

Impact, Mitigation Strategies, and Future Possibilities of Nigerian Municipal Solid Waste Leachate Management Practices: A Review

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ABSTRACT: Landfills and solid waste disposal facilities have historically been the most common point sources of pollution with the potential to release contamination leachate plumes into the environment. Waste disposal is one of the biggest problems that the world is facing. In man's everyday life, he produces waste materials which, if not properly managed, can affect health and environment. The seepage of landfill leachate into groundwater tables and aquifer systems significantly creates a possible danger and threat to human health and environment at large and remains a subject of concern in Nigeria and other parts of the world. This paper provides a review of existing approaches to leachate treatment in Nigeria and current practices across the globe, depicts the impact on environmental implications, documented previous findings, challenges and mitigation measures, and future perspectives of landfill leachate management in Nigeria, and compares with global practice of leachate management. In Nigeria, there are only a few standard techniques of landfill leachate treatment. This resulted in severe environmental impacts that threaten human life, especially in the north-eastern part of the country. Vector-borne and water-related illnesses such as cholera, Dengue, Diarrhoea, Trachoma, typhoid, malaria etc, have become a major source of concern resulting from the leaching effect from landfills. Advanced treatment methods, including membrane filtration, trickling filters, and Batch and Sequencing-Batch Reactors (SBR) are used in some of the cities and private organizations in Nigeria. Most researchers in Nigeria have stressed the necessity to utilise efficient, cost-effective technology in landfill wastewater treatment. Despite this, landfill leachate has continued to have severe effects in Nigeria and the situation seems to be escalating, requiring further study.

KEYWORDS: Landfill leachate, Treatment methods, Environment, Impact, Measures.

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I. INTRODUCTION

The growth of human activity is inextricably linked to the generation of municipal solid waste (MSW). Improved technological improvements and urbanisation worldwide have resulted in increased consumption, contributing to the vast volume of waste discarded each year. According to Hoornweg and Bhada-Tata (2012), around one billion tonnes of waste are produced globally each year. This amount is predicted to grow over time, reaching approximately 2.2 billion tonnes by 2025 (Costa *et al*, 2019). Solid waste generation can have a variety of effects on human health and the environment; when improperly handled, it promotes the spread of vector-borne diseases, the emission of harmful chemicals, soil, and water contamination (Kjeldsen *et al*, 2002). The waste generation rate in Nigeria is estimated to be 0.66kg/cap/d in urban areas to 0.44kg/cap/d in rural areas as opposed to 0.7-1.8kg/cap/day in developed countries, resulting in 42 million tonnes of waste generated annually (Ike *et al*, 2018). This is roughly half of the

62 million tonnes of garbage generated in Sub-Saharan Africa annually (Ike *et al*, 2018).

Organic waste accounts for 52% of all garbage generated, and this organic trash decomposes quickly and aggregates the metabolic rate of the microbial population (Iorhemen *et al*, 2016; Ike *et al*, 2018). Nigeria's solid waste management practice is faced with myriads of challenges such as insufficient waste management databases, economic, technological, and psychological factors, noncompliance with regulations, and an increasing poverty rate. Others include political factors, inadequate funding, insufficient legislation, poor policy execution, limited infrastructure and professionals, lack of knowledge, poor recovery and recycling programmes, and inappropriate disposal techniques. Waste disposal in landfills produces leachate, a highly polluting effluent containing a high concentration of organic material (biodegradable and refractory organics), humic compounds, as well as nitrogenous compounds such as ammonia nitrogen,

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heavy metals, and inorganic salts (Christensen *et al*, 2001; Ziyang *et al*, 2009).

Treatment of leachate necessitates the removal of organic matter and ammoniacal nitrogen, as well as other hazardous components to meet the criteria for leachate release into recipient water bodies. However, it has been reported that a single treatment method is exceedingly complex to treat this variable effluent, thus, combinations of several treatment methods were reported to improve the removal of pollutants such as arsenic and other hazardous components from landfill leachate (Wiszniewski *et al*, 2006; Renou *et al*, 2008). This review article evaluates the current strategies for landfill leachate treatment in Nigeria, outlining the impact, prospects, current practises, challenges, mitigation measures, future perspectives to current problems, new alternatives and technologies that are still in the research phase around the world.

II. DESCRIPTION OF THE STUDY AREA

Nigeria (Figure 1) is a developing country in West Africa with 36 states and the Federal Capital Territory. Nigeria is a West African nation with a geographical area of 923,768 square kilometres and a longitude ranging from 2 to 15 degrees East and latitude ranging from 4 to 14 degrees North (UNOCHA-Nigeria, 2020; Shaaban *et al*, 2014). It has a western border with Benin Republic, and northern and southern borders with Niger and Chad, respectively. Nigeria has two seasons; a rainy season that lasts from April to October and a dry season that lasts from November to March.



Figure 1: Map of Nigeria showing 36 States and the FCT.

Nigeria is made up of six geopolitical zones (northcentral, northeast, northwest, southeast, south-south, and southwest) with about 400 ethnic groups and 450 languages. The rainfall intensity differs according to region, this has to do with

climatic factors and seasonal variations. The wet season extremities are noted in the south-eastern coast, where annual rainfall may reach 330cm, while the dry season extremes are felt farther north. Waste dumping is the most common way of disposing of solid waste in poor nations throughout the globe including Nigeria. According to the Wiedinmyer (2014) study on the World's 50 Biggest Dumpsites released by D-Waste, Nigeria is home to six of Africa's largest dumpsites. These dumpsites are situated in four of Nigeria's major cities: Lagos, kano, Port Harcourt, and Ibadan. Large-scale MSW generation may be a hazardous source of pollutants to receptors (environment and people) if not adequately controlled at disposal sites (Arukwe *et al*, 2012).

In recent decades, the disposal of solid wastes in Nigeria's largest cities has contributed to serious environmental and public health issues because of Nigeria's rapid population expansion and urbanisation, this has been a subject of concern, particularly in Lagos and Kano, the country's most populous cities (Adedosu *et al*, 2013). Open dumpsites are widely used in Nigeria and other poor nations. They are unsanitary, unattractive, and stinky, drawing rodents, insects, snakes, and flies (Udoh and Inyang, 2016). Onwughara *et al* (2010) reported the effects of open dumpsites, such as landfill gases and leachate, on climate change and urban air pollution, impacting both humans and the natural environment.

III. DUMPSITES, LANDFILLS AND LANDFILL LEACHATES

A. Difference between Dumpsites and Landfills

Waste disposal was simple a few decades ago, when the human population was not as enormous as it is now. Dumps, which are dug sections of ground or pits where waste products are deposited, were utilized by the people. Most homes, particularly in rural regions, had dumps, whereas metropolitan groups had communal dumps. Dumps are not regulated by the government, and they lack processing control. They can be found anywhere and may or may not be covered with soil. These dumps are usually not monitored. As such, the possibility of generating leachates that can contaminate groundwater resources is very high.

Open dumps may attract pests like flies and rodents, as well as generate noxious scents that are harmful to humans. As a result, dumps are now considered unlawful and are being replaced with landfills. The ideal landfill is one that is confined to a small area and is covered with layers of soil. It is also required to have a liner at the bottom of the pit to prevent leachate or the liquid from solid waste to seep through and contaminate the nearby water supply.

The United Nations Environment Programme (UNEP) defines Landfill as an engineered pit, in which layers of solid waste are filled, compacted, and covered for final disposal, often lined at the bottom to prevent groundwater pollution (UNEP, 2002). They further stated that engineered landfills, in addition to a lined bottom consist of a leachate collection and treatment system; groundwater monitoring; gas extraction and a cap system, the capacity is often planned, and the site is chosen based on an environmental risk assessment study (UNEP 2002). While this definition does not describe most solid waste management systems in Nigeria because of the

absence of an engineered system, there are however engineered landfill systems existing in cities such as Lagos (Longe and Balogun, 2010; Olorunfemi, 2011) and Ibadan (Aluko *et al.*, 2003) in the southern part of the country which are now operated as dumpsites.

The basic characteristics of dumpsites and landfills are outlined as follows:

Dumpsites

- i. A dump is an excavated piece of land used as storage for waste materials.
- ii. A dump is smaller than a landfill.
- iii. A dump does not have leachate collection and treatment systems while a landfill does

Landfills

- i. landfill is also an excavated piece of land for waste storage, but it is regulated by the government.
- ii. A landfill has a liner at the bottom to catch the liquid produced by solid waste while a dump does not have a liner
- iii. Landfills are covered daily with soil to deter pests and prevent bad smells from being released into the air while dumps may be covered or not.
- iv. landfills might produce toxic gases which are released into the air and ground because the waste materials cannot rot while dumps are hazards because they can be located anywhere.

The term landfill have often been interchangeably used in Nigeria to describe government designated and excavated trenches used for dumping and management of municipal solid wastes notwithstanding their technical differences (Oluyemi *et al.*, 2008; Akinbile, 2012). However, there are only few landfills across Nigeria which are mostly cited in southern part of the country especially Lagos state, most (if not all) of which now operate as dumpsites. However, there are a lot of dumpsites in Northern part of the country, this could be because of low level of awareness and lack of adequate facilities compare to southern part the country.

The scope of this review therefore encompasses both the engineered landfills-turned dumpsites as well as the regular dumpsites across Nigeria since they both share the same characteristics of serving as municipal solid waste management systems and have the capability of generated leachates that are potentially injurious to groundwater resources. Therefore, the continuous use of the term landfill in the manuscript is broadly to describe both systems with emphasis on the leachates arising from the municipal solid wastes dumped or deposited at the sites over time.

B. Leachate Development in Landfills

Landfill leachate is formed when rainwater seeps through the waste layers of a landfill, eventually reaching the soil and ground water (Fan *et al.*, 2006). landfill leachate contains four distinct chemical groups: dissolved organic content (DOC), volatile fatty acids (VFA), humic and fulvic fractions, inorganic components (calcium- Ca^{2+} , magnesium- Mg^{2+} , ammonium- NH_4^+ , iron- Fe^{2+} , manganese- Mn^{2+} , chloride- Cl^-), and heavy metals (arsenic-As, mercury-Hg) (Kjeldsen *et al.*, 2002). Figure 2 describes the formation of landfill leachates and the influence to environmental degradation.

The climate in Nigeria varies according to major regions. Nigeria is equatorial in the south, tropical in the middle, and desert in the north. These climate types have distinct rainy and dry seasons which is encountered on a yearly basis. The average temperature in Nigerian cities remain between 200c and 350c per year (Adedosu *et al.*, 2013). Temperature fluctuations in Nigeria influence the development of landfill leachates in both the southern and northern. As a result, landfill leachate discharge has a wide range of characteristics and compositions (Adedosu *et al.*, 2013).

Climate change has a significant impact on leachate formation owing to development of hydrological cycle (which entails water vapours fleeing to the atmosphere to form condensation nuclei and then returning as rain). Contaminants like heavy metals and volatile organic compounds react with rainfall, the concentration of landfill leachate plumes rise during rainy seasons, resulting in a significant amount of leachate plumes being discharged into surface water, some of which percolates and contaminates groundwater table, as illustrated in Figure 2.

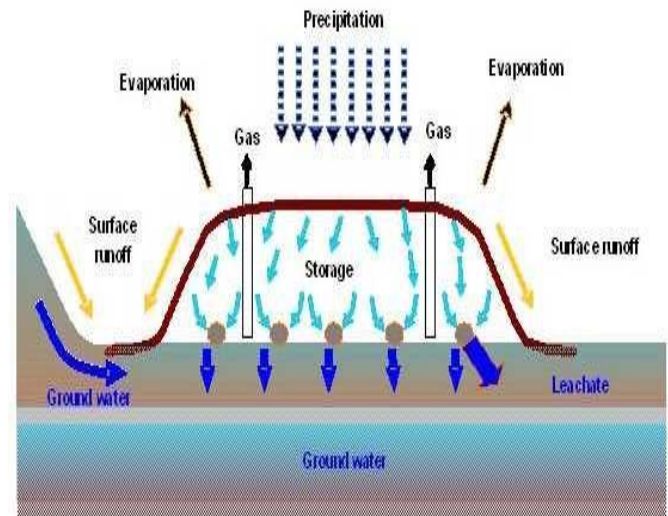


Figure 2: Process of contamination of water sources by landfill leachates (Aziz, 2014).

This has the potential to become an environmental hazard as well as a threat to human health. Furthermore, Rainfall may increase the quantity of leachate and, to some extent, enhance leachate leakage and percolation from landfills (Han *et al.*, 2016; Wijekoon *et al.*, 2021).

Based on the geographical variability of leachate characteristics during waste biodegradation, landfill leachate may be categorised as acetogenic or methanogenic (Ziyang *et al.*, 2009). Due to the presence of organic contaminants, acetogenic leachate has the greatest chemical oxygen demand (COD), biological oxygen demand (BOD), and BOD:COD ratio (Robinson, 2007). Between the aerobic, acetogenic, methanogenic, and stabilising phases of waste processing, the composition of leachate may change significantly (Renou *et al.*, 2008). Three kinds of leachates have been identified based on landfill age: young, intermediate, and mature leachates (Table 1).

Table 1: Relationship between age of the landfill and leachate physicochemical composition.

		Land fill leachate characteristics			
		Acetogenic leachate	Methanogenic leachate		
S/N	Parameters (mgL ⁻¹)	Young age (years) Less than 5	Middle age (years) 5-10	Mature age (years) (Greater than 10)	FEPA standard 1991
1	pH	Less than 6.5	6.5-7.5	Greater than 7.5	6 – 9
2	COD	Greater than 10000	4000-10000	Less than 4000	-
3	BOD	0.5-1.0	0.1-0.5	Less than 0.1	30
4	NH ₃ -N	Less than 0.4	NA	Greater than 4000	-
5	TOC/COD	Less than 0.3	0.3-0.5	Greater than 0.5	-
6	Heavy metals	Low-medium	Low	low	Less than 1
7	Total Kjeldahl nitrogen	1500–4500	400–800	75–300	-
8	P	100–300	10–100	-	-
9	biodegradability	High	Medium	low	low
10	Alkalinity	8000–18,000	4500–6000	-	-
11	Conductivity (µs.cm)	15,000–41,500	6,000–14,000	-	-
12	so ₄ ²⁺	500–2000	200–1000	50–200	-
13	Ca ²⁺	10–250	6200	5500	200
14	Mg ²⁺	40–1150	-	-	200
15	Fe ²⁺	500–1500	500–1000	100–500	10
16	Zn ⁺	100–200	50–100	10–50	<1
17	Cl ⁻	1000–3000	500–2000	100–500	-
18	Total dissolved solids (TDS)	10,000–25,000	5000–10,000	2000–5000	2000
19	Total coliform	-	-	-	400

*Unit in mg. L-1 not applicable to pH parameter. P-Proserous; SO4-Sulphate (-) Not measured

The landfill age has an adverse effect on groundwater and surface water pollution; an old landfill collects a large quantity of leachate containing hazardous chemicals, and the frequency of percolation rises, presenting a severe threat to the groundwater table, while a new landfill accumulates fewer dangerous compounds and has a lower rate of intrusion. Groundwater contamination begins early in the landfill stage and gradually worsens (Ahamad *et al.* 2019). The majority of groundwater contamination occurs within the first 5–20 years, after which it decreases. The quality of leachate generated in MSW landfills changes with age, and the concentration of pollutants in leachate rises with age (Ahamad *et al.* 2019). After reaching its maximum, the concentration begins to decline and eventually stabilises (Kjeldsen *et al.*, 2002; Renou *et al.*, 2008). Chemical component concentrations are high at the start of landfill operation and, except for the pH parameter, tend to drop consistently over time (years) with waste stabilisation. The data in Table 1 may not be applicable to other parts of the world, such as Nigeria, where socioeconomic and climatic conditions, among other variables, may be substantially different. Apart from pH and temperature, the majority of metrics were found to be greater during the dry season than during the wet season, including oxidation-reduction potential (ORP), turbidity, electrical conductivity (EC), and total dissolved solids (TDS) (Xaypanya *et al.* 2018).

The content of the leachate may vary because of variations in the waste type, the amount of garbage crushed and compressed, and the decomposition process (Foo and Hameed, 2009). These factors include the humidity of garbage,

temperature changes, hydrology site, and landfill operations (Aluko and Sridhar, 2013; Grosser *et al.*, 2019). The age of the soil, the composition of garbage, and the intensity of rainfall all have an impact on the nature of the land and the amount of waste generated (Remmas *et al.* 2018). Ammoniacal nitrogen (NH₄⁺-N), sodium (Na⁺), potassium (K⁺), chloride (Cl⁻), calcium (Ca²⁺), magnesium (Mg²⁺), iron (Fe²⁺), manganese (Mn²⁺), sulphate (SO₄²⁻), and hydrogen carbonate (HCO₃) are the most common inorganic components; and heavy metals such as cadmium (Cd²⁺), nickel (Ni²⁺), and chromium (Cr³⁺) (Slack *et al.*, 2005; Schiopu and Gavrilescu, 2010). These variables may all have a role in the persistence of NH₃-N, total alkalinity, COD, total hardness, solvent, and carcinogens in leachate. Numerous variables change when the landfill stabilises; for example, the age of the landfill has an impact on the leachate composition (Kulikowska *et al.* 2008). According to Christensen *et al.* (2001), leachate has a low pH and a high concentration of organic materials and volatile acids that are easily degraded. The pH of leachate is increased in mature landfills, and organic material is present in the form of humic and fulvic fractions (Kurniawan *et al.*, 2006).

C. Impact of Landfill Leachates in Nigeria and Some Countries across the Globe.

The presence of landfill leachates pollution results in the accumulation of hazardous chemicals and heavy metals such as copper, lead, zinc, arsenic, and nickel in surrounding water bodies. These pollutants have a significant effect on soil and groundwater aquifers, posing a risk to aquatic and human life.

This section discussed earlier results on the effect of landfill leachate on groundwater resources and the pollution index on the impact of landfill leachate on groundwater aquifers and human health. In Nigeria, there is an urgent need to monitor and minimise the impact of landfill leachate, toxic inorganic and organic pollutants in aquifers, and to assess potential health risks. According to Ajani *et al.* (2021), an alluvium and porous soils may enable leachate to migrate from the topsoil to the subsurface at various depths, enabling leachate wastewater from the dumpsite to reach the groundwater table except for hardness. Although it was found that, when compared to water samples from residential areas near the dump site, the biochemical oxygen demand, chemical oxygen demand, zinc, and magnesium levels were much greater, but copper levels were low and above the permissible limits. When pathogenic microorganisms such as *E. coli*, *Salmonella* spp., *E. coli*, *Shigella* spp., and *Erwinia* spp. are exposed to the environment, they may cause food poisoning (Ogunlaja *et al.* 2019). Contaminants in the landfill represent a health concern to local people and may be a source of infectious disease epidemics, since metals and other leachate components can bioaccumulate in mammalian tissues (Sanchez and Nadal, 2007).

Water pollution is causing havoc in Nigeria's southern region, which may be a result of increasing water table, rising salinity levels, and the extinction of aquatic species as described in Figure 2. However, there are other forms of pollution connected with leachate wastewater; including oil spills, industrial combustion, and floating plastic debris, which has become a major environmental concern due to its quantity and destiny, presenting a serious danger to aquatic life (Sarijan *et al.* 2018). Wijewardena *et al.* (2012) examined ground penetrating radar (GPR) wave behaviour in groundwater with varying contaminant levels (electrical conductivities-EC) and plume sizes, and concluded that the GPR technique is suitable for identifying highly contaminated areas in groundwater with inorganic ions and has the potential to detect seawater intrusion. The topography of an area has a significant impact on leachate percolation. Leachate percolates easily at a landslide area as described in Figure 2. This can increase the contaminants level in groundwater and pollutes aquatic life.

Fatoba *et al.* (2020) conducted a geophysical and geochemical investigation on landfills in southern Nigeria to determine the cause(s) of pollution and the extent of its impact on surrounding soils and groundwater within the area, and the results showed that the low resistivity values observed at the subsurface layers are caused by the presence of leachate, which has also polluted the groundwater. Asian countries share similar seasonal parameters that can be compared to the Nigerian standard as previously reported. According to Oyeyemi *et al.* (2019), who studied leachate flow in an open dumpsite in Ogun, Nigeria, geoelectrical imaging results show that contaminated leachates occur near the surface at depths of 2.5 m to 4 m and move south-eastwards. The rapid movement of leachate in the southern region of Nigeria could be linked to high rainfall intensity as well as a high-water table. The environmental impact varies by water table depth and groundwater flow direction (Hossain *et al.*, 2014). Contaminants from landfills have gradually pushed deeper into the ground. This effect could be attributable to increasing

dissolved metal concentrations, evaporation, or heavy rain, because of seasonal change and waste type. The mean concentrations of total dissolved solid (TDS), electrical conductivity (EC), temperature, hardness, and most chemical parameters observed during the dry season research are generally greater than those measured during the rainy season, this confirmed the study across different locations in Nigeria (Ameloko *et al.* 2018).

In Indonesia, most of the pollutant has a positive loading, indicating that MSW leachate has an impact on groundwater quality (Mishra *et al.* 2019). Significant geographical variation in TDS, NO₃⁻, and PO₄³⁻ during the pre- and post-monsoon periods indicated anthropogenic impacts on groundwater quality (Mishra *et al.* 2019). Waste landfill leachate pollution in Malaysia is getting worse, as evidenced by the maximum As (787) and Cr (552) values on the Quality Rating Scale (QRS) (Hussein *et al.* 2021). Leachate effluent with toxic metals was released from Malaysian non-sanitary landfills as a result of improper waste management which resulted to a significant pollution (Hussein *et al.* 2021). Metal content increases in landfills are not solely attributable to anthropogenic sources such as the waste disposed, but also to redox conditions, anoxic environments, pH, oxidation state, and many other factors as well (Ashraf *et al.*, 2013).

The quantities of leachate organics, heavy metals, and toxicity were found to be extremely high at the Okhla landfill in Delhi because of the dumpsite being unplanned and positioned in the flood zones of the Yamuna River, creating a significant environmental and health danger (Singh and Mittal 2009). Groundwater quality at the Ramna landfill in Varanasi, India, is rapidly degrading owing to landfill leachate leakage, and is hazardous for drinking since most physico-chemical parameter values are above the world health organisation (WHO) & British standard (BIS) permissible limit of drinking water standard (Mishra *et al.* 2019). The leachate from the Beris Lalang landfill also exceeds the Cr, Cu, Pb, As, and Pb discharge limits, and majority of the workers drink groundwater while working in that region, which can risk their lives (Fadhullah *et al.* 2019). Heavy metals such as (Cd, Ni, Cu, Pb, and As) were discovered in groundwater samples near the landfill at Ampar Tenang (Selangor), Malaysia (Ashraf *et al.*, 2013). Jaishankar *et al.* (2014) observed significant levels of Cd in landfill leachate in Perak and Kedah, India, which is one of the most hazardous metals and is known to cause cancer.

The accumulation of these heavy metals, as well as the emission of gases from landfill sites, are hazardous, toxic, and detrimental to aquatic and human lives. In Austria, domestic items are discarded without distinction at the Leucaena dumpsite, resulting in the production of PFASs because of biological and abiotic leaching from waste products deposited onsite. This has the potential to have a substantial effect on soil and groundwater contamination. Additionally, PFASs have been detected in landfill leachates in Germany (Busch *et al.*, 2010), China (Yan *et al.*, 2015), the United States (Huset *et al.*, 2011), and Australia (Busch *et al.*, 2011). The presence of PFASs in landfill leachate may have an effect on the environmental air quality (Gallen *et al.*, 2017). Figure 3 illustrates the different diseases caused as a results of landfill leachate.

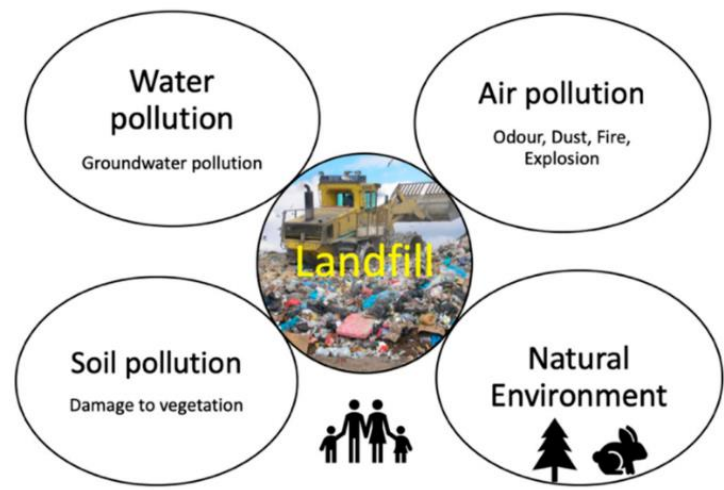


Figure 3: Potential impacts of landfill leachate on the environment (Abd El-Salam and Abu Zaid, 2015).

This might have an impact on seasonal variations as well as different settings of geographic regions.

Seasonal changes have an impact on the properties of leachate. As a result, higher temperatures increase evaporation, increase pollutants concentration, and accelerate metabolic and degradation rates. It aids in the development of the hydrological cycle. During the wet season, landfill leachates generate toxic compounds whose concentrations reduce due to dilution. According to Trankler *et al.* (2005), landfill leachate provides more than 60% of precipitation. The mixing and diluting of pollutants induced by rainwater recharge is one of the natural attenuation processes (Yong-Lee *et al.*, 2021). Several characteristics, however, decrease during the rainy season and rise during the dry season.

D. Major Risks Associated with Landfill Leachate in Nigeria

The risk of a landfill is largely determined by the content and percentage of waste types (hazardous waste and organic matter content), the physicochemical characteristics of the leachate, and the groundwater protection measures that are implemented (Adamcova *et al.*, 2017). When landfill leachate is not carefully handled, treated, or discharged, it can pollute soil, groundwater, and eventually human health. Due to high levels of ammonia, toxic metals, and some organic substances like volatile organic compounds (VOCs), landfill leachate can have harmful toxic effects on the environment and humans, as shown in Fig. 2. As a result, leachate is considered to have potential ecotoxic effects by stressing ecosystem components (Wijekoon *et al.*, 2021). Acidic metal release causes high metal concentrations in leachate, while the leachate from a landfill cannot be eradicated, it can be reduced or even treated to reduce the risk to the environment (Ifeanyichukwu, 2008).

Waste management is the most pressing environmental concern in Nigeria, endangering both groundwater and surface water. This results in epidemic outbreaks. According to UNICEF (2021), lack of access to improved water and sanitation remains a major contributor to high case fatality rates among children under the age of five in Nigeria. Exposure

to waterborne diseases such as diarrhoea, which kills more than 70,000 children under the age of five each year, increases due to the consumption of polluted water and inadequate sanitation.

Arsenic (As) has been found as a prominent potentially hazardous inorganic contaminant in landfill leachate (Udiba *et al.*, 2019). Almost all raw leachate examined in sanitary and non-sanitary landfills had a substantial amount of As (Hussein *et al.*, 2021). Only few studies have looked at the monitoring of As in landfill leachate, most of which discovered significant levels (Hussein *et al.*, 2021). Toxic metals like As, Cd, and Pb can cause a variety of problems, including hypertension, gastrointestinal disorder, stunted development, and carcinogenesis in organs including the lungs, kidneys, bladder, and skin (Kamunda *et al.*, 2016; Udiba *et al.*, 2019). This is in line of the previous studies of (Aluko 2013), that most leachate wastewater in Nigeria have numerous toxic metals which is causing serious environmental degradation.

Apart from As, ammonia-nitrogen is also a very complicated and poisonous compound that carries an adverse risk in the ecosystem. High amounts of ammonia not only cause health and environmental problems, but they also impair the effectiveness of leachate treatment (Haslina *et al.*, 2021).

In landfill leachate, ammonium toxicity is a significant issue, as methanogenic leachate records ammonia concentrations higher than 100mg/L-1 when it settles in the proper phase of the landfill. The toxicity of leachate varies with concentration, salinity, oxidation, and pH (Oman *et al.*, 2008). According to studies, aquatic animals are keenly toxic to ammonium, ammonia values of 0.083 to 4.60 mg/L were very toxic to 18 invertebrates and 29 fish species (Oman and Junestedt, 2008). Yadav *et al.* (2020) stated that Okhla landfill in Delhi, India has a high contamination potential for creating serious environmental and health risks. Leachate treatment must be optimised in order to minimise the negative impact on the environment to the greatest extent possible. It is exceedingly difficult to create a broad guideline for treatment approaches. However, due to the complexities of the leachate

composition, leachates change over time and between locations (Renou *et al.*, 2008). This ammonia nitrogen is abundant in landfill leachate which becomes a nuisance to the environment.

E. Several Methods of Landfill Leachate Treatment Worldwide

There are currently several techniques for landfill leachate treatment, all of which attempt to meet the standard and conform to regulatory requirements. Biological processes (activated sludge, aerobic and anaerobic stabilisation lagoons, and biological filters); physicochemical processes (floatation, coagulation/flocculation, adsorption, chemical precipitation, air stripping, pH adjustment, chemical oxidation, ion exchange, and electrochemical treatment); and membrane filtration processes (microfiltration, ultrafiltration and electrochemical treatment) (Raghab *et al.*, 2013; Logan, 2012). Table 2 summarises frequently cited biological and physicochemical treatment techniques, including their benefits and drawbacks, as well as their efficacy. Numerous studies have shown that combining different methods improves leachate remediation effectiveness (Mahmud *et al.*, 2012). COD, NH₃, organic matter, and other pollutant removal values have been enhanced when leachate treatment techniques are combined (Table 2). Numerous techniques focused on particular contaminants found in landfill leachate, which has been the topic of numerous research as shown in Table 2.

IV. MITIGATION MEASURES, CHALLENGES, AND FUTURE PERSPECTIVES ON MANAGEMENT

A. Mitigation Measures

Some measures for mitigating the problems associated with landfill leachates are briefly described as follows:

- i. Algal leachate treatment may help landfills manage waste more sustainably by recovering low-quality water for reuse and generating significant quantities of algal biomass for biofuel and bio product.
- ii. The federal government has an essential need to rekindle its regulatory framework, which would entice private sector investment in garbage collection, treatment, recycling and reuse, The Registering Council of the Environmental Health Officer of Nigeria ought to step up efforts to monitor and enforce sanitation regulations and control licensee operations in good sustainable model.
- iii. Regardless of the presence of landfill gases, landfill leachate irrigation is an effective treatment technique for reducing leachate volumes and removing ammonium. If the salt concentration of the soil reaches a certain threshold, a control technique such as landfill leachate irrigation may be considered (Watzinger *et al.* 2010).
- iv. Combining several optimal landfill leachate treatment techniques may improve the rate of pollutant removal from leachate-formed biowaste. This would assist Nigeria to meet its national water quality criteria for assessing river water quality.

- v. To mitigate the impact of landfill leachate migration into aquifers, specifically designed dumping sites and leachate collection ponds should be developed at strategic locations.
- vi. Suitable irrigation methods can be employed around the dump sites to minimise the effect of landfill leaching by increasing soil moisture and drainage volumes while also augmenting plant deterioration caused by salt chloride inputs (Watzinger *et al.* 2010).

It is also possible to significantly reduce the risk of groundwater contamination when building new landfills by establishing a buffer zone between the garbage and the boundary line (Lee *et al.*, 2005).

B. Challenges

According to Aluko *et al.* (2013), many Nigerian cities have wastewater treatment problems from sanitary landfills/dumpsites. In fact, utilising solely anaerobic and aerobic stabilisation lagoons has not shown to be the most efficient way of treating landfill leachates since long-term exposure may endanger public health. Most of the time, landfill leachate treatment is still laborious and ineffective owing to several reasons some of which are described as follows.

- i. To reduce global impacts, improve environmental conditions, and sustain long-term growth, unified effort is required as such, leachate discharges need more strict rules and controls due to their periodic problems and geographical unpredictability (Renou *et al.*, 2008).
- ii. Non-technical landfills and open dumps produce significant amounts of landfill leachate because well-engineered sanitary landfills are costly and face difficult technical challenges (Wijekoon *et al.* 2021). Cost has been a significant problem in leachate treatment, particularly in developing countries. Furthermore, a lack of space has hindered the development of better landfilling alternatives for regulating and treating leachate (Ismail and Latifah, 2013).
- iii. Insufficient field data on landfill leachate would restrict viable treatment techniques and field research investigations (Mukherjee *et al.*, 2015). More studies are needed to identify the maximum potential of the leachate remediation approach.
- iv. Biological wastewater treatment techniques alone may not be sufficient to remove certain contaminants from landfill leachates (Schiopu and Gavrilesu, 2010).
- v. The current state of waste management in Nigeria necessitates continuous efforts to educate the general populace, particularly those living in rural regions, about the need for appropriate waste disposal. Additionally, authorities should teach the general public on how to convert garbage to wealth.

Despite the fact that many landfill leachate treatment techniques have been tested and recommended as effective, little research on scale-up treatment has been conducted (Wijekoon *et al.*, 2021).

Table 2: Frequently cited biological and physicochemical treatment techniques.

S/N	Treatment method	Techniques	Merits	Demerits	Scale size	Average contaminants removal (%)	Reference
1	Biological	Stabilization pond	<ul style="list-style-type: none"> Affordability of installation and operation 	<ul style="list-style-type: none"> Biological treatment has the following weaknesses: Due to its low efficiency, it must be used in conjunction with other treatment techniques to satisfy regulatory standards. In order to maximise efficiency, a significant amount of area is needed and Sensitivity to changes in temperature. It causes unpleasant odour Refractory substances may impede the flow of the fluid. 	Pilot scale	COD:40%	(Frascardi <i>et al.</i> , 2004)
		Aerobic membrane bioreactor	<ul style="list-style-type: none"> Settling times for sludge Sensitivity to changes in environmental circumstances is lowered. 	<ul style="list-style-type: none"> It causes unpleasant odour Refractory substances may impede the flow of the fluid. 	Pilot scale	COD:88.95% NH ₃ :80.92%	(Reis <i>et al.</i> , 2020; Abbas <i>et al.</i> , 2009; Chen <i>et al.</i> , 2008)
		Activated sludge process	<ul style="list-style-type: none"> Activated sludge is more broad than lagoon treatment 	<ul style="list-style-type: none"> Difficulty in separating sludge Microbial suppression due to high ammoniacal nitrogen concentrations Highly sensitive to changes in leachate characteristics, and it has been discovered that treating landfill leachate with activated sludge is insufficient. 	Pilot scale	COD: 59%	(Baumgarten and Seyfried, 1996)
		Anaerobic fluidized bed Fenton oxidation	<ul style="list-style-type: none"> Organic loading rates are high, while operating costs are minimal and significant Production of biogas can be achieved 	<ul style="list-style-type: none"> Toxic chemicals may become an issue if effluent concentrations are high. 	Pilot scale	COD:85%	Gulsen and Turan, 2004
		Moving Bed Biofilm Reactor (MBBR)	<ul style="list-style-type: none"> It is simple to use and resistant to elevated ammoniacal nitrogen levels, as well as reducing sludge dispersion. 	<ul style="list-style-type: none"> It has high cost of construction. 	Bench lab scale	COD: 60–81%	Loukidou and Zouboulis, 2001
		Biological filters (Trickling filters)	<ul style="list-style-type: none"> Simple to operate. Low-cost filter media has highly Efficient pollutant removal 	<ul style="list-style-type: none"> Bacterial inhibition of nitrifiers due to the top section of the filter absorbing more N–NH₃ Challenges with clogging whenever there is a large organic load High capital cost It can induce membrane blockage proclivity 	Bench lab scale	COD: 44% BOD: 60%, N–NH ₃ : 15%	(Mondal and Warith, 2008; Renou <i>et al.</i> 2008)
		Membrane Bioreactors (MBR)	<ul style="list-style-type: none"> Increased sludge retention time Improved sludge separation Accelerated treatment Reduced area demand High resistance to sludge retention time 	<ul style="list-style-type: none"> High ammonia concentrations (>500 mg/L) are toxic to microalgae 	Full scale	COD: 89% BOD: 92% N–NH ₃ :97%	(Zhang <i>et al.</i> , 2009, Remmas <i>et al.</i> , 2018)
Microalgae biotechnology Reactor	<ul style="list-style-type: none"> Biofuels are made from biolipids and carbohydrates. It reduces the emission of co₂ in the environment 		Bench scale	N–NH ₃ :70%	Chang <i>et al.</i> , 2018, 2019		
2	Processes of integrated treatments methods Physicochemical processes						
		Coagulation-flocculation	<ul style="list-style-type: none"> Consolidated concept Flexible operations Best utilised as biological pre-treatment. Pollutant removal that is both efficient and cost-effective 	<ul style="list-style-type: none"> It may be necessary to make changes to operating conditions on a regular basis. •High sludge production may cause clogging 	Bench scale	COD:10–50% COD:95.5% DOC:93% Color:83%	Alfaia <i>et al.</i> , 2019; Amokrane <i>et al.</i> , 1997; Webler <i>et al.</i> , 2019; Aziz <i>et al.</i> 2018.

Precipitation	<ul style="list-style-type: none"> • Allows by-products to be reused as manure • Less expensive than other physical-chemical processes • Processes are faster than biological processes. • Costs are lower than those of other physical-chemical processes. 	<ul style="list-style-type: none"> • Finding precipitating agents is extremely challenging, and the procedure's potency is restricted by the pH ranges used in its implementation. 	Bench scale	NH ₃ :90% organic matter: inefficient.	Calli <i>et al.</i> , 2005; Li and Zhao, 2001
Reverse osmosis and Forward osmosis (FO)	<ul style="list-style-type: none"> • It has a powerful capability and an effective method for cleaning landfill leachate wastewater. 	<ul style="list-style-type: none"> • Maintenance is needed regularly • Current membrane separation methods require more power • Membrane is of limited useful life span of (approximately 5 years). 	Pilot scale	Organic contaminants: 99.6%. Flux recovery> 80%	(Ippc 2001; Aftab <i>et al.</i> , 2019
Advanced oxidative treatments	<ul style="list-style-type: none"> • Excellent in enhancing leachate degradability • Reduces operational costs when used as a pre-treatment or cleaning 	<ul style="list-style-type: none"> • Toxic chemicals may be formed as a result of byproducts. • High energy consumption and use of excess chemical inputs 	Bench scale	COD: <50%. Colour: 83% chromium: 99%	Tizaoui <i>et al.</i> , 2007: Webler <i>et al.</i> , 2019
Nanofiltration	<ul style="list-style-type: none"> • High refusals for oxidizing agents and organic dissolves • High Functionality • Higher flow and lesser demand for power than reverse osmosis. • This process requires less pressure than reverse osmosis 	<ul style="list-style-type: none"> • Membranes have a short lifespan (around 5 years) • Maintenance tasks need to be completed on a regular basis. • It has High initial cost 	Pilot scale	COD:65% NH ₃ -N:50% Toxicity:100%	(Martinen <i>et al.</i> , 2002; Trebouet <i>et al.</i> , 2001; Reis <i>et al.</i> , 2020; Ahn <i>et al.</i> , 2002
Air Stripping	<ul style="list-style-type: none"> • Effective ammonia removal techniques even at relatively high concentrations 	<ul style="list-style-type: none"> • It is necessary to operate at high temperatures and pH levels in order to maximise process efficiency. • It requires high amounts of energy and chemical inflow. • There is a risk of air pollution and groundwater contamination. 	Bench scale	NH ₃ -N:99.5 % COD: poor	Calli <i>et al.</i> , 2005: Ferraz <i>et al.</i> , 2013
Wetland/Microbial fuel cell/ Phytoremediation	<ul style="list-style-type: none"> • Low energy consumption 	<ul style="list-style-type: none"> • If discarded, the microbes and toxic chemicals found in leachate can cause harm to the environment. 	Full scale	NH ₃ -N: 89.7% COD: 98.47% Nitrite:99% Phosphate:70% Filtered volume> 57%	Li Wang, 2021: Chen <i>et al.</i> , 2019; Torretta <i>et al.</i> , 2017
Adsorption/biochar Anammox	<ul style="list-style-type: none"> • Usage of reagents Pollutant emissions are minimal. • Adsorbents of low cost are readily available. • Reduction of organic debris fouling the Forward • Osmosis membrane in landfill leachate 	<ul style="list-style-type: none"> • Fouling caused by carbon Adsorption of activated carbon is expensive. 	Bench scale		Foo and Hameed, 2009: Aftab <i>et al.</i> , 2019
Bioreactors Partial nitration Anammox Sequencing batch reactor process	<ul style="list-style-type: none"> • Landfill leachate can generate methane and remove nitrogen. • Advancement stage of treatment 	<ul style="list-style-type: none"> • Complicated process • It requires careful monitoring 	Bench scale	NH ₃ :94% Nitrate:78%	Chen <i>et al.</i> , 2019;
			Full scale	COD-53% CH ₄ :76% COD-97.3% NH ₃ -99% P:75%	Sun <i>et al.</i> , 2020 Li <i>et al.</i> , 2009a, 2009b

C. Future Perspectives

From the foregoing discussions, the future perspectives of leachate management is described as follows:

- i. An integrated approach of treatments would provide the best possibility for pollutant removal from leachate.
- ii. To safeguard groundwater from contamination that may occur from landfill leachate intrusion, a comprehensive lifecycle assessment can be carried out to estimate possible pollution levels of municipal solid wastes over a long period of time.
- iii. Appropriate modifications can be made to upgrade existing dumpsites and engineered landfills to enable the recovery of energy resources in the form of methane from the biodegradable component of the wastes. This will reduce the residence time of the waste which will, in turn, reduce the amount of leachate that may be generated.
- iv. The government should ramp up public awareness campaigns targeted at persuading people to sort their waste at the source.
- v. Population expansion and modernization both contribute to a significant amount of municipal solid garbage and rubbish generation. As a result, the quantity of pollutant level of waste disposal leachate has significantly increased, and more attention has to be placed on leachate treatment via different integration methods.
- vi. The toxicity, pollutant transport, and aquifer pollution caused by landfill leachate need further study, while health and life-cycle assessment studies of the ecosystems are minimal.

The right data and understanding of leachate characteristics may aid in the selection of the most appropriate treatment technique, as well as sophisticated mathematical models that can forecast and collect data, such as artificial intelligence.

V. CONCLUSION

This review paper noted that waste management in many areas of Nigeria is substandard and entwined with numerous difficulties at every stage of the management process. It may be noted that, though engineered landfills existed in some cities in the southern part of Nigeria, they have all been turned into dumpsites as a result of inappropriate operations. It may be inferred that dumpsites are a primary source of groundwater pollution. Seasonal changes have a major impact on the production and properties of landfill leachate in Nigeria cities. Inadequate wastes disposal, illiteracy, and a lack of regulatory enforcement are the primary barriers to effective waste management in Nigeria, which produces tonnes of rubbish at active and closed sites resulting in soil leachates posing serious environmental problems. Landfill soils serve as the ultimate sink for contaminants from solid waste, posing a threat to human health and plant and animal biodiversity.

There is an urgent need to enhance Nigeria's existing landfill/dumpsite leachate treatment technique. Effluent regulations serve as the basis for protecting public health and the environment from the detrimental effects of wastewater, using the most cost-effective treatment technology available. From the exhaustive literature review, key leachate quality

indicators such as COD, DOC, NH₃, organic matter, and colour have been substantially decreased when sustainable landfill leachate treatment techniques such as those described in this review are used. Each of these techniques has a number of advantages and disadvantages. The present national discharge requirements should be evaluated on a regular basis and adjusted to reflect the country's actual reality. As a result, it becomes essential to implement effective leachate management practises at all landfills in Nigeria to safeguard the environment's quality and human health.

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