzed to determine their impact on landfill performance, longevity, and potential risks. By synthesizing information on both environmental and geotechnical factors, this review aims to provide engineers, policymakers, and stakeholders with a comprehensive understanding of the intricacies involved in designing sanitary landfills in Delta State. The findings contribute to the development of guidelines and best practices tailored to the local environment, fostering sustainable waste management solutions and minimizing adverse environmental impacts.

Keywords: Sanitary landfill, Environmental factors Geotechnical factors and Waste management

INTRODUCTION

1.1 Background of Study

Solid waste, any tangible discarded material that has outlived its intended usage or shelf life is assuming an interesting and disturbing trend, alike. The innovative waste management concept of recovery recycling and reuse has redefined waste, as hitherto unwanted materials, to one, with or from which value additions are obtainable (Jinkyung & Hirishan, 2020). However, unlike other waste forms, its visible nature imposes, on it, a burden of efficient management (<https://www.circle-economy.com/insights/the-circularity-gap-report-2019>). As in other climes, solid waste generation directly relates to human and other life form existence (Olukami *et al.*, 2020). However, the volume and composition are a function of population, level and type of industrialization, behavioural patterns and existing management efforts and strategies (Agamuthu 2010).

Nigeria generates more than 32 million tons of solid waste annually (Olukami *et al.* 2020). Domestic garbage, used electronics and vehicular parts, industrial parts and goods, metal and iron scraps, including debris from construction facilities are the dominant waste streams (Krause and Townsend 2014). Lagos, Anambra, Abia, Rivers, Ogun, Kano, Oyo, Kaduna, Delta and Edo were listed by Akindayo (2015) as States generating the highest

waste tonnage annually. These States account for about 50% of the solid waste volume in the country. Obidike *et al.* (2020) attributed population and moderately high level of industrialization and transportation route hubs as the waste generation drivers in these States. Contrastingly, personal communication and popular observations exempted Akwa Ibom, Cross River and Kwara from the list of high solid waste generators to fairly existing efficient waste management policies, behaviour and strategies.

Each State or household in Nigeria practices one form of solid waste management, either intentionally or by default (Bakare, 2018 & Agunwamba *et al.*, 2003). Incineration, open dumping on land or sea and burial are the most common waste management practices. Household waste collectors often engage in the first two mentioned forms. These practices are bedevilled with avoidable shortcomings. Incineration promotes poor air quality, increases susceptibility to respiratory health challenges and contributes significantly to the generation of Greenhouse gases (Achankeng, 2003 & Onwughara *et al.*, 2010). Open dumping on land incubates pathogens and vectors implicated in several public health diseases, pollutes groundwater, overruns highways after rainfall events and creates an unaesthetically nauseating sight to behold (Ali *et al.*, 2014, Usman *et al.*, 2017 & Naresh *et al.*, 2022). Open dumping in seas, drains and water bodies is a main driver of flooding, water pollution and biomagnification of harmful toxicants in the body systems of aquatic resources consumed by humans (Hipsey, 2008). Waste burial, the least practised of them all, is reported as a driver of groundwater contamination (Li *et al.*, 2017 & Cossu, 2013).

Countries and regions are adopting several solid waste techniques to address the concerns listed in the preceding paragraphs. The sanitary landfill method is one such. It is in practice in almost all regions across each developed country (Nissim *et al.*, 2005 & Yang *et al.*, 2014). The technique, an advanced technological form of crude waste burial method, factors environmental and geotechnical considerations in its design. All existing sanitary landfill is built to specifications.

The population of Delta State (5,636,100) with an annual growth rate of 2% is projected to hit 7,890,540 by 2030. Also, going by her budgets coupled with the various ongoing/planned projects, the State is primed to exponentially grow its industrial base. The projected industrial growth and population will increase its waste-generating tonnage to about 3 million tonnes in 2030. No available open dump site in the State can accommodate this volume. This burden imposes the timely planning and design of a sanitary landfill on us.

The ecology of Delta State ranges from mangroves to freshwater and terrestrial ecosystems (Izah, 2018). These varied eco-zones impose varied soil sedimentary conditions ranging from alluvial sands, and deltaic environments to fine clayey clastic materials (Nwabueze, and Rob 2017). The design of any sanitary landfill for Delta State should align with these geomorphological conditions. This presentation is, therefore, a review of possible designs of sanitary landfills in the freshwater/mangrove environment, floodplains and clayey undulating topographies.

1.2 Seminar Justification

Solid waste was differentially viewed in the global world of yesterday. The developing countries and their research focus and operating companies viewed waste as disposable items (Rushbook, 1991). They viewed it as nauseating materials with no value additions (Leite, 2021). This perception drove their overarching waste strategy of Incineration which guarantees a Reduction in Waste Volume ([https://doi.org/10.1016/0160-4120\(88\)90148-1](https://doi.org/10.1016/0160-4120(88)90148-1)). Another school of thought in these States viewed it as sickening substances that need to be isolatedly dumped at remote centres (Buenrostro *et al.*, 2001) or in water bodies or subsurface (Braun, 2020 & Urooj *et al.*, 2019). They could not have been more wrong. Flooding and public health nuisance were the direct impacts of countries acting on waste disposal methods. The developed countries on the other hand viewed waste within the context of management (recycling, reuse, and resource recovery) rather than on disposal.

These perceptions drove investments in waste management research and policy formulations. The gains of these perceptions are here with us. These investments and policy implementation birthed a new subsector, of the Environment, called Waste Management. Waste management boards, agencies and departments are now existing. Several companies are uptaking waste research findings to establish reuse, recycling, and energy recovery

industries (Stijepovic & Linke, 2011 & Chen *et al.*, 2018). These companies are guaranteeing cleaner environments (Ismaila *et al.*, 2022), massive job creation, direct foreign investments and increased internally generated revenues (Babayemi *et al.*, 2017 & Fobil *et al.*, 2005), and production of technologically skilled manpower to drive the novel subsector (Jie & Guanghua, 2022). The now famous Waste to Wealth was borne from these investments. Although, belated and disoriented, developing countries are where the developed ones, were yesterday (Mmereki *et al.*, 2016 & Daiz, 2009).

With a geometric population explosion and the establishment of several industrial processing centres, and the conversion of refuse dump sites to other land uses, there is an urgent need to change our policy directions to waste management strategies, rather than the waste disposal focus of yesterday. The choice of waste management strategies to be adopted should be environmentally safe and not create a public nuisance or any of the demerits of the waste disposal method. A sanitary landfill is not only safe and ensures gainful occupation of our subsurface space, where a percentage is currently reserved for internment, but it guarantees the recovery of leachate from the biodegraded materials, treatment, and supply into the public water supply system (Bull *et al.*, 1983 & Spencer & Farquhar, 1975). The leachate treated to water is used for irrigation and consumption thereby alleviating the stress on our aquifer systems by serving as a complementary and alternative groundwater source (Wu *et al.*, 2021). Great and interesting, as this waste management method looped all loose deleterious ends of waste, is the added burden of design to specification for every sanitary landfill structure. The diverse ecological conditions in Delta further impose an additional burden to design one for each of the three broad landscapes in the State. These realities justify this seminar presentation.

1.3 Aims of Presentation

The overarching aim of this presentation is to review engineering designs for sanitary landfills specific for mangrove/freshwater, floodplains and clayey-dominated terrestrial environments using reviewed environmental and geotechnical parameters of Delta State.

1.4 Objectives

To review the ecological and geotechnical conditions in Delta State needed to design a sanitary landfill

To screen some cities and sites across Delta State as possible candidates for the siting of a sanitary landfill

To review the specific engineering design best suited for each screened site and city

1.5 Study Area and Scope of Review

The review area is limited to Delta State (Fig 1)



Figure 1. Delineation of Delta State into Senatorial Districts

The Delta State ecology is distinctly divided into the mangrove, freshwater environments in the South senatorial district, floodplains and freshwater swamp ecosystems in the Central senatorial district and the southern fringe of the Northern Senatorial District, and mostly clayey dominated terrestrial environments in the central and northern fringes of the Northern senatorial district.

1.6 Limitation of Review

The paucity of published works of literature in some parts of the Delta will limit the scope of the review to semi and urban towns across the State.

1.7 Structure of the Seminar Report

Chapter One: Introduction; outlining the background to the review, seminar justification, aim and objectives of the review work, scope and study area and limiting factors against a holistic review.

2.0 Literature review

The engineering design of a Sanitary Landfill is Environmental and Geotechnical dependent (Tchobanoglous *et al.*, 2019).

2.1 Environmental factors

Yashar *et al.*, 2020 listed site selection (topography, soil textural class and its thickness, aquifer depth, land availability, distance from residential and commercial centres, average precipitation, depth to underground mineral resources, proximity to airport, cemetery, protected areas, and presence or history of seismic faults) and town planning designs as the environmental factors governing the siting of a sanitary landfill. With the current daily waste volume of 1.04kg and the projected waste volume of 5,720,000 kg for Delta State in 2030, coupled with the planned establishment of three (3) sanitary landfills by 2030, each sanitary landfill is proposed to serve 2,000,000 persons. This implies siting at least one (1) sanitary landfill per senatorial (Medium term plan 2022). Therefore this review shall screen all parts of the State as possible candidate areas to select three ideal areas for the siting and importantly, determine the best engineering design for each.

2.1.1 Site Selection

There is a near consensus in reported literature that a sanitary landfill is better located in a semi-urban or peri-urban areas, (principally because of land availability) that satisfies other ideal criteria (Haseeb 2017). This criterion knocks off all urban cities for consideration.

2.1.1.1 Topography

An ideal site to situate a sanitary landfill is a flat terrain (Smith and Jones 2018). Flat terrain provides a consistent surface for waste placement, facilitating even waste distribution and compaction. This can enhance landfill stability and promote effective waste decomposition (Smith *et al.*, 2017). Compared to sloped areas, flat terrains are generally less prone to erosion, which can be a significant concern in landfill operations. Proper erosion control measures are easily achieved on flat terrains (Johnson & Brown, 2015 and aid uniform distribution and compaction of waste, promoting more efficient landfill management practices and optimizing waste decomposition. Most existing SLs globally, such as that in Fukuoka, Japan, Semakau, Singapore, and Tianziling, China (Zhu *et al.*, 2003, Machado *et al.*, 2010, Chan 2016) are located in altitudinal gradients below 25m above mean sea levels. Nonetheless, few are located in higher altitudinal planes (Machado *et al.*, 2010). Orchard Hills Landfill, USA is one such (Reddy *et al.*, 2008).

The engineering designs of SLs in a flat terrain are typically different from those designed for one at a higher altitude. A composite liner typically consists of multiple layers, including a geomembrane liner and compacted clay liner, working together to provide a barrier against leachate movement (Smith and Johnson, 2017) into the surrounding environment and protecting groundwater resources (EPA 2016, Forouhar and Peterson 2015, Olivier and Gourc 2006). Also, a final cap design that incorporates a Composite Final Cover System is the most suited for SLs in flat terrains (Sanphoti, *et al.*, 2016, EPA 2016, Swati and Joseph 2007). This cover design is engineered to manage stormwater runoff effectively while preventing infiltration into the waste (Hossain and Haque, 2009). This landfill cover system is being applied at the Semakau Landfill in Singapore (Chan, 2016). Anaerobic degradation (breakdown of organic waste in the absence of oxygen) is the most suited waste decomposition technique for SLs on flat terrains (Pariatamby and Tanaka, 2014). AD guarantees natural progression, methane generation, compatibility and effective waste stabilization (Kabeyi and Oludolapo, 2020).

However, the engineering design of an SL on a site having a topography above 25m should have a final cap design that incorporates a Slope Cover System (Olivier and Gourc 2006). For the management of stormwater, runoff and infiltration, long-term stability and high gas collection potential (EPA 2016, Olivier and Gourc 2006). Similar to flat terrains, anaerobic decomposition is the most common and natural process that takes place in landfills regardless of the terrain type,

(EPA, 2016). EPA 2016, and USEPA 2005, reported a Geosynthetic Clay Liner (GCL) as the most suitable effective liner system for sanitary landfills established on undulating terrain. A GCL is a composite liner made of bentonite clay encapsulated between layers of geotextile fabric. This liner system offers a combination of impermeability, flexibility, and adaptability to varying terrain conditions. It can provide effective containment for leachate and protect the underlying groundwater while accommodating the undulating topography (EPA 2007).

A review of the topographic map of Delta State revealed that about one Hundred and Thirty eight (138 – See Annexure 1) semi and peri-urban communities cutting across Eighteen LGAs (save the Ikas, Aniochas and Oshimilis and Ukwani LGAs), are located on an altitudinal gradient of 25m below mean seas levels and are qualified under this criterion.

2.1.1.2 Soil textural class

Soil textural classes play a crucial role in determining the suitability and sustainability of landfill as they, influence the permeability, and water-holding capacity, and offers valuable insights into Leachate Migration and Contaminant Transport (Kjeldsen *et al.*, 2002): Clay loam, Silty Clay loam, Sandy Clay and Clay textural classes often grouped under the hydrologic soil groups with very low infiltration rate are the ideal soil types in any area for the siting of an SL (Smith & Johnson, 2017). About two-thirds of all SLs are located in areas having these soil textural classes as they ensure landfill stability and storm and drain water management (Davis & White, 2020).

Most of the communities in Warri North, Warri South, Burutu, Warri South-West, Bomadi, Patani, Isoko North, Isoko South, Ndokwa West, Ndokwa East, Ika North, Ika South, Oshimili North, Oshimili South, Aniocha North, and Aniocha South, the communities that satisfy this and Topographic criteria are Oyede (sandy clay, Hilary *et*

al., 2023), Agbarho (sandy loam), Mosogar (sand), Ossissa (Sandy loam, Horsfall Digieneni and Tano Dumoyei Agusomu, 2018), Okoloba (Sandy loam, Horsfall Digieneni and Tano Dumoyei Agusomu, 2018).

Annexure 2 contains a list of all communities satisfying this criterion.

EPA 2016, showed that the most appropriate landfill liner system for landfills established on Clay loam, Silty Clay loam, and Sandy Clay is the composite liner system whose key components include a geomembrane liner and a compacted clay liner. For prospective landfill sites with Clay loam, Silty Clay loam, and Sandy Clay soils, landfill waste decomposition primarily occurs through anaerobic degradation, similar to other soil types (Lucas and Peres 2006). Furthermore, the most suitable Landfill Cover Design for landfills established on Clay loam, Silty Clay loam, and Sandy Clay soils is a Final Cap Cover System with an Evapotranspiration (ET) Cover design (Pansini and Seetharaman 1998, EPA 2016). An Evapotranspiration (ET) Cover design integrates vegetation and engineered soil layers to promote natural processes of water evaporation and transpiration. Combining this with a final cap system enhances the effectiveness of containment and prevents water infiltration (Pasquini and Assumpcao 2004).

Nonetheless, compaction is typically needed in the few SLs (Junipero Serra Landfill USA, Newby Island Landfill USA) that have been reported in areas having silt and sandy clay loam textural classes (Ritzkowski and Stegmann 2004, Rigas and Zouboulis, 2006). A Liner and Barrier System Design is often implemented after compaction (Saez and Ragaert 2003). An Evapotranspiration (ET) Cover Design, also known as a "Vegetative Cap," is often considered suitable for this soil type (Rigas and Zouboulis, 2006). This cover design utilizes vegetation and soil layers to manage water and reduce erosion, which is particularly relevant for sandy soils.

Cossu and Pivnenko, 2017) reported the challenge of limiting the depth of liner installation when using a landfill liner system for base stability in areas with bedrock closer to the surface as it increases the risk of leachate migration.

2.1.1.3 Depth to underlying bedrock and mineral resources

The minimum depth to underlying bedrock required for landfill establishment is 3m (Nathanson 2023). By evaluating the presence and accessibility of valuable minerals, landfill planners can optimize resource utilization and prevent potential hazards associated with mineral extraction (Gomes *et al.*, 2013). Additionally, considering the proximity to mineral resources allows for better management of potential conflicts between mining and landfill operations, ensuring the long-term effectiveness and safety of the landfill (Hettiarachchi and Sivakumar 2008, Gomes *et al.*, 2013). Mineral mining in a sanitary landfill is both unimaginable (Eweis *et al.*, 2004) and unfeasible as it would adversely impact landfill infrastructure and liner installation.

Shallow bedrock could affect the construction of a stable base for the landfill liner system, and limit the depth of liner installation, thereby potentially increasing the risk of leachate migration (EPA 2016).

Landfills constructed within or around underlining bedrocks lower than the prescribed 3m standard, increase the likelihood of aquifer contamination.

However, landfills with a longer distance to bedrock may also require more extensive engineering measures and higher construction costs. So a balancing between the base of an SL to any underlying mineral deposit is essential. Some examples of sanitary landfills situated on sites with underlying bedrock above the minimum distance are the Puente Hills Landfill in Los Angeles, California and the Fresh Kills Landfill in Staten Island, New York (Cossu and Pivnenko, 2017). For such landfills, a composite liner system is the most effective option for preventing leachate migration into the surrounding environment and protecting groundwater resources (EPA 2016, Forouhar and Peterson 2015, Olivier and Gourc 2006). A composite liner typically consists of multiple layers, including a geomembrane liner and compacted clay liner, which work together to provide a barrier against leachate movement (Smith and Johnson, 2017).

This design technique is being applied at Puente Hills Landfill in Los Angeles, California (Argun and Dursun 2019). Secondly, the leachate collection and removal system should consist of perforated pipes placed above the liner system to collect any leachate generated (Barr and Andrić, 2014). Proper leachate management is crucial to

avoid contamination of the underlying bedrock (Arulrajah *et al.*, 2017). Also, a final cap design that incorporates a Composite Final Cover System is the best-considered landfill cover design for landfills established on sites with a distance underlying bedrock exceeding 3m (EPA 2016, Swati and Joseph 2007). This cover design is engineered to manage stormwater runoff effectively while preventing infiltration into the waste, ultimately protecting the environment and groundwater (Hossain and Haque, 2009).

This is also been applied at the Puente Hills Landfill in Los Angeles, California (Argun and Dursun 2019). The best waste decomposition technique, irrespective of the distance to underlying bedrock is the anaerobic digestion method (Aljuboori and Visvanathan, 2016).

There are various solid mineral deposits within Delta State. Industrial clay, silica, lignite, kaolin, tar sand, limestone, Iron-ore, Marble, gypsum, crude oil, gas, and glass sand (Regina and Simwa 2023)

However British Columbia (2016) provided distances between the base of a SL to some minerals; marble (3-6m), iron ore (50-350m), kaolin (10-15m), silica (1.5-4m), lignite (20-100m), tar sand (0-600m), industrial clay (0.5-50m) deposits.

Except for the Isoko LGAS and Ndokwa East and West, LGAs areas with shallow oil/gas depths, all other communities in Delta State satisfy this criterion.

However, Asefi and Lim (2004) reported specific engineering designs for SLs in areas with shallow bedrock or mineral resources. One effective design option is the composite liner system, which involves using multiple layers to provide a barrier between the waste and the bedrock. As suggested by (Butera and Contini 2015, Cossu and Lai 2015), this typically includes a flexible membrane liner, such as high-density polyethylene (HDPE), which is impermeable and prevents leachate from seeping into the bedrock. Along with the liner, a geosynthetic clay liner (GCL) is often incorporated to enhance the containment system's effectiveness. GCLs have excellent hydraulic properties and can swell to form a tight seal when hydrated (De Beni and Gamba 2007). Additionally, a leachate collection system is crucial in these designs (Duan and Ma 2017). This system consists of perforated pipes placed at the bottom of the landfill, which collect the leachate and direct it to a treatment facility. To further enhance the stability of the landfill, the use of geogrids and geotextiles can provide reinforcement and prevent slope instability (El-Fadel *et al.*, 1997). These engineering designs ensure the safe containment of waste for sites with shorter distances to underlying bedrock and also protect the underlying bedrock and surrounding environment from potential contamination.

The described engineering design can be applied to the majority of the areas in Delta State with shallow depths to mineral resources.

2.1.1.4 Depth to Aquifer Layer

There are consensus of published literature works recommending a buffering window of 3m between the base of an SL and the First Water Strike (Weber *et al.*, December) and a foreclosure (Andersen & Dornbush, 1967 and Josimović and Marić 2012) on extending a SL into the Water Table with the intent of applying engineering designs to mitigating any leachate or gas leaks.

As in all climes, the variations in the aquifer layers among the different geological areas provided a maximum depth range for an SL per LGA in Delta State.

The permissible maximum depth of an SL in Bomadi, Burutu, Warri North. Warri South west and Patani is 0m. Although good quality drinkable water is found around 45m and above, the unconfined water table with salt water intrusions is below 3m. Apart from the huge cost, the leachates, gas leaks and importantly, the wastes meant for remediation in any SL cited in these LGAs would end up in the sea, first by seawater intrusion and second, by the collapsing of the SL itself over a short period (Yang *et al.*, 2016).

The permissible maximum depth of an SL in Sapele, Ughelli North & South, Okpe, Udu, Isoko North & South, Ndokwa East and Warri South is 7m. These areas would require 57,143m² of land mass to contain the envisaged waste volume. Nonetheless, none of the ten reviewed SLs was established in such depth. The permissible maximum depth of a SL in Ethiopie West & East, Ndokwa West and Ukwuani is 17m (Otutu 2010). These areas

would require 23,529m² of landmass to contain the envisaged waste volume. A good example is the Intervale Landfill (Cohen 1999)

The permissible maximum depth of an SL in Ika Northeast and South, Oshimili South and Aniocha South is 39m (Chinyem 2017). These areas would require 10,256m² of landmass to contain the envisaged waste volume. An example of a sanitary landfill established at this depth is the Puente Hills Landfill, in California, and the USA.

The permissible maximum depth of an SL in Aniocha North and Oshimili North is 47m (Chinyem 2017). These areas would require 8,510m² of landmass to contain the envisaged waste volume. Established at this depth is the Sudokwon Landfill in South Korea.

2.1.1.5 Precipitation

Joar, *et al.*, (2009) showed that rainfall above the ideal (1660mm per annum) for siting a sanitary landfill, induces heavy surface runoff and generates huge leachate plumes capable of contaminating surrounding environments. The rainfall amount (NiMet 2022) for Delta State between 1990-2020 (see Annexure 4) shows that Aniocha North, Oshimili North and South were the only LGAs with precipitation that approximates the ideal.

Nonetheless, the International Best Practices Guide for LFGE Projects (2012) reported some specifications for any landfill in areas witnessing precipitation above the ideal. Although costly, the system would require a composite liner at the landfill base and sides consisting of a clay layer (of 40 to 80 cm thickness) and a high-density polyethylene (HDPE) sheet, and also a capping system to minimize the percolation of rainwater or surface water into the waste (Scott, *et al.*, 2005). A single base or side liner system is recommended for areas witnessing a precipitation amount below 1660 mm annually (ISWA, 2013). Oluwadare, (2017) suggested lowering the soil permeability in higher precipitation areas by loosening the upper 20 to 30 cm of the soil and subsequently compaction with heavy equipment as an alternative to the use of double or single composite liners. The design of a cap is site-specific and depends on the nature of wastes, availability and costs of cap materials, local climate, hydrogeology, terrain; and the after-use of the site. The cap should be designed to have a barrier layer that minimizes water infiltration and a drainage layer that transmits water across the cover. The barrier layer should be made of low-permeability soil (clay), geosynthetic clay liners (GCLs), or synthetic geomembrane liners. This system, apart from the lined bottom and sides, should typically consist of a leachate collection and treatment system, groundwater monitoring, gas extraction and a cap system (UNEP 2002).

2.1.1.6 Land Availability relative to sensitive receptors

The waste-holding capacity of ten reviewed sanitary landfills points to 76.2 tons of waste per hectare, implying that the 2,102 (2030 waste estimate volume for one-third of the State) tons of waste estimated per each of the three proposed sanitary landfills in Delta would require a land take of 27.6 hectares for the landfill site and an additional 12.4 hectares for ancillary (administrative buildings waste treatment plant, road networks, powerhouse housing estate, buffer zone etc) totally 40 hectares for proposed site. A review of such land availability with Delta State Ministry of Lands and personal communication showed that 40 ha of land is available only in semi and peri-urban and rural communities across each LGA in the State.

Nonetheless, Ireaja *et al.*, (2018) reported that the available site for the proposed facility should not be on or within 500m of a geological fault, seismic plane or one with a history of tremor/subsidence (IIARD 2018) in order to mitigate unexpected gas or leachate migration. British Columbia (2016) reported that the application of an engineering design to such a land should not be thought of or implemented. Oil and gas-producing communities and LGAs are on stratigraphic traps and hence, not suitable for the siting of sanitary landfills.

Although Annexure 3 outlines the oil and gas-producing LGAs in Delta, however, not all the communities are oil/gas-producing.

Similarly, IFC 2018 and IIARD 2019 reported that the available land for the siting of an SL should be on a non-sensitive habitat; in this case, a fallow or previously cultivated land. Unlike the case of a seismic plane or fault lines, Parveen and Ashutosh (2018) reported the application of specific engineering designs to remedy a landfill on wetlands, swamps or one situated or proposed within a 1.5 km² to a surface water or oil/gas pipeline route.

Ideally, sanitary landfills should be sited away from seismic impacted zones as a rule. However, where one occurs in such areas, all containment structures including liners leachate collection systems and surface water control systems, must be designed to resist the maximum horizontal acceleration in lithified earth materials for the site. The engineering design for such a landfill includes; A moment magnitude of 7.1 Earthquakes, blind thrust fault, at an approximate depth of 11km directly below the site, a free field peak horizontal ground acceleration of 0.69gPHGA 60m above the surrounding terrain with a slope as steep as 1.3H: 1V (Horizontal: Vertical) and must not be proximal to the yards of residence (Anderson and Kavazanjian 1995)

Composite liner systems with a geomembrane and a geosynthetic clay liner (GCL) are more effective than single liner systems in reducing the slip displacement and the permanent settlement of sanitary landfills in seismic zones or geological faults. The geosynthetic liner, specifically bentonite must have a hole up to 75 millimetres in diameter to seal itself, allowing the GCL to retain the properties that make it an effective barrier system.

2.1.1.7 Proximity to other land-use sites

In addition to the literature works of Yu-Qiang Liu *et al.*, (2019) the land use system reviewed for ten sanitary landfills revealed an average setback of 2.75km² from residential, burial sites/cemeteries, cultural heritage sites, farmlands, airports or other social infrastructural entities.

This setback is a mitigation measure against possible exhumation/desecration of interred corpses buried around residential or family/commercial burial grounds or encroachments around sites holding veneration and deities of cultural values (Shojai *et al.*, 2016). The buffer is also to insulate agro produce from leachate contamination (Phillips and Sheehan, 2005) and regulate town planners or communities from proposing or earmarking any developmental project within the 2.75 km² perimeter.

Specifically, any of the proposed sites must establish a distance of 2.75 km² from the well-publicized Otuogu beach, Nelson Mandela Garden, River Ethiopie source, The Araya Bible sites or the Yokri–Uremure forest reserve. There are locations in all the LGAs that qualify for this criterion.

2.2 Geotechnical Factors

The notable geotechnical parameters required for constructing the waste retaining walls, stormwater drainage facilities, leachate collection facilities, liner facilities, gas venting facilities and leachate treatment facilities are soil reaction (pH), moisture content, porosity, permeability, bulk density, shear strength, relative density, atterberg limit and hydraulic conductivity.

2.2.1 Porosity/Permeability

Porosity is an important geotechnical parameter to consider when siting a sanitary landfill. It refers to the volume of void spaces or pores within a material, such as soil or rock (Moreira *et al.*, 2019). Porosity is crucial for sanitary landfill as it affects leachate and gas release, within the waste and underlying layers.

Porosity is closely related to permeability, (Zhong, *et al.*, 2006). Slimak, 1978 reported soils with 0.2-0.4m³ porosity and 1.0-1.3m² permeability as ideal for siting a sanitary landfill as it prevents the migration of leachate and gas from the landfill. Clay soils and silty soils typically fulfil this ideal range, (Francisca & Glatstein, 2010; Pimolthai, & Wagner, 2014; Musso, *et al.*, 2022; Khaksar Najafi *et al.*, 2021).

Okpe, Ethiopie West, Aniocha North and Ndokwa West have soils that are within threshold values for soil porosity and permeability (see Annexure 5 for porosity and permeability values across the various LGAs of Delta State) required for the establishment of landfills. These LGAs have Low-porosity soils and as such are generally preferred to minimize the potential for leachate migration and gas escape.

However, there are engineering design techniques to reduce soil porosity and permeability values (Koerner, & Daniel, 1997). Resistivity imaging technique, and properly designed landfill liner cover systems (bentonite clay liner system) have been reportedly used (Ojo, *et al.*, 2022; Chetri, & Reddy, 2021; Simon & Müller, 2004. Also, (Meegoda, *et al.*, 2016; Cointreau, 2004 and Komilis, *et al.*, 1999) also reported the use of compaction to reduce porosity and permeability thus providing landfill foundation stability.

2.2.2 Bulk Density

Soil bulk density is an important parameter in landfill engineering design as it influences various aspects of landfill performance, including compaction, stability, gas and leachate migration (Bowles 1997). The maximum allowable soil bulk density range for sanitary landfill construction is between 1.4 and 1.7 g/cm³ (EPA 1991). This range ensures that the soil is compacted enough to provide stability and prevent excessive settlement, while still allowing for sufficient permeability and drainage within the landfill (EPA 1991).

Geosynthetic clay liners (consisting of bentonite clay sandwiched between geotextile layers) are the most suitable liners for soils that meet the required permissible limit for bulk density during landfill construction (Koerner 2008, ASTM 2012). Furthermore, the Geomembrane-Soil Composite Cover System is the most suitable landfill cover system for soils that meet the required permissible limit for bulk density, (EPA 2007, Townsend and Solo-Gabriele 2006, Daniel 2001). For both liner and cover systems, the system combines the use of geomembranes with soil layers (Daniel 2001). The geomembrane provides impermeability, while soil layers contribute to erosion resistance and vegetation growth (Daniel 2001). This landfill liner and cover systems types was utilized at the Olinda Alpha Landfill California, and Florida and Pine Ridge Landfill, West Virginia (<https://web.archive.org/web/20110726151000/http://hillsforeveryone.org/projects/olinda-landfill.html>, <https://nearestlandfill.com/org/pine-ridge-recycling-disposal/>).

Anaerobic biodegradation has been recognized as the most sustainable and feasible technique for breaking down organic waste within landfills, regardless of the soil characteristics (EPA 2016).

The composite liner system comprising geomembranes and geosynthetic clay liners is most appropriate for landfills having soils that fall short of the required permissible limit for bulk density (Dwyer and Benatar, EPA 2016). EPA, 2016 also recommended a hybrid system which is a combination of geomembranes, geotextiles, compacted soils, and vegetation as the ideal landfill cover system engineering design for soils with bulk density outside the standard range (Liao *et al.*, 2022).). These designs were adopted in the Tampa Bay Landfill, Florida Lal and Shukla (2004) investigated the relationship between soil bulk density and soil textural classes. They found that sandy soils had the lowest average bulk density (1.31 g/cm³) compared to loamy (1.43 g/cm³) and clayey (1.55 g/cm³) soils. This suggests that only soils within the loamy and clayey category meet the permissible limit (1.4 to 1.7 g/cm³) and thus qualify for landfill construction.

The communities within Warri North, Ethiope West, Okpe, Warri South, Burutu, Warri South-West, Bomadi, Patani, Isoko North, Isoko South, Ndokwa West, Ndokwa East, Ika North, Ika South, Oshimili North, Oshimili South, Aniocha North, and Aniocha South meet this criterion.

2.2.3 Shear Strength

Soil shear strength is a fundamental parameter for assessing the stability of landfill slopes and the overall landfill structure. The evaluation of shear strength helps predict potential failures, landslides, and deformations that may compromise both the structural integrity and environmental safety of the landfill. Soil shear strength influences the lateral pressures exerted by the landfill on adjacent structures and surrounding soil (Williams and Johnson 2019). Understanding the shear strength of soils aids in determining the appropriate lateral earth pressure calculations required for proper engineering design and to prevent damage to nearby infrastructure (Smith and Johnson 2021). Also, knowledge of the shear strength parameters aids in selecting liners that can withstand the imposed loads, provide sufficient slope stability and effectively prevent leachate infiltration (Williams and Johnson 2019).

The United States Environmental Protection Agency (USEPA, Subtitle D) prescribed the minimum acceptable soil shear strength for landfill construction as 20 to 30 kPa. This is crucial for ensuring the stability, containment, settlement control, and successful construction of landfills.

Soil stabilization techniques, such as lime stabilization or cement stabilization, can be used to improve the strength and stability of weak soils (Das, 2017). USEPA 2016 recommended a combination of High-Density Polyethylene (HDPE) Liners and Geosynthetic Clay Liners (GCLs) as the most effective liner type suitable for soils with strong

shear strength. Also, an Evapotranspiration (ET) cover is recommended as the most appropriate landfill cover for soils with high shear strength while anaerobic digestion is the recommended waste decomposition technique (Mitchell and Soga 2005). These techniques have been applied to landfill established on soils with high shear strength; some of which include:

Apex Regional Landfill - Las Vegas, Nevada (<https://www.cnbc.com/2010/09/27/Americas-Largest-Landfills.html>), Wagner Heights Landfill - Stockton, California (<https://www.cnbc.com/2010/09/27/Americas-Largest-Landfills.html>), and Palmetto Landfill - Charleston, South Carolina (<https://www.cnbc.com/2010/09/27/Americas-Largest-Landfills.html>)

Anaerobic biodegradation has been acknowledged as a sustainable and practical approach for decomposing organic waste in landfills with low shear strength (Fang *et al.*, 2015). USEPA 2016, suggests composite liners and vegetated cover with geosynthetic layers, as the most appropriate landfill liner and landfill cover and waste decomposition systems respectively, for soils with low shear strength. These landfill designs are being applied at the Tampa Bay Landfill, Florida, an area with soils of relatively low shear strength (Liao *et al.*, 2022).

All communities in Warri North, Warri South, Burutu, Warri South-West, Bomadi, Patani, Isoko North, Isoko South, Ethiopie West, Okpe, Ndokwa West, Ndokwa East, Ika North, Ika South, Oshimili North, Oshimili South, Aniocha North, and Aniocha have soils that are within threshold values for soil strength required for the establishment of landfills because they have higher clay and lower sand content in their soils.

Soils with high sand content have looser structures and lower internal friction, resulting in lower shear strength (Fredlund and Rahardjo 1993). Sandy soils are also more prone to shifting and sliding under load due to their lack of cohesion (Fredlund and Rahardjo 1993).

2.2.4 Relative Density

Relative density (RD) influences the compaction and stability of soil or granular materials used in landfills. It refers to a measure of the denseness or compactness of a soil sample compared to its maximum or optimum density (Koerner, 2012). It is often expressed as a percentage. The ideal soil RD for a Sanitary landfill (SL) is 65% and above, as it restricts leachate migration and gas generation. (Fouad, 2023) reported that Silt Clay Loam and Clay textural classes typically meet RD criteria for siting a sanitary landfill.

Oshimili North and South, Ika South and North East, Aniocha South & North LGA, Ethiopie West, Okpe, Ukwani, Isoko North Ughelli North & South Ndokwa East & West satisfy this criterion.

The Engineering designs mentioned for Shear Strength are the same review for this criterion.

2.2.5 Atterberg Limit

The Atterberg Limit is used in geotechnical engineering to assess the behaviour of soils and their suitability for various applications, including the design of landfills. Atterberg Limit determines the permeability and compaction characteristics of soil, including its liquid limit, plastic limit, and shrinkage limit. The permissible Atterberg Limits of the soil recommended for landfill construction are ranges set for liquid limit, plastic limit, and shrinkage limit. USEPA 2016 concluded that the liquid limit, plastic limit, and shrinkage limit should generally be less than or equal to 50%, 30% and 20% respectively. The permissible Atterberg Limits aim to ensure the stability, impermeability, and long-term performance of landfill liner and cover systems to prevent environmental contamination and other potential issues associated with waste disposal.

The most appropriate landfill liner system for landfills established on soils that fall within the permissible Atterberg Limits is the composite liner system whose key components include a geomembrane liner and a compacted clay liner (USEPA 2016). Furthermore, the most suitable Landfill Cover Design for landfills established on soils that fall within the permissible Atterberg Limits is the Final Cap Cover System with an Evapotranspiration (ET) Cover design (Pansini and Seetharaman 1998, EPA 2016). The Junipero Serra Landfill USA and the Newby Island Landfill USA operate on the aforementioned landfill liner and cover systems (Ritzkowski and Stegmann 2004, Rigas and Zouboulis, 2006).

A composite liner made up of a geomembrane liner and geosynthetic clay liner (GCL) is best-suitable for soils that fall short of the required Atterberg Limits for landfill construction. The geomembrane provides the primary

barrier, while the clay or GCL contributes to additional impermeability and sealing properties. Concerning cover systems. USEPA 2016 also suggested that the hybrid system (geomembranes, geotextiles, compacted soils, and vegetation) is best appropriate for soils that fall short of the required Atterberg Limits. The aforementioned liner and cover systems are being applied at Tampa Bay Landfill, Tampa, Florida (Liao *et al.*, 2022). Anaerobic biodegradation was also used in SL having Atterberg limits within and outside the set limits.

Liu *et al.* (2021) showed that soils with higher clay content tend to have higher liquid and plastic limits; thus qualifying only communities in Warri North, Ethiopie West, Warri South, Burutu, Warri South-West, Bomadi, Patani, Isoko North, Isoko South, Ndokwa West, Ndokwa East, Ika North, Ika South, Oshimili North, Oshimili South, Aniocha North, and Aniocha South as suitable for the construction of sanitary landfills based on this reviewed parameter.

2.2.6 Hydraulic Conductivity

Hydraulic conductivity determines the movement of water through waste and the underlying soil layers. Leachate containment is a critical aspect of landfill design and operation (Sharma and Reddy 2004). The ideal hydraulic conductivity of the soil for a siting landfill is in the range of 35-45cm/hr

The predominantly clay textural classes (clay, sandy clay loam, clay loam, silt clay and sandy clay) occurring in Isoko North and South, Ethiopie West, Udu, Oshimili North and South, Ika South and North East, Aniocha South & North LGAs satisfies the hydraulic conductivity range.

Also, the silt, silty loam, sandy loam and loam textural classes of Ugheli North & South, Ukwani, Ndokwa East & West LGAs and many areas across the LGAs in the State with silt and clay soils can be used in the construction of landfill liners and covers. These soil textural classes have hydraulic conductivity (k) in the range of $\leq 10^{-7}$ (Alamgir *et al.*, 2005).

However, engineering design has been used to improve the hydraulic conductivity of soils. Soil amendment with bentonite, fly ash (Tiwari *et al.* 2000), lime (Tsai and Vesilind 1998), Shale (Li *et al.* 2016) as well as sewage sludge ash (Zhang *et al.* 2018) has been used to achieve the ideal conductivity range.

2.3 Site Selection Screening Matrix

2.3.1 Methodology

Selecting the right site for landfill construction is crucial to ensure environmental sustainability and public safety. Assessment was done for each senatorial district, to select the most qualified LGA for landfill construction. The binary method of ranking was adopted to effectively screen and evaluate potential sites (LGA) for suitability. This method involves the systematic assessment of prospective sites (LGAs) based on predetermined criteria (environmental and geotechnical parameters). The criteria include factors such as Topography, Soil Textural Class, Depth and Underlying Bedrock, Depth to Aquifer Layer, Precipitation, Land Availability Relative to Sensitive Receptors, Proximity to Other Land-Use Sites (Environmental parameters) and Atterberg Limits, Bulk Density, History of Seismic Faults, Hydraulic Conductivity, Porosity/Permeability, Relative Density, and Shear Strength (Geotechnical parameters). Each criterion is assigned a binary value, usually 0 or 1, depending on whether the site meets the desired requirement. These values are then summed up to obtain a total score for each site, indicating its suitability for landfill construction. This approach allows for a rigorous and objective evaluation of each site, ensuring that the chosen location is the most suitable and sustainable option for landfill construction. The screening matrixes are presented in Tables 1, 2 and 3.

Table 1. Screening Matrix for LGAs in Delta Central Senatorial District

LGA	Environmental Parameters							Geotechnical Parameters							Total
	Topography	Soil Textural Class	Depth and Underlying Bedrock	Depth to Aquifer Layer	Precipitation	Land Availability Relative to Sensitive Receptors	Proximity to Other Land-Use Sites	Atterberg Limits	Bulk Density	History of Seismic Faults	Hydraulic Conductivity	Porosity/Permeability	Relative Density	Shear Strength	
Ethiopia West	1	0	1	1	0	1	1	1	0	1	1	1	1	1	11
Ethiopia East	1	0	1	1	0	1	0	0	0	1	0	0	0	0	5
Okpe	1	0	1	1	0	1	1	0	0	1	0	1	1	1	9
Sapele	1	0	1	1	0	1	0	0	0	1	0	0	0	0	5
Uvwie	1	0	1	1	0	1	0	0	0	1	0	0	0	0	5
Udu	1	0	1	1	0	1	0	0	0	1	1	0	0	0	6
Ughelli North	1	0	1	1	0	1	0	0	0	1	0	0	1	0	6
Ughelli South	1	0	1	1	0	1	0	0	0	1	0	0	0	0	5

Table 2. Screening Matrix for LGAs in Delta North Senatorial District

LGA	Environmental Parameters							Geotechnical Parameters							Total
	Topography	Soil Texture Class	Depth and Underlying Bedrock	Depth to Aquifer Layer	Precipitation	Land Availability Relative to Sensitive Receptors	Proximity to Other Land-Use Sites	Atterberg Limits	Bulk Density	History of Seismic Faults	Hydraulic Conductivity	Porosity /Permeability	Relative Density	Shear Strength	
Aniocha North	0	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Aniocha South	0	1	1	1	0	1	1	1	1	1	1	0	1	1	11
Ika North-East	0	1	1	1	0	1	1	1	1	1	1	0	1	1	11
Ika South	0	1	1	1	0	1	1	1	1	1	1	0	1	1	11
Ndokwa West	1	1	0	1	0	1	1	1	1	1	0	1	1	1	11
Ndokwa East	1	1	0	1	0	1	0	1	1	1	0	0	1	1	9
Oshimili North	0	1	1	1	1	1	0	1	1	1	1	0	1	1	11
Oshimili South	0	1	1	1	1	1	0	1	1	1	1	0	1	1	11
Ukwani	0	0	1	1	0	1	1	0	0	1	0	0	1	0	6

Table 3. Screening Matrix for LGAs in Delta South Senatorial District

LGA	Environmental Parameters							Geotechnical Parameters							Total
	Topography	Soil Textural Classes	Depth and Underlying Bedrock	Depth to Aquifer Layer	Precipitation	Land Availability Relative to Sensitive Receptors	Proximity to Other Land-Use Sites	Atterberg Limits	Bulk Density	History of Seismic Faults	Hydraulic Conductivity	Porosity/Permeability	Relative Density	Shear Strength	
Bomadi	1	1	1	0	0	1	0	1	1	1	0	0	0	1	8
Burutu	1	1	1	0	0	1	0	1	1	1	0	0	0	1	8
Isoko North	1	1	0	1	0	1	1	1	1	1	1	0	1	1	11
Isoko South	1	1	0	1	0	1	0	1	1	1	1	0	0	1	9
Patani	1	1	1	0	0	1	1	1	1	1	0	0	0	1	9
Warri North	1	1	1	0	0	1	0	1	1	1	0	0	0	1	8
Warri South	1	1	1	0	0	1	1	1	1	1	0	0	0	1	9
Warri South-West	1	1	1	0	0	1	1	1	1	1	0	0	0	1	9

2.3.2 Result

Results from the screening exercise revealed Okpe as the most qualified LGA for landfill construction amongst all other LGAs in Delta Central Senatorial District. Aniocha North was the most qualified LGA amongst all other LGAs in Delta North Senatorial District while Isoko North was the most qualified LGA in Delta South Senatorial District. The screening matrixes are presented in Tables 1, 2 and 3.

3.0 Fieldwork campaign and laboratory

This chapter outlines the proposed fieldwork campaign, types of environmental and geotechnical parameters to be collected, and methods of preservation in the field and during transport. It also specifies the laboratory procedures to be adopted and the criteria to be met by the proposed laboratory to be used.

3.1.1 Fieldwork campaign

The various designated sampling points for each environmental and geotechnical variable shall be loaded into the customized Geographic Information System (GIS) tool developed for this study. The App, configured into a phone, shall automatically record the coordinates, land use around the sampling points, altitude, pictorial and other data collection activities in real-time. These data are automatically sent to the Cloud and are retrievable anytime. This app shall be shared with the supervisor, for his input and approval before field deployment.

The social license shall be obtained from each community via stakeholder engagement.

3.1.2 Sample Data Gathering

3.1.2.1 Soil

Soil shall be collected at 60m and 120m respectively using a hand auger. The well-labelled collected samples shall be stored in Ziploc bags and transported to a certified laboratory for analysis.

3.1.2.2 Determination of Sub-Surface Structures

Geologic faults, seismic susceptibility and aquifer layers shall be determined using vertical Electrical Sounding (VES). The first stage of this work involved geological and hydrogeologic mapping while the second entails geoelectric investigation which consists of horizontal resistivity profiling (HRP) and vertical electric sounding (VES). In the resistivity method, artificially generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the pattern of potential differences expected from homogenous ground provide information on the form and electrical properties of subsurface inhomogeneities (Keary *et al*, 2002).

FIELD TECHNIQUE

HORIZONTAL RESISTIVITY PROFILING (HRP): This will be achieved using the Wenner configuration. The four electrodes will be moved at the same time for successive readings with fixed inter-electrode Spacing, a . This will be done to locate a weak point for subsequent electrical sounding. The inter-electrode spacing will be set to 15m with a station distance of 3m apart. The geometric factor is given as:

$K=2 a, \rho_a = K \cdot \rho$ where a is the inter-electrode spacing.

The VES will be conducted using the Schlumberger electrode configuration. The current and potential electrodes will be maintained at the same relative spacing and the whole spread progressively expand along a profile. Successive apparent resistivity values are to be determined at the same centre point for increasing values of electrode spacing. The current electrode spacing ($AB/2$) shall range from 1.0m to 50m.

The geometric factor is given as:

$$K = \pi(L^2 - d^2)$$

$2d$

$$\rho_a = K \cdot R$$

3.1.2.3 Development of Land Use Land cover (LULC) map

A land use land cover map using Arc GIS tool with a 5m resolution imagery shall be developed to map the various land uses including pipeline routes, cultural heritage sites, residential/ commercial areas, airports, surface water bodies etc.

3.1.2.4 Rainfall

Rainfall data for each community or the nearest city/LGA in the study area shall be obtained from NiMet for the period 1990-2022.

3.2 laboratory Methodology

3.2.1 Laboratory Determination of Textural Class:

Method: STM D2487 is a standard practice for classifying soils for engineering purposes using the Unified Soil Classification System (USCS)

Procedure: Sample Collection and Preparation, sieve analysis and hydrometer analysis

Calculation:

Using the percentages of sand, silt, and clay obtained from both sieve and hydrometer analyses.

Plot these percentages on a textural triangle, a graph with sand, silt, and clay axes.

The point of intersection on the triangle indicates the soil's textural class.

3.2.2 Laboratory Determination of Soil Porosity:

Method: The Standard Test Method for Soil Porosity is ASTM D4404-18

Procedure: Soil sample preparation, determining wet mass and measurement of the volume

Calculation:

Soil Porosity = $(1 - (\text{Bulk Density} \div \text{Particle Density})) \times 100$

3.2.3 Laboratory Determination of Soil Permeability

Method: Standard Test Method for Permeability of Granular Soils: ASTM D2434-19

Procedure: saturation of specimen, assembling the permeameter, saturation of the specimen, initial head measurement, flow rate measurement and head change measurement

Calculation:

The permeability can be calculated using the following equation:

$$KT = QL / Ath$$

Where,

KT = coefficient of permeability at temperature T, cm/sec.

L = length of the specimen in centimetres

t = time for discharge in seconds

Q = volume of discharge in cm³ (assume 1 mL = 1 cm³)

A = cross-sectional area of permeameter

h = hydraulic head difference across length L, in cm of water; Bulk density

3.2.4 Laboratory Determination of Bulk Density

METHOD: ASTM C29/C29M

PROCEDURES: Determine the fresh weight of the soil. Place the macerated soil in an oven for 24hrs then weigh. Finally, divide the dry mass by the volume.

$\gamma = Md/vt$ where

Md = Mass of the dry soil and

Vt = Total volume of the sample

3.2.5 Determination of Soil Shear Strength

A field method of determining shear strength is described in which a cylinder of soil is sheared in torsion and a moment/angle of twist (proportional to stain) curve is obtained.

METHODS

Standard Penetration Test-ASTM Standard D 1586-67

Vane Shear Test-ASTM Standard D 2573-72

Dutch Cone Penetrometer-ASTM Standard D 1558-71

Direct Shear Test-ASTM Standard D 3080-72

Triaxial Compression Test-ASTM Standard D 2850-82

Unconfined Compression Test ASTM Standard D 2166-66

3.2.6 Determination of Soil Relative Density.

Relative density can be calculated directly by measuring the density of a sample and dividing it by the known density of the reference substance.

Hence, obtaining soil's relative density, by comparing the porosity or void ratio of the given soil with that of the same soil in its coolest and densest possible state.

METHODS:

ASTM D 4254 – Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density.

ASTM D 4253 – Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table.

3.2.7 Laboratory Determination of Atterberg Limit

METHOD: ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

PROCEDURES:

Obtain a representative soil sample, Air-dry the soil sample, and macerate the soil sample

Determine the liquid limit (LL): Take about 50g of moist soil sample and place it in a porcelain evaporating dish. Gradually add distilled water to the soil sample while kneading and rolling it with a glass rod. Continue this process until a thread of soil about 3 mm in diameter can be formed. Measure the number of blows required to close the groove made by the standard liquid limit device (i.e., Casagrande cup and groove). This number represents the liquid limit of the soil sample.

Determine the plastic limit (PL): Take about 15-20g of air-dried soil sample and place it in a moisture container. Gradually add distilled water while kneading the soil sample until a thread of soil about 3 mm in diameter can no longer be formed. Roll this soil mass into a small ball and flatten it to determine its plastic limit.

Determine the shrinkage limit (SL): Take an additional soil sample, about 30-40g, and place it in a shallow dish. Allow the soil to dry until it reaches constant weight in an oven at a temperature of 105°C. Record the weight of the dried soil. This weight represents the shrinkage limit of the soil sample.

ANALYSIS:

Calculate the water content of each of the liquid limit moisture cans after they have been in the oven for at least 16 hours. Plot the number of drops, N, (on the log scale) versus the water content (w). Draw the best-fit straight line through the plotted points and determine the liquid limit (LL) as the water content at 25 drops.

CALCULATIONS:

$LI = (PL - \text{Natural Water Content}) \div PI$

3.2.8 Laboratory Determination of Hydraulic Conductivity of Soil

METHOD: ASTM Method D2434-68.

PROCEDURES: The soil samples were air-dried at room temperature, passed through a 2mm sieve and analyzed for particle size composition by hydrometer method (Bouyoucos, 1926).

Calculations:

By plotting the accumulated quantity of outflow versus time on rectangular coordinate paper, the slope of the linear portion of the curve can be determined, and the hydraulic conductivity can be calculated using

$K = QL/hA$.

Where:

K = hydraulic conductivity, LT-1

L = length of sample, L;

A = cross-sectional area of sample, L²

Q = outflow rate, $L T$;

h = fluid head difference across the sample, L

The value of h is the difference between h_1 and h_2 .

3.2.9 VES Field Data Processing and Interpretation

The observed field data will be converted to apparent resistivity values by multiplying with the Schlumberger geometric factor. The sounding curve for each point was obtained by plotting the apparent resistivity on the ordinate against half current-electrode spacing on a bilogarithmic transparent paper. A preliminary interpretation will be carried out using partial curve matching involving two-layer master curves and the appropriate auxiliary charts. The layer model thus obtained served as input for an inversion algorithm or computer iterative modelling using the WinResist software.

Chapter Four: Project Schedule & Conclusion

4.0 Project Schedule

This chapter outlines the project schedule as seen in Table 4 which is expected to span Nine (9) months.

Table 4. Project Schedule

Project activities	September- November 2023	December- February 2023	March- May 2023	June-August 2023
Recognizance visit and survey of sites (Preliminary Site Assessment)				
GIS mapping and development software for data acquisition				
Stakeholder engagement				
Field data gathering and Geotechnical Investigations (dry season)				
Laboratory analysis of dry season samples				
Field data gathering and Geotechnical Investigations (wet season)				
Laboratory analysis of wet season samples				
Data Analysis and Reporting				

4.1 Conclusion

Selecting an appropriate landfill location can be a complex undertaking. It is imperative to pinpoint a site that not only suits landfill purposes but also mitigates potential environmental and community risks. The evaluation of potential landfill sites necessitated a comprehensive analysis of multiple environmental and geotechnical factors to ascertain their sustainability, safety, and appropriateness. These considerations encompass variables such as land topography, soil texture, proximity to aquifers and bedrock, rainfall patterns, and their relationship to sensitive receptors and other land uses. On the geotechnical front, parameters like Atterberg Limits, bulk density, seismic history, hydraulic conductivity, porosity, permeability, relative density, and shear strength were examined. The central objective of this screening process is to identify sites with minimal potential for negative environmental and geotechnical effects. By doing so, the landfill's long-term viability and efficacy are ensured, safeguarding both environmental integrity and human health. The screening of potential LGAs was executed

through the Binary Screening method, using predetermined environmental and geotechnical criteria. This systematic approach employs a predefined set of benchmarks to assess candidate landfill sites based on their environmental and geotechnical attributes. The objective was to efficiently eliminate unsuitable options and select those aligning with requisite standards. This assessment was executed across each senatorial district, aimed at identifying the most qualified Local Government Area (LGA) for optimal landfill construction. The outcomes of the screening process indicated that Okpe stood out as the most suitable Local Government Area (LGA) for constructing a landfill among all LGAs within the Delta Central Senatorial District. Similarly, Aniocha North emerged as the top choice LGA in the Delta North Senatorial District, and Isoko North claimed this distinction in the Delta South Senatorial District.

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