Sanitary Landfills: Geological and Environmental Factors that Influence Their Siting, Operation and Management

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Abstract
The generation of municipal solid wastes is increasing year by year and there are many options for handling and disposing these wastes. Attaining sustainability in waste management requires an option that is environmental friendly. Sanitary landfill amongst all other waste disposal methods (including open air burning, Hog feeding, composting, etc.) has been proven to be the most effective method to manage waste because it reduces threat to human health and the entire ecosystem. Sanitary landfills can be defined as engineered buried facilities for disposal of solid waste; designed, constructed, and operated in a manner that the contained solid wastes will not cause potential hazard to public health or the environment. The siting and operations of sanitary landfills are discussed in this paper. The paper also focuses on the strategies for effective management of sanitary landfills and sustainable measures (reduce, reuse and recycle) to minimise the amount of waste that ends up in landfills.

Keywords: *Landfills; geological; environmental; solid waste; management; sustainable measures.*

1.0 Introduction

The disposal of waste began with the mere elimination of waste from living areas. Waste generation can be traced as far back as the beginning of human civilization. The term 'waste' is defined as any material that is discarded, abandoned, or is not of any direct economic value to its owner and which bears an environmental liability. Waste can be broadly classified into solid, liquid, or gaseous wastes with solid waste being the most critical in waste management. The various methods for disposing solid waste include open dumping, composting, Hog feeding, Incineration, open-air burning, ordinary landfill, and sanitary landfill.

Sanitary Landfilling – defined as placing solid and semi-solid wastes on a lined ground, compacting and covering it with suitable materials to isolate it from the environment – is still one of the most common and favored methods for solid waste disposal. In recent years expansion of cities and growth of human population worldwide have resulted to a decrease in availability of land for waste disposal. In addition, years of uncontrolled and unplanned dumping of waste on land have caused severe groundwater, soil, and air pollution in different parts of the world. Awareness of and necessity for effective solid waste management led to the modern day concept of sanitary landfill. Most of the developed and developing countries today use design criteria that take into account topography, site geology, and hydrogeology, along with engineering, economic, and legal requirements for the construction and operation of landfills.

The inability to manage these wastes effectively becomes an issue of great concern as some of the municipal solid wastes contain both organic and inorganic toxic pollutants (such as heavy metals) that threaten the health of humans and the entire ecosystem. Hence, the need for a **Sanitary Landfill.**

2.0 Sanitary Landfill: Advantages & Disadvantages, By-Products and Components.

Sanitary landfills are engineered buried facilities for disposal of solid waste; designed, constructed, and operated in a manner that contained solid waste will not cause a present or potential hazard to public health or to the environment. Sanitary landfills typically could be described as a place where the controlled deposition of waste takes place in an environmentally responsible manner.

The concept of sanitary landfilling was first introduced in the United Kingdom in 1912; in the United States sanitary landfilling became a common method of Solid waste disposal during the 1930s.

In 1937, Fresno municipal sanitary landfill opened in Fresno, California. This is considered the first modern sanitary landfill in the United States, innovating the techniques of trenching, compacting and daily covering of waste with soil.

The advantages of sanitary landfill are:

1. It does not pollute the groundwater and air
2. It prevents unsightliness and odour nuisance
3. It is a source of useful energy like methane gas
4. It checks fly breeding, infestation by rodents and vermin and birds clustering for aircrafts
5. It creates employment for unskilled labor, which is available in abundance in developing countries
6. It is a big business for investors
7. It is useful in waste management

The disadvantages of sanitary landfill are:

1. Nutrients contained in dead animals are wasted
2. Transportation cost
3. Damage to access roads by heavy vehicles
4. Off gassing of methane generated by decaying waste can endanger the inhabitants of the area
5. The properties or lands surrounding the sanitary landfill may be devalued
6. The restriction against building heavy infrastructure because of settling and sinking after the landfill is finished
7. Few landfills accept dead animals and hazardous waste
8. The acquisition of Land is often a problem due to local inhabitants' opposition to the selected site (known as the NIMBY phenomenon: Not In My Back Yard) for various reasons:
   · Lack of knowledge of the sanitary landfill technique
   · The term sanitary landfill is associated with the open dump
   · Citizens' evident distrust of local administrations that do not guarantee the quality or the sustainability of the work
   . Legal problems regarding land registration

— **By-Product of a Sanitary Landfill**

i. **Landfill leachate:** Leachate is a liquid that has percolated through solid waste and has extracted, dissolved, and suspended materials that may include potentially harmful materials (Warith, 2003). Leachate can cause serious problems since it able to transport contaminating materials that may cause a contamination of soil, groundwater and surface water.

ii. **Landfill Gas:** The primary gases that can be found in landfills include ammonia, carbon dioxide, methane, nitrogen and oxygen. They are produced from the decomposition of the organic fraction of municipal solid waste. Methane and carbon dioxide are considered the main landfill gases that are produced from biodegradable organic waste components in landfill.

— **Components of a Sanitary Landfill**

i. **Bottom Liner**: The bottom liner separates and prevents the buried waste from coming in contact with underlying natural soils and groundwater. The liner is generally constructed with some type of durable, puncture-resistant synthetic plastic HDPE (high density polyethylene) combined with compacted clay soils.

ii. **Cells (old and new)**: This is an area in the landfill designated for the disposal of waste. The cell ranges from a few acres to large acres depending on the waste received and inside these larger cells are smaller cells known as daily workface (this is where waste is placed on daily basis and covered by a layer of clay before another is deposited.

iii. **Leachate collection system**: This comprises of the plumbing system and a sump. The plumbing system is situated at the bottom of the landfill which consists of a series of perforated pipes, gravel packs and a layer of sand while the Sump is a ditch where the leachate passing through the plumbing system is collected.

iv. **Storm Water Drainage**: This is an engineered system designed to control and collect water runoff during rain or storm events.

v. **Methane Collection System**: The series of pipes are embedded in the sanitary landfill to collect methane gas since it has the potential to explode.

vi. **Cover (or Cap)**: Waste that is placed in a cell is required to be covered daily with either six inches of compacted soil or an alternative daily cover. Some examples of alternative daily covers are the application of spray-on cover material, such as foam or a flame-retardant fiber material or a large panels of tarpaulin-type material that is laid over the waste at the end of each day and removed the next day before waste is placed.

vii. **Groundwater Monitoring Stations**: Stations are set up to directly access and test the groundwater around the landfill for leachate contamination. It comprises of up-gradient wells (which test water quality before it moves under disposal area) and down-gradient wells (which test water after it has passed under the disposal area); for comparison in order to make sure there has been no impact on groundwater.

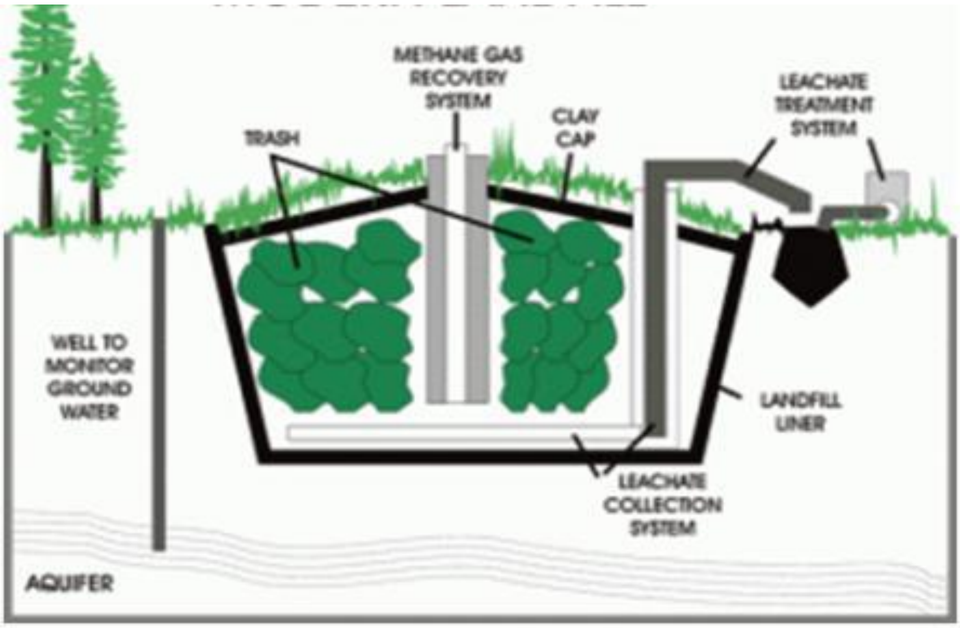

Figure 1: A typical sanitary landfill showing the components.

3.0 Geological and Environmental Factors that influence siting

After the need for a proposed project has been identified, a proper Environmental Impact Assessment (EIA) is required for the sake of the environment. This is the first step before any factor is put into consideration.

i. **Land Use:** The landfill footprint must not be located within 500m of an existing or planned sensitive land use (EPA, 2000). Sensitive land uses include, but are not limited to: schools, residences, hotels, restaurants, food processing facilities, churches, and municipal parks. Land uses such as heavy industry, forestry operations, aggregate extraction/mining, railways/rail yards, etc. are not considered sensitive land uses. Proximity analysis (buffering) using ArcGIS can be used to exclude sensitive areas.

ii. **Topography:** This has to do with the natural and physical features of the area. It is desirable to have a topographic surface that tends to shed water in order to reduce ponding and infiltration. Karst topography is a landscape formed by the dissolution of soluble rocks such as limestone, dolomite, and gypsum. It is characterized by underground drainage systems with sinkholes and caves. Sanitary landfills should not be constructed on karst topography

iii. **Steep Slope:** A completely flat area is exposed to accumulations of water during raining seasons and a very steep slope can be easily eroded. If the slope is too steep, it is difficult and costly to construct the landfill. Slope is a very important factor when siting a landfill; hence higher slopes would increase surface runoff of pollutants from the landfill and thereby contaminate areas that are further away. The landfill area having steep gradient (where stability of slope would be problematic) should not be selected.

Figure 2: A Sloppy terrain

iv. **Seismic zones and Fault areas:** A long term protection of landfill from an earthquake is to avoid sites within 100m of a fault line. Landfills should not be sited on active fault lines as these fault lines can allow unpredictable movement of gas and leachate.

v. **Vadose zone:** This is the zone between the top soil level and the groundwater table (wolf, 2009). It plays a major role in vertical mobility of contaminants toward the water table, and also could play an important role in their attenuation or degradation. Before a site is selected, the following vadose zone properties should be put into consideration: mineralogy, porosity, organic matter content, particle size distribution, soils structure, as well as some information about its cation exchange capacity, temperature, soil pH value and the availability of microorganisms.

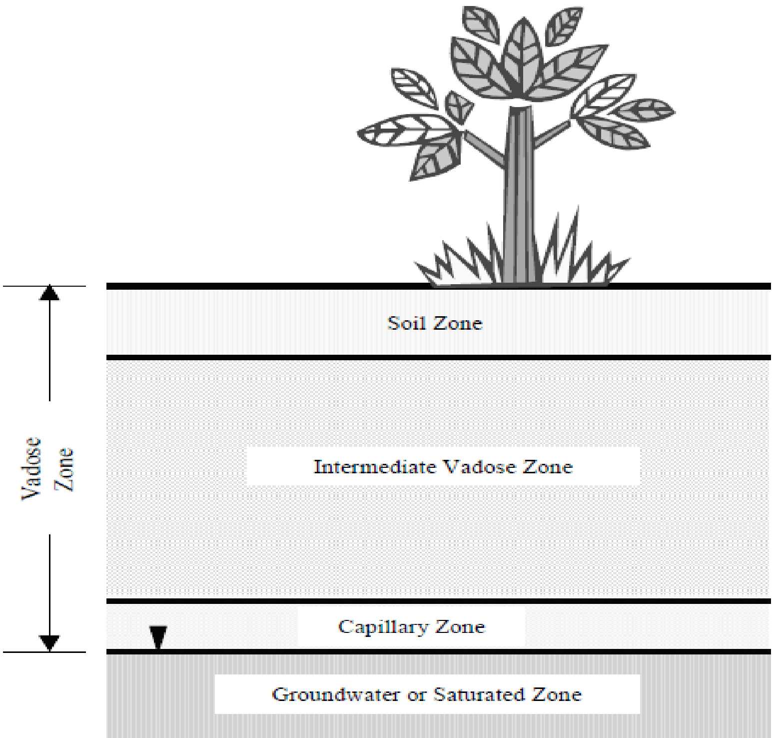

Figure 3: Representation of a vadose zone

vi. **Groundwater level and Surface water bodies:** The groundwater level of a designated site for landfill construction should be sufficiently below the base of excavation. Also landfills should be sited in areas where beneficial uses of groundwater is minimal because groundwater contamination by leachate is difficult to remediate. Landfills should not be sited close to surface water because contamination of water bodies could be hazardous to aquatic lives.

vii. **Vegetation:** For a sanitary landfill, vegetation has the role of ensuring long-term stability and performance of the final landfill cover (UNEP, 2005: Wolf, 2009). Grasses and trees can be planted to help control erosion and to act like natural barriers against harsh climatic factors.

viii. **Soil:** Soil for bottom liner or top layer should be available on site already chosen to cut down cost of transportation. Also soil characteristics should be put into consideration in order to help in checkmating migration of contaminants.

4.0 Operation and Management

4.1 Sanitary Landfill operation

In a typical sanitary landfills, in order to meet standard specifications, the following operations are carried out:

- Confined to as small an area as possible
- Compacted to reduce their volume
- Covered (usually daily) with layers of soil.

During landfill operations, the waste collection vehicles are weighed at a weighbridge on arrival and their load is inspected for wastes that do not accord with the sanitary landfill's waste acceptance criteria. After loads are deposited, compactors or bulldozers are used to spread and compact the waste on the working face. Typically, in the working face, the compacted waste is covered with soil or alternative materials daily. Alternative waste-cover materials are chipped wood or other "green waste", several sprayed-on foam products, chemically 'fixed' bio-solids and temporary blankets. Blankets can be lifted into place at night then removed the following day prior to waste placement.

4.2 Sanitary Landfill Management

i. **Air Quality:** The ambient air quality should be analysed regularly within the landfill, and the mean concentrations of gaseous emissions should conform to United State Environmental Protection Agency (USEPA) 2004 ambient air quality standard.

ii. **Landfill Gas Monitoring:** In order to manage landfill gas and minimise greenhouse gas emissions, appropriate landfill gas containment (for example, landfill cap, basal and side liners) and landfill gas collection systems must be developed, implemented and monitored. The landfill gas management system should be designed prior to establishing the landfill and should be progressively installed during the operational period of the landfill.

iii. **Landfill Leachate Control:** Leachate from landfills must not be allowed to seep into the water ways, rivers, aquifers etc., by installing a good bottom liner and plumbing system to channel leachate to treatment facility. The selection of the liner material must take into account of the stabilization period and should last throughout this period. Once the landfilled waste has stabilized over a period of time, the effects on the surrounding environment due to leachate and gases will be lesser (Technical guidelines, 2004).

iv. **Landfill Odour management:** Landfill odour is a key consideration in landfill siting. Landfill odours have two main sources; odour from the aerobic decomposition of freshly deposited wastes and odour from landfill gas generated by the anaerobic decomposition of wastes. Leachate ponds can also be a source of offensive odours. Good operation and adequate buffers are essential in odour management. These buffers are set to account for upset conditions and are not a substitute for best-practice management at the landfill or for normal operating conditions. The key means of managing landfill gas odour is to manage the landfill gas in general by oxidising it. Odour from aerobic waste deposition is managed by minimising the exposure of these wastes to the atmosphere.

v. **Landfill fire prevention/control:** landfill fires are difficult to extinguish, so the primary objective should be to prevent a fire from starting. This is done by removing potential ignition sources, such as hot coals, from the tipping area. Other measures include not burning waste and not lighting fires on or near areas where wastes have or are being deposited. Finally, wastes should be covered with non-combustible material. The level of carbon monoxide in landfill gas provides some indication whether there is or has been a subsurface landfill fire. Carbon monoxide levels in excess of 1,000 ppm strongly indicate that there is a fire burning within the landfill. Levels above 100 ppm are not as conclusive but should be investigated as part of the fire investigation plan with further gas and temperature measurements to determine if and where there is or was a fire (Aderemi and Falade, 2012).

vi. **Disease vector control:** The main mechanisms for the control of disease vectors are the use of cover material to cover waste daily and eliminating any water bodies that are not required for fire, sediment and leachate control. Other measures, such as scare devices and traps, can also be used to reduce or control infestations. Professional pest exterminators should be employed to reduce problem infestations of vermin.

vii. **Contingency plan:** Contingency planning should form part of the site environment management system. All staff at the landfill must be trained in the implementation of the contingency plan. The contingency plan must encompass all impacts, such as; the detection of contamination of surface or groundwater, detection of landfill gas, blockage of leachate and landfill gas collection pipes, a landfill fire, deposit of unauthorised waste, offensive odours or dust beyond the boundary of the premises, litter beyond the boundary of the premises, equipment breakdown, flare or power outage.

4.3 Sustainable Waste management

At several stages in the life cycle of a product, materials efficiency can be increased by more efficient design, material substitution, product recycling and quality cascading (Bogner et al., 2007). Reduction, reuse and recycling of bio-degradable and non-biodegradable waste is very essential in waste management because it reduces the quantity of solid wastes that is finally disposed in the landfill site. This approach is known as 3Rs approach.

i. **Reduction of solid waste:** Reducing the amount you buy is the most significant of all the options to manage waste. The key is to only purchase goods that we need in the right amount. Packaging waste makes up about one-third of municipal waste and it has doubled in recent years. Banning certain types of packaging which are not biodegradable could help reduce solid waste. Reducing use of plastics in packaging would be a good start because it takes hundreds if not thousand years for it to breakdown; it could be replaced by paper bags because they decompose faster.

ii. **Reuse of solid waste:** The idea of being wasteful makes many people uncomfortable. Most people waste because they can't think of anything better to do with old or worn-out products/materials. Reuse means that a product can be used again with little or no processing. The process of reusing starts with the assumption that the used materials that flow through our lives can be a resource rather than refuse. If we really look at things we are throwing away, we can learn to see them as materials that can be reused to solve everyday problems and satisfy everyday needs. For instance: containers can be reused at home or for school projects, reuse wrapping paper, plastic bags, boxes, and lumber, give outgrown clothing to friends or charity, buy beverages in returnable containers, donate broken appliances to charity or a local vocational school, which can use them for art classes or for students to practice repairing, offer furniture and household items that are no longer needed to people in need, friends, or charity, amongst so many others.

iii. **Recycling of solid waste:** Recycling is the reuse of material to make new products by reducing the need to harvest, mine and process virgin materials, recycling conserves wood, minerals, energy and water. Recycled aluminum for example takes about 95% less energy in processing than producing new aluminum cans because making aluminum is a very electrically intensive process. Recycling also reduces the emission of greenhouse gases especially CO_2 as reprocessing is less energy intensive than original processing. Recycling cuts pollution in the community and saves wastes that are finally sent to the landfill (Kenneth et al., 2015).

5.0 Conclusion

Lack of sanitary landfills in developing and underdeveloped countries has led to indiscriminate waste disposal in open dumps. Indiscriminate waste disposal has been one of the major problems facing Nigeria as wastes are dumped in unauthorized and uncompromising manner. Waste is indiscriminately dumped along streets, roads, market places, etc. and this exposes the environment to all kinds of hazards such as erosion, flooding, depletion of the Ozone layer and natural resource, as well as health hazard (e.g. diarrhoea, malaria, typhoid, cholera etc.). Some dumpsites in Nigeria include Aluu dumpsite in Rivers state, Olososun dumpsite in Lagos state and Gwosa dumpsite in Abuja amongst others which are not environmentally friendly.

The only sanitary landfill in Nigeria is in Epe, Lagos state which is still under construction by Vision cape sanitation. The sanitary landfill, which is the first in Nigeria is expected to serve as an Eco park where waste-to-energy plans, waste water treatment, material recycling and other vital environment friendly procedure are carried out daily.

The importance of sanitary landfill cannot be over emphasized; not only does it cut down environmental pollution, it also reduces potential risk to human health. Also the $3R_s$ approach should efficiently put into consideration.

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