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 (Iorhémen 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 extremes 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 (Adedosa 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. A 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 (Oluwemii 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).](image)

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; Wijeeton 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).
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 (Poo 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 (NH\textsubscript{3}\textsuperscript{+}-N), sodium (Na\textsuperscript{+}), potassium (K\textsuperscript{+}), chloride (Cl\textsuperscript{−}), calcium (Ca\textsuperscript{2+}), magnesium (Mg\textsuperscript{2+}) iron (Fe\textsuperscript{2+}), manganese (Mn\textsuperscript{2+}), sulphate (SO\textsubscript{4}\textsuperscript{2−}), and hydrogen carbonate (HCO\textsubscript{3}−) are the most common inorganic components; and heavy metals such as cadmium (Cd\textsuperscript{2+}), nickel (Ni\textsuperscript{2+}), and chromium (Cr\textsuperscript{3+}) (Slack et al., 2005; Schiopu and Gavrilescu, 2010). These variables may all have a role in the persistence of NH\textsubscript{3}-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.

| S/N | Parameters (mg/L) | Acetogenic leachate | Methanogenic leachate |
|-----|------------------|---------------------|----------------------|
|     |                   | Young age (years)   | Middle age (years)   | Mature age (years) |
|     |                   | Less than 5         | 5-10                 | Greater than 10    |
| 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\textsubscript{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\textsubscript{4}\textsuperscript{2−} | 500–2000            | 200–1000             | 50–200             | -      |
| 13  | Ca\textsuperscript{2+} | 10–250             | 6200                | 5500               | 200    |
| 14  | Mg\textsuperscript{2+} | 40–1150             | -                    | -                  | 200    |
| 15  | Fe\textsuperscript{2+} | 500–1500            | 500–1000             | 100–500            | 10     |
| 16  | Zn\textsuperscript{2+} | 100–200             | 50–100               | 10–50              | <1     |
| 17  | Cl\textsuperscript{−} | 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\textsuperscript{-1} not applicable to pH parameter. P-Prosperous; SO\textsubscript{4}-Sulphate ( ) Not measured
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 present 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 (Sarjjan 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 Oeyyemi et al. (2019), who studied leachate flow in an open dumpsite in Ogun, Nigeria, geoelectrical imaging results show that contaminated leaches 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 Leucena 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 result of landfill leachate.
Figure 3: Potential impacts of landfill leachate on the environment (Abd El-Salam and Abu Zuid, 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 on the environment and humans, as shown in Fig. 2. 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/floculation, 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 in 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 Gavrilescu, 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                 | • Affordability of installation and operation | • 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. | Pilot scale| COD:40%                          | (Frascari et al., 2004)                           |
|     |                             | Aerobic membrane bioreactor        | • Settling times for sludge Sensitivity to changes in environmental circumstances is lowered. | • It causes unpleasant odour. • Refractory substances may impede the flow of the fluid. | Pilot scale| COD:88.95% NH₃:80.92%            | (Reis et al., 2020; Abbas et al., 2009; Chen et al., 2008) |
|     | Activated sludge process    |                                    | • Activated sludge is more broad than lagoon treatment | • 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 |                            | • Organic loading rates are high, while operating costs are minimal and significant Production of biogas can be achieved | • Toxic chemicals may become an issue if effluent concentrations are high. | Pilot scale| COD:85%                          | Gulsen and Turan, 2004                              |
|     | Moving Bed Biofilm Reactor (MBBR) |                                    | • It is simple to use and resistant to elevated ammoniacal nitrogen levels, as well as reducing sludge dispersion. | • It has high cost of construction. | Bench lab scale| COD:60–81%                         | Loukidou and Zouboulis, 2001                       |
|     | Biological filters (Trickling filters) |                            | • Simple to operate. • Low-cost filter media has highly Efficient pollutant removal | • 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 | Bench lab scale| COD: 44% BOD: 60%, N–NH₃: 15% | (Mondal and Warith, 2008; Renou et al. 2008)       |
|     | Membrane Bioreactors (MBR)  |                                    | • Increased sludge retention time • Improved sludge separation • Accelerated treatment • Reduced area demand • High resistance to sludge retention time | • High capital cost • It can induce membrane blockage proclivity | Full scale| COD: 89% BOD: 92%, N–NH₃: 97% | (Zhang et al., 2009, Remmas et al., 2018)           |
|     | Microalgae biotechnology Reactor |                                    | • Biofuels are made from biolipids and carbohydrates. • It reduces the emission of co2 in the environment | • High ammonia concentrations (>500 mg/L) are toxic to microalgae | Bench scale| N–NH₃:70%                         | Chang et al., 2018, 2019                           |
| 2   | Processes of integrated treatments methods |                           |                                             |                                                                          | Bench scale| COD:10–50% COD:95.5% DOC:93% Color:83% | Alfaia et al., 2019; Amokrane et al., 1997; Webler et al., 2019; Aız et al. 2018 |
### Precipitation
- 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.
- Finding precipitating agents is extremely challenging, and the procedure's potency is restricted by the pH ranges used in its implementation.

### Reverse osmosis and Forward osmosis (FO)
- It has a powerful capability and an effective method for cleaning landfill leachate wastewater.
- Maintenance is needed regularly
- Current membrane separation methods require more power
- Membrane is of limited useful life span of (approximately 5 years).

### Advanced oxidative treatments
- Excellent in enhancing leachate degradability
- Reduces operational costs when used as a pre-treatment or cleaning
- Toxic chemicals may be formed as a result of byproducts.
- High energy consumption and use of excess chemical inputs
- Maintenance tasks need to be completed on a regular basis.
- It has High initial cost

### Nanofiltration
- High refusals for oxidizing agents and organic dissolve
- Higher flow and lesser demand for power than reverse osmosis
- Membranes have a short lifespan (around 5 years)
- It has High initial cost

### Air Stripping
- Effective ammonia removal techniques even at relatively high concentrations
- 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.

### Wetland/Microbial fuel cell/Phytoremediation
- Low energy consumption
- If discarded, the microbes and toxic chemicals found in leachate can cause harm to the environment.

### Adsorption/biochar
- 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
- Fouling caused by carbon Adsorption of activated carbon is expensive.

### Anammox
- Landfill leachate can generate methane and remove nitrogen.
- Complicated process
- It requires careful monitoring

### Bioreactors Partial nitrification Anammox Sequencing batch reactor process
- Landfill leachate can generate methane and remove nitrogen.
- Advancement stage of treatment
- Complicated process
- It requires careful monitoring
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.

REFERENCES

Abbas, A. A.; G. Jingsong; L. Z. Ping; P. Y. Ya and W. S. Al-Rekabi. (2009). Review on Landfill leachate treatments. Journal of Applied Sciences Research, 5(5), 534-545.

Abd El-Salam, M.M. and Abu-Zuild, G.I. (2015). Impact of landfill leachate on the groundwater quality: A case study in Egypt. Journal of advanced research, 6(4), 579-586.

Abila, B., and Kantola, J. (2013). Municipal solid waste management problems in Nigeria: Evolving knowledge management solution. In Proceedings of World Academy of Science, Engineering and Technology (No. 78, p. 292). World Academy of Science, Engineering and Technology.

Adamcova, D., M. Radziemsk; A. Ridoskova; S. Barton; P. Pelcova; J. Elbl; J. Kynicky; M. Brtnicky; M. D. Vaverkova. (2017). Environmental assessment of the effects of a municipal landfill on the content and distribution of heavy metals in Tanacetum vulgare L. Chemosphere 185, 1011–1018

Adonedu, H. O.; G. O. Adewuyi and G. U. Adie (2013). Assessment of heavy metals in soil, leachate and underground water samples collected from the vicinity of olusosun landfill in Ojota, Lagos, Nigeria. Transnational Journal of Science and Technology, 3(6), 73-86.

Aftab, B., Y. S. Ok; J. Cho and J. Hur. (2019). Targeted removal of organic foulants in landfill leachate in forward osmosis system integrated with biochar/activated carbon treatment. Water research, 160, 217-227.

Ahamad, A., N. J. Raju; S. Madhav; W. Gossel and P. Wycisk. (2019). Impact of non-engineered Bhalwa landfill on groundwater from Quaternary alluvium in Yamuna flood plain and potential human health risk, New Delhi, India. Quaternary International, 507, 352-369

Ahmed, A. T.; A. E. Alluqmani and M. Shafiquzzaman. (2019). Impacts of landfill leachate on groundwater quality in desert climate regions. International Journal of Environmental Science and Technology, 16(11), 6753-6762.

Ahmed, F.N. and Lan, C.Q. (2012). Treatment of landfill using membrane bioreactors: a review. Desalination 287, 41–54.

Ahn, W. Y.; M. S. Kang; S. K. Yim; K. H. Choi. (2002). Advanced landfill leachate treatment using an integrated membrane process. Desalination 149, 109–114.

Akinbile, C. O. (2012). Environmental impact of landfill on groundwater quality and agricultural soils in Nigeria. Soil and Water Research, 7(1), 18-26.

Ajani, O. O.; T. A. Adagunodo; A. A. Adeniji; B. Fashae; M. Omeje and O. O. Adewoyin. (2021).

From the 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.
Investigation of groundwater contamination from leachate migration: a case study of Bowen University dumpsite, Nigeria. In IOP Conference Series: Earth and Environmental Science, 655(1), 1-14. IOP Publishing.

Ali, A. (2013). Groundwater Pollution Threats of Solid Waste Disposal in Urban Kano, Nigeria: Evaluation and Protection Strategies. The University of Manchester (United Kingdom).

Aluko, O. O.; M. K. Sridhar and Oluwande, P. A. (2003). Characterization of leachates from a municipal solid waste landfill site in Ibadan, Nigeria. Journal of Environmental Health Research, 2(1), 32-37.

Aluko, O.O. and Sridhar, M.K.C. (2013). Evaluation of leachate treatment by trickling filter and sequencing batch reactor processes in Ibadan, Nigeria. Waste Manag. Res. 31 (7), 700–705.

Ameloko, A. A., and AyoLABI, E. A. (2018). Geophysical assessment for vertical leachate migration profile and physicochemical study of groundwater around the Olusosun dumpsite Lagos, south-west Nigeria. Applied Water Science, 8(5), 1-15.

Amokrane, A.; C. Comel and J. Veron. (1997). Landfill leachates pre-treatment by coagulation-flocculation. Water research, 31(11), 2775-2782.

Arukwe A.; T. Eggen and M. Müder. (2012). Solid waste deposits as a significant source of contaminants of emerging concern to the aquatic and terrestrial environments — A developing country case study from Owerri, Nigeria. Sci Total Environ 438: 94–102.

Ashraf, M.A.; I. Yusoff; M. Yusof and Y. Alias. (2013). Study of contaminant transport at an open-tipping waste disposal site. Environ. Sci. Pollut. Control Ser. 20 (7), 4689e4710.

Awodele, O.; A. A. Adewoye and A. C. Oparah. (2016). Assessment of medical waste management in seven hospitals in Lagos, Nigeria. BMC Public Health, 16(1), 1–11.

Aziz, H.A.; Y. C. Yii; S. F. F. Syed Zainal; S. F. Ramli and C. O. Akinbile. (2018). Effects of using Tamarindus indica seeds as a natural coagulant aid in landfill leachate treatment. Glob. Nest J. 20, 373-380.

Aziz, S.Q., (2013). Produced Leachate from Erbil Landfill Site, Iraq: Characteristics, Anticipated Environmental Threats and Treatment. In The 16th International Conference on Petroleum, Mineral Resources and Development, Cairo, Egypt. 10-12.

Baumgarten, G., and Seyfried, C. F. (1996). Experiences and new developments in biological pre-treatment and physical posttreatment of landfill leachate. Water Science and Technology, 34(7-8), 445-453.

Bulc, T.G. and Justin, Z. (2007). Sustainable solution for landfill leachate with a use of phytoremediation. In: Velini, A.A. (Ed.), Landfill Research Trends. Nova Science Publishers, New York. 103–139

Busch, J.; L. Ahrens; R. Sturm and R. Ebinghaus. (2010). Polyfluoroalkyl compounds in landfill leachates. Environ. Pollut. 158, 1467–1471.

Calii, B.; B. Mertoglu and B. Inanc. (2005). Landfill leachate management in Istanbul: applications and alternatives. Chemosphere, 59(6), 819-829.

Chang, H.; Q. Fu; N. Zhong; X. Yang; X. Quan; S. Li; ... and C. Xiao. (2019). Microalgal lipids production and nutrients recovery from landfill leachate using membrane photobioreactor. Bioresource technology, 277, 18-26.

Chang, H.; X. Quan; N. Zhong; Z. Zhang; C. Lu; G. Li; ... and L. Yang. (2018). High-efficiency nutrient reclamation from landfill leachate by microalgae Chlorella vulgaris in membrane photobioreactor for bio-lipid production. Bioresource technology, 266, 374-381.

Chen, S.; D. Sun and J. S. Chung. (2008). Simultaneous removal of COD and ammonium from landfill leachate using an anaerobic–aerobic moving-bed biofilm reactor system. Waste Manag. 28, 339–346.

Chinadé, A. U.; S. Y. Umar and K. J. Osinubi. (2017). Effect of municipal solid waste leachate on the strength of compacted tropical soil for landfill liner. International Research Journal of Engineering and Technology, 4(6), 3248-3253.

Christensen, T.H.; P. Kjeldsen; P. Bjerg; D. L. Jensen; J. B. Christensen; A. Baun; H. J. Albrechtsen and G. Heron. (2001). Biogeochemistry of landfill leachate plumes. Appl. Geochem. 16, 659–718.

Costa, A. M.; R. G. D. S. M. Alfaia and J. C. Campos. (2019). Landfill leachate treatment in Brazil—An overview. Journal of environmental management, 232, 110-116.

Dajić, A.; M. Mihajlović; M. Jovanović; M. Karena; D. Stevanović and J. Jovanović. (2016). Landfill design: need for improvement of water and soil protection requirements in EU Landfill Directive. Clean Technol. Environ. 1, 753–764.

Amasuomo, E. and Baird, J. (2016). Investigating the Wastes Management Practices of Businesses in Nigeria. J. Manag. Sustain., 6(4), 107-203.

El-Fadel, M.; E. Bou-Zed; W. Chahine and B. Alayli. (2002). Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content. Waste Manag. 22, 269–282.

El-Fadel, M., F. Matar and J. Hashisho. (2013). Combined coagulation-flocculation and sequencing batch reactor with phosphorus adjustment for the treatment of high strength landfill leachate: experimental kinetics and chemical oxygen demand fractionation. J. Air Waste Manag. Assoc. 63 (5), 591–604. https://doi.org/10.1080/10962247.2013.775086.

Fadullah, W.; M. A. Kamaruddin; N. Ismail; N. Sansuddin and H. Abdullah. (2019). Characterization of landfill leachates and its impact to groundwater and river water quality: a case study in beris ilang waste dumpsite, Kelantan. Pertanika Journal of Science and Technology 27 (2), 633-646

Fan, H.; H. Y. Shu; H. S. Yang and W. C. Chen. (2006). Characteristics of landfill leachates in central Taiwan. Sci. Total Environ. 361, 25–37.

Farquhar, G.J. (1989). Leachate: production and characterization. Can. J. Civ. Eng. 16, 317–325. H. Billard, Centre de stockage des d´echets Exploitation, 2001.

Fatoba, J. O.; A. B. Eluwole; O. A. Sanuade; O. S. Hammed; W. N. Igoboa and J. O. Amosun. (2020). Geophysical and geochemical assessments of the environmental impact of Abule-Egba landfill, southwestern...
Nigeria. Modeling Earth Systems and Environment. 7(2), 695-701.

Ferraz, F.M.; J. Povinelli and E. M. Vieira. (2013). Ammonia removal from landfill leachate by air stripping and absorption. Environ. Technol. 34, 2317–2326

Foo, K. and Hameed, B. (2009). An overview of landfill leachate treatment via activated carbon adsorption process. Journal of Hazardous Materials, 171 (1–3), 54–60.

Frascari, D., F. Bronzini; G. Giordano; G. Tedioli and M. Nocentini. (2004). Long-term characterization, lagoon treatment and migration potential of landfill leachate: a case study in an active Italian landfill. Chemosphere, 54(3), 335-343.

Fudala-Ksiazek, S.; M. Pierpaoli and A. Luczkiwicz. (2017). Fate and significance of phthalates and bisphenol A in liquid by-products generated during municipal solid waste mechanical-biological pre-treatment and disposal. Waste Management, 64, 28-38.

Gajski, G.; V. Orescanin and V. Garaj-Vrhovac. (2012). Chemical composition and genotoxicity assessment of sanitary landfill leachate from Rovinj, Croatia. Ecotoxicol. Environ. Saf. 78, 253–259.

Gallen, C.; D. Drage; G. Eaglesham; S. Grant; M. Bowman and J. F. Mueller. (2017). Australia-wide assessment of perfluorooalkyl substances (PFASs) in landfill leachates. J. Haz. Mat. 331, 132–141.

Grosser, A.; E. Neccaj; M. Madela and P. Celary. (2019). Ultrasound-assisted treatment of landfill leachate in a sequencing batch reactor. Water, 11(3), 516.

Gulsen, H. and Turan, M. (2004). Treatment of sanitary landfill leachate using a combined anaerobic fluidized bed reactor and Fenton’s oxidation. Environ. Eng. Sci. 21, 627–636

Han, Z.; H. Ma; G. Shi; L. He; L. Wei and Q. Shi. (2016). A review of groundwater contamination near municipal solid waste landfill sites in China. Sci. Total Environ. 569, 1255–1264.

Haslina, J.; H. NorRuwaida; M. Dewika; M. Rashid; M. P. Khairunnis and M. A. D. Azmi. (2021). Landfill Leachate Treatment Methods and Its Potential for Ammonia Removal and Recovery-A Review. In IOP Conference Series: Materials Science and Engineering (Vol. 1051, No. 1, p. 012064). IOP Publishing.

Hoornweg and Bhada-Tata (2012). What a Waste: A Global Review of Solid Waste Management, Urban Development Series; Knowledge Papers no. 15, World Bank

Hossain, M.L.; S. R. Das and M. K. Hossain. (2014). Impact of landfill leachate on surface and ground water quality. J. Environ. Sci. Technol. 7, 337–346.

Huset, C.A.; M. A. Barlaz; D. F. Barofsky and J. A. Field. (2011). Quantitative determination of fluorochemicals in municipal landfill leachates. Chemosphere 82, 1380–1386.

Hussein, M.; K. Yoneda; Z. Mohd-Zakri; A. Amir and N. Othman. (2021). Heavy metals in leachate, impacted soils and natural soils of different landfills in Malaysia: An alarming threat. Chemosphere, 267, 128874. Ifeanyichukwu, M.J., 2008. New Leachate Treatment Methods. Sweden Lund Univ., Lund.

Hussein, M.; K. Yoneda; Z. M. Zaki and A. Amir. (2019). Leachate characterizations and pollution indices of active and closed unlined landfills in Malaysia. Environ. Nanotechnol. Monit. Manag. 12, 100232

Ifeanyichukwu, M. J. (2008). New leachate treatment methods. Lund, Sweden: Lund University.

Ike, C. C.; C. C. Ezeibe; S. C. Anijiofor and N. N. Daud. (2018). Solid waste management in Nigeria: problems, prospects, and policies. The Journal of Solid Waste Technology and Management, 44(2), 163–172.

Iorhemen, O. T.; M. I. Alfa and S. B. Onoja. (2016). The review of municipal solid waste management in Nigeria: the current trends. Advances in environmental research, 5(4), 237-249.

IPCC, 2001. Climate Change 2000. The Science of Climate Change. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Jaishankar, M.; T. Tseten; N. Anbalagan; B. B. Mathew and K. N. Beersegowda. (2014). Toxicity, mechanism and health effects of some heavy metals. Interdisciplinary toxicology, 7(2), 60.

Kamunda, C.; M. Mathuthu and M. Madhuku. (2016). Health risk assessment of heavy metals in soils from Witwatersrand gold mining basin, South Africa. Int. J. Environ. Res. Publ. Health.

Kjeldsen, M.A.; A. P. Barlaz; A. Rooker; A. Baun and T. H. Ledin. (2002). Christensen, Present and long-term composition of MSW landfill leachate: a review, Crit. Rev. Environ. Sci. Technol. 32 (4) 297–336

Kulikowska, D. and Klimiuk, E. (2008). The effect of landfill age on municipal leachate composition. Bioresource. Technol. 99, 5981–5985.

Kurniawan, T.A.; W. Lo and G. Y. S. Chan. (2006). Physical-chemical treatments for removal of recalcitrant contaminants from landfill leachate. J. Hazard. Mater. 129, 80–100.

Lanza, V.C.V. and Carvalho, A.L. (2006). Basic Operations for Landfill Operation. FEAM, Belo Horizonte, pp. 07–34 (In Portuguese)

Lee, G.F. and Jones Lee, A., (2005). Public health, groundwater resource and environmental protection from MSW leachate pollution by single and double composite lined dry tomb landfills

Li, X. Z., and Zhao, Q. (2001). Efficiency of biological treatment affected by high strength of ammonium-nitrogen in leachate and chemical precipitation of ammonium-nitrogen as pretreatment. Chemosphere, 44(1), 37-43.

Logan B. E. and Rabaey K. (2012). Conversion of wastes into bioelectricity and chemicals by using microbial electrochemical technologies. Science, 337:686–90.

Longe, E. O., and Balogun, M. R. (2010). Groundwater quality assessment near a municipal landfill, Lagos, Nigeria. Research journal of applied sciences, e

Loukidou, M. X., and Zouboulis, A. I. (2001). Comparison of two biological treatment processes using attached-growth biomass for sanitary landfill leachate treatment. Environmental pollution, 111(2), 273-281.

Mahmud, K.; M. D. Hossain and S. Shams. (2012). Different treatment strategies for highly polluted landfill
leachate in developing countries. Waste Management 32 (11), 2096–2105.

Marttinen, S. K.; R. H. Kettunen; K. M. Sormunen; R. M. Solimassuo and J. A. Rintaala. (2002). Screening of physical–chemical methods for removal of organic material, nitrogen and toxicity from low strength landfill leachates. Chemosphere, 46(6), 851-888.

Mishra, S.; D. Tiwary; A. Ohri and A. K. Agnihotri. (2019). Impact of Municipal Solid Waste Landfill leachate on groundwater quality in Varanasi, India. Groundwater for Sustainable Development, 9, 100230.

Mojiri, A.; H. A. Aziz; N. Q. Zaman; S. Q. Aziz and M. A. Zahed. (2014). Powdered ZELIAC augmented sequencing batch reactors (SBR) process for co-treatment of landfill leachate and domestic wastewater. Journal of environmental management, 139, 1-14.

Mojiri, A.; L. Ziyang; R. M. Tajuddin; H. Farraji and N. Alifar. (2016b). Co-treatment of landfill leachate and municipal wastewater using the ZELIAC/zeolite constructed wetland system. J. Environ. Manage. 166, 124–130.

Mondal, B., and Warith, M. A. (2008). Use of shredded tire chips and tire crumbs as packing media in trickling filter systems for landfill leachate treatment. Environmental technology, 29(8), 827-836.

Mukherjee, S.; S. Mukhopadhyay; M. A. Hashim and B. Sen Gupta. (2015). Contemporary environmental issues of landfill leachate: assessment and remedies. Crit. Rev. Environ. Sci. Technol. 45, 472–590.

Nathanson, J. A. (2020) "Hazardous-waste management". Encyclopedia Britannica, 30 Oct 2020, https://www.britannica.com/technology/hazardous-waste-management. Accessed 27 August 2021.

Ogunlaja, A.; S. O. Abarikwu; C. A. Otuechere and O.O. Oshoro. (2019). Characterization of leachates from waste landfill sites in a religious camp along Lagos-Ibadan expressway, Nigeria and its hepatotoxicity in rats. Chemosphere, 217, 636-645.

Ojoawo, S. O.; O. A. Agbede and A. Y. Sangodoyin. (2012). System dynamics modelling of dumpsite leachate control in Ogbomosho land, Nigeria. Journal of Environmental Protection, 3(1), 120-128.

Olorunfemi, F. B. (2011). Landfill development and current practices in Lagos metropolis, Nigeria. Journal of Geography and Regional Planning, 4(12), 650.

Oluyemi, E. A.; G. Feuyit; J. A. O. Oyekunle and A. O. Ogunfowokan. (2008). Seasonal variations in heavy metal concentrations in soil and some selected crops at a landfill in Nigeria. African Journal of Environmental Science and Technology, 2(5), 089-096.

Oman, C.B. and Junestedt, C. (2008). Chemical characterization of landfill leachates–400 parameters and compounds. Waste Manag. 28, 1876–1891.

Onwughara, I. N.; I. C. Nnorom and O. C. Kanno. (2010). Issues of Roadside Disposal Habit of Municipal Solid Waste, Environmental Impacts and Implementation of Sound Management Practices in Developing Country “Nigeria”. International Journal of Environmental Science and Development 1(5), 409-418.

Oyeyemi, K. D.; A. P. Aizebeokhia; A. N. Ede; O. J. Rotimi; O. A. Sanuade; O. M. Olofinmade; ... and O. O. Attat. (2019). Investigating the near surface leachate movement in an open dumpsite using surficial ERT method. In IOP Conference Series: Materials Science and Engineering (Vol. 640, No. 1, p. 012109). IOP Publishing.

Qasin, S.R. and Chiang, W. (1994). Sanitary Landfill Leachate - Generation, Control and Treatment. CRC Press LLC, Florida

Quan, X.; R.Hu; H. Chang; X. Tang, X.; Huang; C. Cheng; ... and L. Yang. (2020). Enhancing microalgal growth and landfill leachate treatment through ozonisation. Journal of Cleaner Production, 248, 119182.

Rabl, A.; J. V. Spadaro and A. Zoughaib. (2008). Environmental impacts and costs of solid waste: a comparation landfill and incineration. Waste Manag. Res. 26, 147–162.

Raghab, S.M.; A. M. A. El Meguid and H. A. Hegazi. (2013). Treatment of leachate from municipal solid waste landfill. HBCR J. 9, 187–192.

Reis, B.G.; A. L. Silveira; Y. A. R. Lebron; V. R. Moreira; L. P. T. Teixeira; A. A. Okuma; M. C. S. Amaral and L. C. Lange. (2020). Comprehensive investigation of landfill leachate treatment by integrated Fenton/microfiltration and aerobic membrane bioreactor with nanofiltration. Process Saf. Environ. Prot. 143, 121–128.

Remnas, N.; S. Ntougias; M. Chatzopoulou and P. Melidis. (2018). Optimization aspects of the biological nitrogen removal process in a full-scale twin sequencing batch reactor (SBR) system in series treating landfill leachate. Journal of Environmental Science and Health, Part A, 53(9), 847-853.

Renou, S.; J. G. Givaudan; S. Poulain; F. Dirassouyan and P. Moulin. (2008). Landfill leachate treatment: review and opportunity. J. Hazard. Mater. 150, 468–493.

Rim-Rukeh A (2014). An assessment of the contribution of municipal solid waste dump sites fire. Open Journal of Air Pollution, 3(03), 53.

Robinson, H. (2007). The composition of leachates from very large landfills: an international review. Communications in waste and resource management, 8(1), 19-32.

Salami, H. A.; J. O. Adegite; T. T. Bademosi; S. O. Lawal; O. O. Olutayo and O. Olowosoke. (2018). A review on the current status of municipal solid waste management in Nigeria: Problems and solutions. Journal of Engineering Research and Reports, 3(4):1-16.

Sanchez-Chardi, A. and Nadal, J., (2007). Bioaccumulation of metals and effects of landfill pollution in small mammals. Part I. The great white-toothed shrew, Crocidura russula. Chemosphere 68, 703-711.

Sarajian, S.; S. Azman; M. I. M. Said; Y. Andu and N. F. Zon. (2018). Microplastics in sediment from Skudai and Tebrau river, Malaysia: a preliminary study. In MATEC Web of Conferences (Vol. 250, p. 06012). EDP Sciences.

Schiopu, A.-M. and Gavrilescu, M. (2010). Options for the treatment and management of municipal landfill leachate: common and Specific Issues. Clean. - Soil, Air, Water 38, 1101–1110.
Shaaban M. and Petirin J. O. (2014). Renewable energy potentials in Nigeria: Meeting rural energy needs. Renew Sust Energ Rev 29: 72-84.

Singh V. and Mittal A. K. (2009). Toxicity analysis and public health aspects of municipal landfill leachate: a case study of Okhla landfill, Delhi. In: 8th world wide workshop for young environmental scientists WWW-YES 2009: urban waters: resource or risks? 2–5 June 2009.

Slack, R.J.; J. R. Gronow and N. Vouvolis, N., (2005). Household hazardous waste in municipal landfills: contaminants in leachate. Sci. Total Environ. 337, 119–137.

Sun, F.; W. Zhang; G. Jiang; Y. Liu; S. Wu; D. Wu; ... and Y. Zhou. (2020). Effective biological nitrogen process and nitrous oxide emission characteristics for the treatment of landfill leachate with low carbon-to-nitrogen ratio. Journal of Cleaner Production, 268, 122289.

Syafalni, S.; M. H. Zawawi and I. Abustan. (2014). Isotopic and hydrochemistry fingerprinting of leachate migration in shallow groundwater at controlled and uncontrolled landfill sites. World Appl. Sci. J. 31 (6), 1198-1206.

Tizaoui, C.; L. Bouselmi; L. Mansouri and A. Ghrabi. (2007). Landfill leachate treatment with ozone and ozone/hydrogen peroxide systems. Journal of hazardous materials, 140(1-2), 316-324.

Trankler, J.; C. Visvanathan; P. Kuruparan and O. Tubtimthai. (2005). Influence of tropical seasonal variations on landfill leachate characteristics—Results from lysimeter studies. Waste Management, 25(10), 1013–1020.

Udiba, U.U.; E. R. Akpan and E. E. Antai. (2019). Soil lead concentrations in Dareta village, Zamfara, Nigeria. Journal of Health and Pollution. 9(23), 15.

Udoh, I. B., and Inyang, S. A. (2016). Purview of public Solid Waste Collection, Disposal and Management Practices in Akwa Ibom State. International Research Journal of Environmental Sciences, 5(7), 55–63.

Vital, M.H.F.; M. Ingouville and M. A. C. Pinto. (2014). Estimate of investments in landfills to meet targets established by the National Solid Waste Policy between 2015 and 2019. BNDES Set. 40, 43–92. (In Portuguese)

United Nations Environment Programme (UNEP) (2002). A Directory of Environmentally Sound Technologies for the Integrated Management of Solid, Liquid, and Hazardous Waste for Small Island Developing States (SIDS) in the Pacific Region. The Hague: United Nations Environment Programme (UNEP). Available online at https://iwlearn.net/documents/3901. Accessed on May 2, 2022.

United Nations Office for the Coordination of Humanitarian Affairs, Nigeria (UNOCHA-Nigeria, 2020). Nigeria - Subnational Administrative Boundaries. Available online at: https://data.humdata.org/dataset/cod-ab-nga. Accessed on April 15, 2022.

Waheed ul Hasan, S. and Ani, F. N. (2014). Review of limiting issues in industrialization and scale-up of microwave-assisted activated carbon production. Industrial and engineering chemistry research, 53(31), 12185-12191.

Watzinger, A. (2010). Microbial phospholipid biomarkers and stable isotope methods help reveal soil functions. Soil Biology and Biochemistry, 86, 98-107.

Webler, A.D.; F. C. Moreira; M. W. C. Dezotti; C. F. Mahler; I. D. B. Segundo; R. A. R. Boaventura and V. J. P. Vilar. (2019). Development of an integrated treatment strategy for a leather tannery landfill leachate. Waste Manag. 89, 114–128.

Wiedenmyer, C.; R. J. Yokelson and B. K. Gullett. (2014). Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. Environmental science and technology, 48(16), 9523-9530.

Wijekoon, P.; P. A. Koltyabandara; A. T. Cooray; S. S. Lam; B. C. Athapattu and M. Vithanage. (2021). Progress and prospects in mitigation of landfill leachate pollution: Risk, pollution potential, treatment, and challenges. Journal of Hazardous Materials, 421, 126627.

Wisniewski, J.; D. Robert; J. Sumacz-Gorska; K. Milksch and J. V. Weber. (2006). Landfill leachate treatment methods: a review. Environ. Chem. Lett. 4, 51–61.

Xaypanya, P.; J. Takemura; C. Chiemchaisri; H. Seingheng and M. A. N. Tanchuling. (2018). Characterization of landfill leachates and sediments in major cities of Indochina peninsular countries—Heavy metal partitioning in municipal solid waste leachate. Environments, 5(6), 65-88.

Yadav, S.; I. Ibrar; A. Altaee; A. K. Samal; R. Ghorbadi and J. Zhou. (2020). Feasibility of brackish water and landfill leachate treatment by GO/MoS2-PVA composite membranes. Science of the Total Environment, 745, 141088.

Yan, H.; I. T. Cousins; C. J. Zhang and Q. Zhou. (2015). Perfluoroalkyl acids in municipal landfill leachates from China: occurrence, fate during leachate treatment and potential impact on groundwater. Sci. Total Environ. 524, 23–31.

Yong, L. L.; V. Anggraini; M. E. Raghunandan and M. R. Taha. (2021). Macrostructural and Microstructural Properties of Residual Soils as Engineered Landfill Liner Materials. Environmental and Engineering Geoscience.

Zhang, L.; A. Li; Y. Lu; L. Yan; S. Zhong and C. Deng. (2009). Characterization and removal of dissolved organic matter (DOM) from landfill leachate rejected by nanofiltration. Waste Management, 29(3), 1035-1040.

Ziyang, L.; Z. Youcai; Y. Tao; S. Yu; C. Huili; Z. Nanwen and H. Renhua. (2009). Natural attenuation and characterization of contaminants composition in landfill leachate under different disposing ages. Sci. Total Environ. 407, 3385–3391.