

Promoting Integrated and Sustainable Solid Waste Management System in A Developing City for Public Health and Cleaner Environment

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Abstract

The approaches for sustainable waste management should be compatible with the nature of a particular city because solid waste is an integral part of every human society. This study aims to develop an integrated and sustainable waste management system for a city in a developing nation. An overview of the city's current waste management system reveals that most waste is either openly burned or dumped into drainage systems and bodies of water, indicating inadequate waste management. This research involves the use of a waste analysis, waste characterization study and data consolidation to effectively and precisely gather and analyze data. An estimated 13,337.88 kg of waste are generated daily, of which 52.84% are biodegradable, and the remaining waste and recyclables account for 28.57% and 18.59%, respectively. This is based on data from a waste analysis and characterization study. The estimated per capita waste generation is 0.80 kg/day. The three R's of an efficient and successful sustainable waste management are reduction, reuse, and recycling. These are some of the main methods that make up the Integrated Solid Waste Management strategy. The appropriate and sustainable management of generated solid wastes is a major issue for many governments across the world. In developing countries, solid waste management interventions include building landfills; using recycling programs and better disposal procedures; and upgrading technology, accessibility, and service operations. The promotion of integrated and sustainable waste management will surely assist sustainable development, public health and the environment in all ramifications.

Keywords: Landfill, Solid Waste Management, Sustainable development, Waste Characterization, Waste Generation

1.0 INTRODUCTION

Refuse disposal is a major environmental challenge in developing countries, according to Nwigwe (2008). The lack of effective waste management practices in Nigeria has resulted in health hazards, traffic congestion, unsightliness, discomfort, and drainage system blockages, to name just a few of the issues. In developing countries, such as Nigeria, where urbanization has increased at a rapid rate in the past four decades, solid waste disposal is addressed lightly. Africa's natural environment is very dangerous for people because people don't care about how to dispose of waste in the modern world (Afangideh et al., 2012). In contrast, one of the Western world's goals is to create a more sustainable environment. Solid waste production is an inevitable byproduct of human existence. Eliminating such waste corresponds to a higher standard of living. In order to preserve public health, solid waste management (SWM) strategies originally only sought to remove waste from the vicinity of livable places. A comprehensive program for trash avoidance, recycling, composting, and disposal is called Integrated Solid Waste Management (ISWM). An efficient ISWM system takes into account the best practices for solid waste management, recycling, and prevention in order to safeguard the environment and public health. A modern, methodical approach to solid waste

management is represented by Integrated Solid Waste Management (ISWM).

There has been a significant increase in the amount of solid waste generated in our society as a result of the rapid growth in industrialization and population in the world at large today. As a result, increased waste volumes are a result of both economic growth and a rise in the human population. Environmental concerns have been raised in major cities of most developing countries due to a lack of suitable framework, inefficient laws, insufficient basic infrastructure, and a deficient technological approach to solid waste management. The problem is that many of these wastes are not collected and delivered to the final dumping site because of inadequate infrastructure. Waste disposal patterns in society lead to the release of greenhouse gases and other pollutants, which are harmful to human health and the environment as a whole. (Nwigwe, 2008). The amount of biodegradable municipal waste that is deposited in landfills must also be reduced. That's why it's necessary to move away from simply throwing everything away in landfills and instead focus on sorting through waste to determine what can be recycled, what can be composted and what can be reused. Engineering, humanities, sociology, and biology all have a role in waste management. A country's level of development is reflected in its choice of solid waste management and the impact it has on its solid waste management (Hefa et al., 2007).

Solid waste management is the establishment of procedures and solutions that best cater to the solid waste created in a certain region. Kogi and Nigeria as a whole should implement new waste management systems that encourage waste recycling and treatment of both home and industrial waste to utilize their energy content. Poor data has caused major delays in resolving waste management issues. This is especially true in places like undeveloped countries, where there is a lack of observational capacity. This study intends to promote the optimization of database management systems as a tool for municipal solid waste management to attain a sustainable environment.

Sustainable waste management necessitates a thorough understanding of the quantity and types of waste generated. All sustainable solid waste management systems must be quantified and characterized, according to Senzige et al. Identifying the types and composition of waste at a specific location is essential to integrating recycling and resource recovery into the applicable solid waste management systems. With the use of this information, infrastructural, policy, and planning choices connected to the integrated solid waste management program may also be made. Before disposing of solid waste, it is critical to have a thorough understanding of its classification. Waste management will assist civilization and public health, environment, and sustainable development (Oyebode et al., 2023; Oyebode, 2022; Oyebode and Otoko, 2022; Oyebode, 2019; Oyebode and Abdulazeez, 2023; Oyebode, 2013; Oyebode, 2015; Oyebode, 2018).

The characteristics of solid waste are significantly impacted by improper waste disposal practices, collection, transfer, and/or transport systems (Hazra and Goel, 2009). In addition, bad route design, a lack of knowledge about collection schedules, a lack of solid waste collection vehicles, and poor roads and infrastructure are all effects of the solid waste's characteristics (Rotich et al., 2006). When it comes to treating solid waste, the authorities' knowledge of treatment processes is critical. Tadesse et al. investigated the factors that influence household waste disposal. They discovered that people's waste disposal preferences are strongly influenced by the accessibility of trash disposal facilities. According to this theory, there was a greater risk of waste being abandoned by the roadway and in open places due to a lack of waste containers and the longer distances required to deliver them (Tadesse et al., 2008).

1.1 Problem Statement

Poor waste management and improper waste disposal have been compounded by environmental issues in urban ecosystems. (Singh, 2019). A poor waste disposal, collection, transfer, and/or transport system have been shown to have a big

effect on the way solid waste looks and behave (Hazra and Goel, 2009).). Another factor that might affect the characteristics of solid waste is a lack of understanding about the collection schedule, a lack of solid waste collection vehicles, and inadequate roads and infrastructure (Rotich et al., 2006). A lack of quality data gives rise to waste management system problems. Environmental concerns have been raised in major cities of most developing countries due to a lack of suitable frameworks, inefficient laws, insufficient basic infrastructure, and a deficient technological approach to solid waste management.

Characterization and composition studies are important in waste management because they help determine which solid waste transportation, storage, and disposal methods will be most effective. In the same way, it is important to carefully look at the effects on the environment, both on nature and on people. Growing amounts of waste production and improper disposal of wastes in several unhygienic waste dumps in cities have increased the prevalence of flies, cockroaches, rodents and several pests which transmit diseases, plagues and other infections which could have catastrophic effects on the lives of the residents and the environment at large. The poor ineffective waste management of the case study of Lokoja if not looked into would lead to the loss and destruction of roads, an unhygienic environment and in a worst-case scenario, an increase in the mortality rate of the city.

Public health and the environment can be safeguarded through the proper disposal and management of municipal solid waste. The handling, treatment, and disposal of waste must be done in a manner that does not endanger public health or the environment (Oyebode, 2018). The sustainable management of solid waste will become inevitable in all phases of societal development, from planning, to design, and to operations. From different research, it is known that; The environmental sustainability of MSW management and monitoring in developing nations will be improved by incorporating geospatial data and integrated communication technologies (Olaide et al., 2018); GIS and remote sensing techniques can be used to maximize the efficiency of waste management systems. (Singh, 2019). The surface properties of waste are analyzed by the DBMS – Image Sensing System (DBMS-ISS), which yields an approximation of the waste's composition (Rahul et al., 2020).

This project aims to develop a model for effective management of waste, transportation of waste, characterization of waste, treatment, re-use, recycling, and disposal of waste in Kogi-State and this can be achieved by the integration of data management for the development and optimization of new and already existing waste management systems in Kogi-State and the country at large.

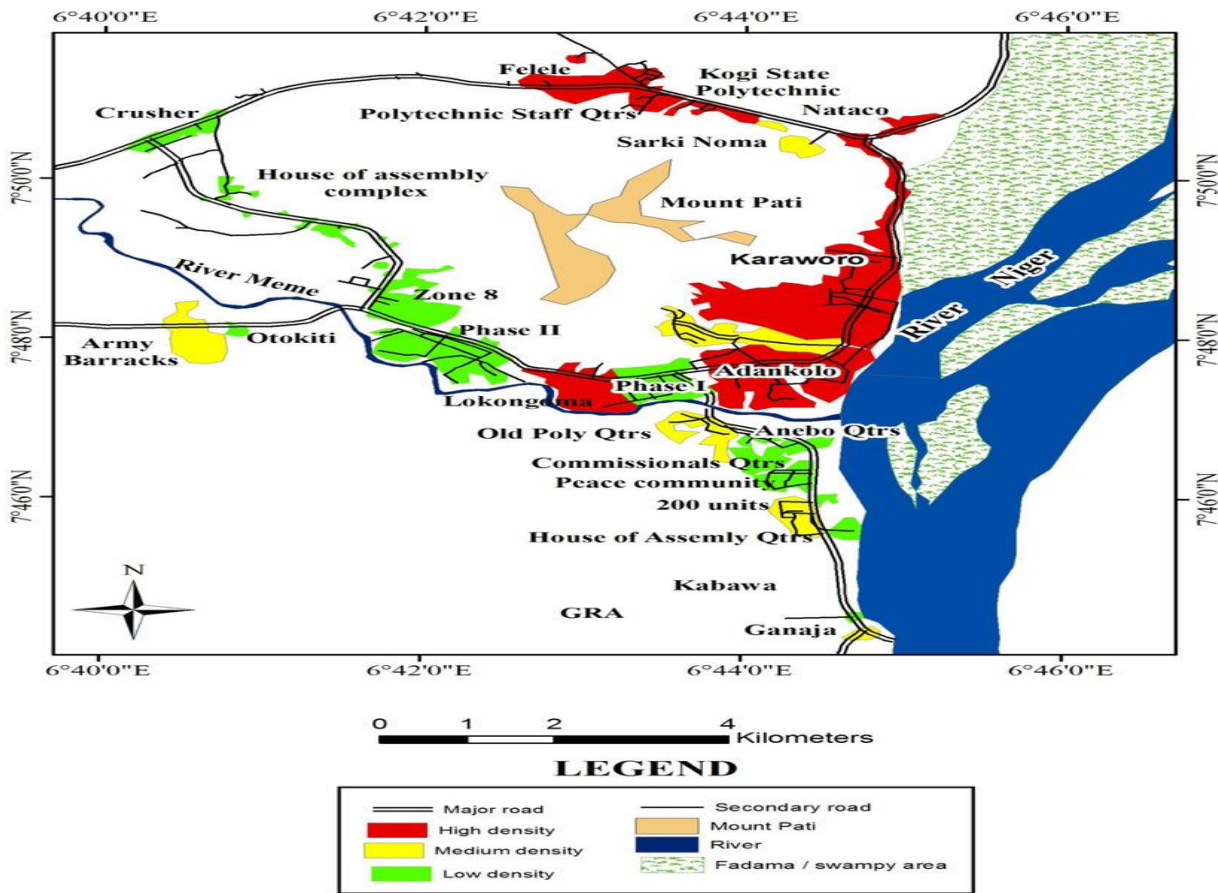


Figure 1: Map of study area showing waste distribution (Adeyinka et al. 2014)

2.0 LITERATURE REVIEW

According to the RCRA, solid waste includes anything that's thrown away by humans, such as garbage, refuse, and sludge from water supply plants, mines, and agricultural facilities.

There are several types of solid waste, including the diverse combinations of waste seen in urban areas as well as more homogeneous accumulations of paper, food waste, and packaging materials like plastic, metal, and so on, which all need to be disposed of. Construction debris, such as glass, is one example.

2.1.1 Solid Waste Management

The rate of waste generation is rapidly increasing around the world. A study by the World Bank shows that the world's cities generated 2.01 billion tons of solid waste in 2016, which results in an average of 0.74 kilograms per person per day. With the rapid growth in population and urbanization, annual waste generation is expected to increase by 70% from 2016 levels to 3.40 billion tons in 2050. Disposing of waste in unregulated dumps or openly burning it can have a devastating effect on

developing countries like Nigeria. A breeding ground for disease vectors, methane production fuels global warming, and urban violence is encouraged by these poor disposal methods. The appropriate disposal of waste is vital for the development of communities that are both sustainable and livable, but it is a problem that many developing countries and cities face (Dong, 2010).

2.1 Objectives of Solid Waste Management

The main aim of solid waste management is first to find a means of reducing and eliminating the severe impacts of waste on the environment and human health, to support economic development and a superior quality of life. According to the World Bank, the following objectives should guide a country/state in the development of any sustainable waste management system:

1. Infrastructure
2. Financial sustainability
3. Citizen engagement
4. Social inclusion
5. Health and Safety

2.1.1 Classes of Solid Waste

For this project, we'll be discussing four classes of solid waste which are listed below:

1. Municipal Solid Waste
2. Hazardous Solid Waste
3. Industrial Solid Waste
4. Agricultural Solid Waste

2.2 Municipal Solid Waste Management

"Municipal solid waste" is commonly understood as the waste accruing in a municipality (town, village, city). Municipal solid waste is a term generally used to describe mostly the non-hazardous solid waste resulting from cities, towns or villages daily activities and requires regular collection and transportation to a processing or disposal site (Olawepo, 2009). The vast majority of this solid waste is generated without any sort of segregation, so it can be both dangerous and innocuous. Waste recycling, composting, landfilling, and incineration are all part of the municipal solid waste sector. Generation, storage, collection, sorting, processing, transfer and transportation, and final disposal/utilization are the first steps in the waste management process.

1. **Waste Generation:** Everything that is done to get rid of or recycle items that have been deemed no longer useful or valuable is included here.
2. **Waste Handling and Storage:** This component includes all waste management actions up to and including the placement of waste in storage containers for collection. Before collection, on-site storage is essential due to public health and aesthetic issues.
3. **Collection:** In addition to the collecting of municipal solid waste and recyclable products, this functional element comprises the transportation of these materials to the point where the collection truck is empty. Primary, secondary, and direct collection systems for municipal solid waste are currently the norm in the majority of developing countries. Recyclables, such as glass, cans, and plastic bottles, can also be collected in separate bins.
4. **Sorting, Processing and Transformation:** Selected items are recovered from landfills, solid waste is sorted and processed in remote areas, and the material is transformed into new products away from the source of waste generation.
5. **Transfer and Transport:** This element of municipal solid waste management involves two steps:
 - i. The transfer of wastes from smaller collection mediums (e.g. bins and waste dumps) to the larger transport equipment.
 - ii. The subsequent transport of wastes to a processing or disposal site.

6. **Disposal:** Finally, municipal solid waste management has come to an end. Landfilling or uncontrolled dumping has become the final resting place for all types of solid waste, whether they are household wastes that have been collected and carried straight to a landfill or waste residues from waste combustion or composting rejections.

2.3 Hazardous Solid Waste Management

According to the EPA, simply defined hazardous waste is a waste with properties that make it dangerous or capable of hurting human health or the environment. Hazardous solid waste is waste in a solid form that creates substantial or potential threats to the environment or public health. Hazardous solid wastes are a special type of waste and should be treated as such because they cannot be disposed of by normal or common means like other solid wastes generated in our daily lives. Every year, millions of chemicals are utilized in chemical manufacturing enterprises, oil refineries, pulp and paper mills, plastics industries, and smelters, making them potential sources of hazardous waste. They can be dangerous to people's health and the environment if they are used incorrectly or inappropriately (Suleiman et al., 2020).

The following are the primal steps involved in hazardous solid waste management:

1. **Generation:** Hazardous waste generators are the initial link in the waste management chain, according to the EPA's Resource Conservation and Recovery Act (RCRA). Generators must first assess if the trash they are producing is harmful, and then devise a plan for disposing of it safely.
2. **Treatment:** Chemical, biological, thermal, and physical procedures can all be used to remediate hazardous waste. Neutralization and ion exchange are examples of chemical procedures. Some organic wastes can be detoxified and destroyed using high-temperature incineration, one of the thermal technologies at our disposal.
3. **Surface Storage and Land Disposal:** The proper disposal of hazardous waste that cannot be eliminated through incineration or other chemical procedures is necessary. Due to environmental concerns, land disposal is a common final destination for these wastes, even though it is not a desirable technique. Subterranean injection and landfilling are the most typical methods of land disposal.
4. **Secure Landfills:** Landfills for hazardous waste are regulated more stringently than municipal waste landfills. A minimum gap of 3 meters (10 feet) must be maintained between the landfill's bottom and the underlying bedrock or

groundwater table to dispose of hazardous wastes. To have a safe hazardous waste disposal, you need two impermeable liners and a collection system for the leachate (Rakesh and Gyathri, 2011).

2.4 Industrial Solid Waste Management

In the context of waste management, industrial solid waste refers to both waste generated by businesses in the course of industrial or manufacturing processes and waste generated by non-manufacturing activities. Manufacturing and industrial processes as well as service and commercial facilities generate industrial trash. Disposing of non-hazardous, non-household garbage is a complicated process that requires a comprehensive assessment. Most successful waste management systems aim to reduce, reuse and recycle as much as possible while ensuring that the environment is not harmed. The following are a few of the most successful methods for dealing with industrial waste.

- 1. Segregation and Recycling:** A company's manufacturing, shipping, and packing needs generate a lot of waste that is neither reusable nor compostable, but it can still be recycled. The first stage in any industrial waste management program is to identify what can be recycled and to put up recycling bins or dumpsters to sort it. At most recycling centers, glass, paper, and plastic can all be recycled.
- 2. Landfill:** Traditionally, industrial and household waste have been disposed of in this manner, but modern methods prioritize the recycling of all materials before disposing of the rest. Sites for landfills are carefully chosen, and there are measures in place to minimize the possibility of soil contamination. In a landfill, waste is contained in a small area, compacted if necessary, and then buried. Environmental impact is also minimized by building cost-effective landfills.

2.5 Agricultural Solid Waste Management

In agriculture, agricultural wastes are the remnants left over from the production and processing of raw agricultural products such as fruits, vegetables, and livestock. There may be useful materials in agriculture's by-products, but their economic value is less than what it costs to collect, transport, and process them so that people can use them (Obi et al., 2016; Aderoju et al., 2018). Agricultural waste, also known as agro-waste, includes crop waste (corn stalks, sugarcane bagasse, drops and culls from fruits and vegetables, prunings), food processing waste (only 20% of maize is canned, leaving 80% as waste), animal waste (manure, carcasses), and hazardous and toxic agricultural waste (pesticides, insecticides, and herbicides, among other things).

Agricultural waste can be handled in a variety of ways. Shafts from the palm oil processing industry have long been used as a source of wood fuel for home heating and cooking. A few of these waste products have recently been put to better use. Agriculture waste can be used to fill cement or water glasses, to make ethanol or animal feed, to generate power or biogas. It can also be used to mulch or compost or to remove heavy metals from the soil. Recycling agricultural solid wastes to create valuable products is an effective way to manage them (Adejumo and Adebisi, 2020; Zhang et al., 2010; Emmanuel et al., 2017; Gequinto, 2017; Cheng et al., 2007). This can be accomplished by:

- 1. Composting:** Anaerobic digestion of kitchen wastes, mainly agricultural solids from food waste, might be sterilized and used for animal feed, fertilizer, and biofuel. Composting these wastes is a viable option due to their high levels of organic matter and nutrients, however the high levels of salt, moisture, and oil may complicate the composting process.
- 2. Non-Conventional Feed Ingredient:** Several attempts have been made to feed agricultural solid wastes to cattle as a recycling method and a cheap supply of feed for raising animal-source protein. Agricultural solid wastes such as mushrooms, feathers, dried sweet oranges, and many others are useful in the production of feed for livestock due to their high protein and mineral contents.
- 3. Production of Silica:** Silica and silicates are formed by silicon, the second most prevalent non-metallic element in the Earth's crust. As a result of its propensity for oxygen, it is extremely rare to come across it in its elemental state. Many foods contain this trace element, which is said to provide health benefits. Vitamin E has numerous health benefits, including a reduction in the risk of atherosclerosis and a boost in immunity, bone mineralization as well as bone calcification. (Martin, 2007).

Alternative Energy Source and Bio-Fuel Production:

Agricultural solid wastes can be transformed into green energy by anaerobic digestion, providing an alternative energy source and biofuel generation (Bracco et al. 2018). Anaerobic digestion's stability may be jeopardized by the high protein and fat content of these wastes, as well as a lack of efficient technology for disposing of biogas residues.

2.6 Waste Analysis and Characterization

Analyzing your waste stream's composition to determine the volume of various elements such as paper, glass, and food scraps is known as waste characterization. Waste characterization data helps in the formulation of trash reduction plans, the

establishment of recycling systems, and the conservation of resources. Solid waste planning is aided by waste characterization data (Bhalla et al., 2012). Every municipality must therefore have trustworthy data on waste management to conduct informative and critical assessments of waste before they can be subjected to any effective trash utilization and management processes. Many cities and municipalities around the country do not have access to these basic facts. Most of the data that cities say they have is contradictory because it is based on assumptions instead of scientific measurements and comes from sources that haven't been checked and can't be trusted (Gentil et al., 2011). Waste management efforts around the country are sometimes hindered by unconfirmed data, which can cause confusion and scepticism. Waste Analysis and Characterization Study (WACS) is the best source for accurate data on waste management because of this (Chung and Poon, 2001). Waste Analysis and Characterization would require that all the waste produced be divided into 4 classes which include;

1. Reusable Waste
2. Recyclable Waste
3. Compostable(Biodegradable) Waste
4. Residual Waste

2.5 Waste Minimization

Waste minimization is a technique to reduce the quantity and toxicity of the trash that is generated in the first place. All wastes, not just hazardous wastes, should be minimized by the Environmental Protection Agency (EPA). Waste minimization methods that focus on preventing waste from ever being created are source reduction and recycling. Most processes that create waste can use these methods at different points, but they require careful planning, creative problem-solving, changes in behaviour, financial investment, and a real commitment to the cause. Waste generation can be kept at a minimum by using the 3 R's principle; Reduce, Reuse, and Recycle.

1. **Reduce:** Waste prevention means using and disposing less. This is a successful method of reducing waste generation. Purchasing good, long-term environmentally friendly goods; products and packaging that are free of toxins, backyard composting, using double-sided copying papers, and redesigning products to use less raw materials in production are some of the various practices that have yielded substantial environmental benefits.
2. **Reuse:** This refers to the process of reusing items which could involve donating said items to charity, repairing them or selling them. Engineers should do well to reuse existing materials and structures in this area, significantly reducing resource requirements while cutting waste volumes and saving money.

3. **Recycling:** To cut down on the amount of new materials needed and the amount of waste going to landfills, it is preferable to use leftover or near-end-of-life resources as raw materials. Batteries, yard waste, and paper and paperboard are all examples of recycled resources. Through drop-off sites, deposit systems, and buy-back schemes, these and other materials can be reused (Sara et al., 2008; Oyenuga, 2015).

3.0 METHODOLOGY

3.1 Study Area

Located at the confluence of the Niger and Benue rivers, Lokoja is the state capital. Farmers can ship their produce from the state's riverine regions to Lokoja, where most of the state's people dwell, through these two rivers. Like many Nigerian cities, Lokoja Metropolis has had a significant increase in its population during the past three decades. The rapid growth of the city's population, which has led to more demand for goods, is a direct cause of a rise in waste production.

3.2 Reconnaissance Survey

A reconnaissance survey of Lokoja was carried out to get familiar with the area, and locate all dumpsite locations and different sources of waste. With this, the study area was divided into three residential densities which include; high residential density, medium residential density and low residential density (which is equivalent to high, medium and low waste generation areas).

3.3 Waste Analysis and Characterization Study

There are 5 major activities carried out in this stage namely:

1. Collection of waste samples from every waste dump in the city in a plastic bag. This is repeated for 7 consecutive days of the week to capture every scenario and possible behaviour of citizens.
2. The collected waste samples are delivered to a sorting area; all collected samples from each day are weighed. The net weight of the waste is obtained and recorded.
3. The wastes are sorted out into; recyclable, compostable (biodegradable), reusable and residual (incineration and disposal) wastes.
4. The segregated wastes are put in different containers and are weighed to obtain their respective weights.
5. The weight and volume of each characterized weight were obtained concerning any 1 cubic meter of random waste sample collected. All waste collected will be properly disposed of.

Figure 2 presented Waste collection from a dumpster.



Figure 2: Waste collection from a dumpster

Solid Waste Management Design

Waste management, which includes waste collection, separation, transfer, disposal, and recycling, can be regarded as a strategic concern for any government. To a considerable extent, having a robust disposal and recycling supply chain is beneficial in preventing environmental

contamination. We would apply the waste management hierarchy approach designed by the USEPA for this study, which advocates waste reduction first before any other practice, and then proper waste disposal when all other choices have been exhausted, which range from reuse and recycling to treatment and composting. For final waste disposal, this study uses a landfill system.

Figure 3 presents a Solid waste management design.

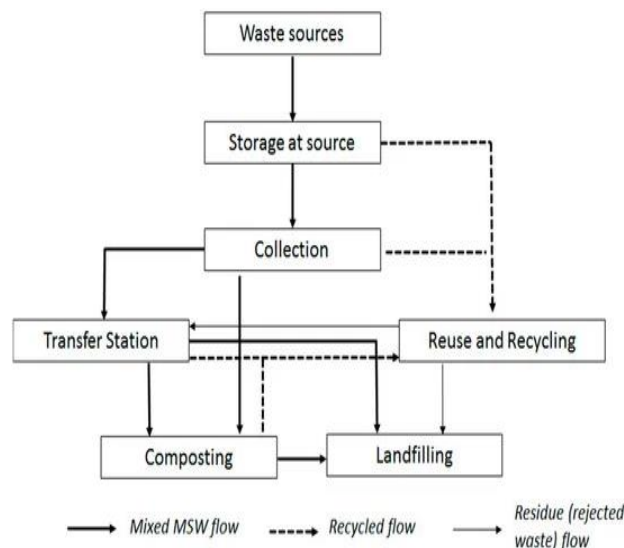


Figure 3: Solid waste management design

3.5 Calculation of Total Waste Generated

The total waste generated is obtained from the State Ministry of Environment and is used to calculate the different percentages of recyclable, compostable (biodegradable), reusable and residual (incineration and disposal) wastes generated in Lokoja; the values obtained will help calculate the volume, total mass and design life of landfills, recycling plants and waste-to-energy facilities that would be needed for an effective solid waste management system. It would also help determine the number and sizes of

waste bins and dumps needed around the city, and how they should be labelled and the amount of waste trucks needed to transport total waste generated daily.

3.6 Collection and Sorting

At every dump site in the city, there would be 3 large waste bins labelled 'Recycle', 'Compostable' and 'Residual'. This helps the citizens know how to dispose of the wastes they have already sorted in the right bins. The amount of waste generated

determines the amount of trucks that would be required for effective waste management and their respective capacities. All wastes collected would be brought to a sorting site for further and more intensive sorting. Every other solid waste that cannot be utilized will end up in the landfill.

3.7 Landfill Planning and Design

Waste is disposed of in landfills that have been carefully planned and are meticulously maintained. Landfills are placed, designed, managed, and monitored by federal regulations. The construction of landfills in environmentally sensitive areas is prohibited, and those that are built must be accompanied by environmental monitoring equipment on-site (Emmanuel et al., 2018). The process of planning and designing a landfill consists of the steps listed below:

1. PLANNING:

a) Site Selection criteria:

Landfill site selection should meet the following criteria;

- >200m away from a lake or pond
- >100m away from a river
- >500m away from a highway
- >500m away from human habitation
- >500m from a water supply well
- >3000m to 20km away from an airport
- Shouldn't be around a critical habitat
- Shouldn't be around a wetland
- Should have a protective embankment

A site projected for the development of a landfill should preferably be located in areas having:

- Low population density
- Clay content in the sub-soil
- Low groundwater contamination potential
- Low alternate land use value

b) Site Investigation Criteria:

- Subsoil investigation: type of soil, GWT and bedrock depths, permeability of various strata, strength parameters, and extent of liner material availability
- Groundwater / Hydrogeological Investigation: GWT Depth, GW Flow Direction, and GW Quality Parameters at Baseline
- Hydrological Investigation: To estimate runoff quantities to build drainage infrastructure that is appropriate.
- Geological and seismic investigations: are conducted to determine the bedrock profile underlying the landfill base.

c) Factors to be considered for deciding the section of a landfill:

- The area's general topography

- Depth to the groundwater table from the proposed landfill's base
- Liner and cover material are readily available in the area.

2. **DESIGN:** The following steps are involved in the design of a landfill

a) The evaluation of the landfill capacity and the factors used to determine this:

- Volume of waste
- Volume occupied by liner and cover (daily, intermediate, final)

b) Liner System: The purpose of a liner system is to keep leachate created inside a landfill from reaching the soil and groundwater beneath the landfill. The purpose of a leachate collecting facility is to:

- Remove leachate from a landfill using a liner system and treat and dispose of it.
- Control and reduce the amount of leachate in the landfill.
- Damage to the liner system should be avoided.

Landfill liners comprise Compacted clays, Geomembranes, Geosynthetic clay liners, and Combinations of them.

c) Leachate Collection System: A leachate drainage network and a leachate removal facility are part of a leachate collection system. Coarse-grained soils, perforated pipes, and geotextile drainage layers make up drainage networks. A drainage removal system is made up of sumps, wells, and pumps.

d) Gas Collection and Treatment: Landfill gas has the potential to move laterally and produce explosions. As a result, gas collection and processing facilities are installed at landfills. Depending on the operating process, the rate of gas generation fluctuates (Rakesh & Gayathri, 2011). It's difficult to forecast the rate and quantity of gas production over time.

e) Cover System: The cover of a landfill is usually made up of many layers. The final cover system's goal is to improve surface drainage, reduce infiltration, and provide vegetative support. Most landfill designers prefer to utilize a geo membrane liner as a barrier layer to limit the entry of surface water and regulate the emission of waste gases.

4.0 RESULTS AND DISCUSSIONS

A two-day reconnaissance survey and a seven-day Waste Analysis and Characterization Study (WACS) to accurately were done to determine waste disposal behaviour for all seven days of the week, as well as a recommendation for the design of a waste management system as a solution to some of the environmental challenges that citizens of Lokoja,

Kogi-state, face. The results are displayed in charts and tables.

Sources and Types of Waste Generated

Every day, a significant amount of solid waste is deposited at various waste disposal sites. A wide range of agricultural operations, as well as private residences, schools, businesses, and other public institutions, generate this waste. Waste disposal

facilities generate a nasty odour if they are not properly stored and treated. Among Lokoja's major sources of solid waste are the following:

1. Households
2. Commercial Facilities
3. Institutions
4. Municipal Services
5. Medical Facilities

Location of Waste Dumps

Table 1: Location of dumpsters

Area of Dumpster	Dumpster Number
Adankolo	AD1
Phase 2	PH2
Felele	FL3
Lokongoma	LK4
Karaworo	KR5
Karaworo	KR6
Barracks	BR7
Zone 8	ZN8
Old Poly Qtrs	OPQ9
Kabawa	KB10
Otokiti	OT11
Nataco	NT12
Crusher	CR13

Source: (Fieldwork, 2022)

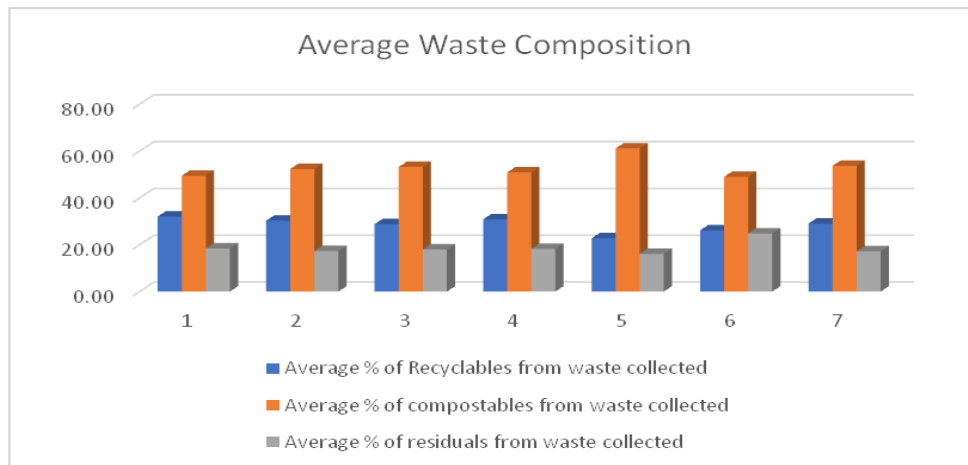


Figure 4: Bar chart of average waste composition

Table 4.9: Average daily waste composition

DAY	Average amount of waste collected(kg)	Average % of Recyclables from waste collected	Average % of compostable waste collected	Average % of residuals from waste collected
1	17.97	32.07	49.50	18.43
2	18.53	30.32	52.36	17.31
3	19.05	28.81	53.22	17.96
4	18.46	30.85	50.90	18.24
5	17.80	22.76	61.14	16.09
6	20.07	26.13	49.04	24.83
7	17.75	29.03	53.73	17.19
Total Average	18.52	28.57	52.84	18.59

Source: (Fieldwork, 2022)

The tables above show the result of the waste analysis and characterization study (WACS) carried

out for more than 7 days. Waste samples were collected from 13 different dumpsters across the

city which was characterized into recyclable waste, compostable waste and residual waste which produced the following results: Average, 28.57% of waste generated in Lokoja is regarded as recyclable wastes which are further characterized into glass, paper, plastic, polythene, metal and textiles. Majority of the waste generated in Lokoja are characterized as compostable waste which includes all forms of food and organic wastes, this makes up

for 52.84% of the total waste generated within the city. Figure 5 presents the bar chart of daily waste collection.

Wastes that cannot be characterized as either recyclable or compostable are characterized as residual wastes which include P.H.W (potentially hazardous waste), ashes/dust, rubbles, etc. and this makes up an average of 18.58% of wastes generated in Lokoja.

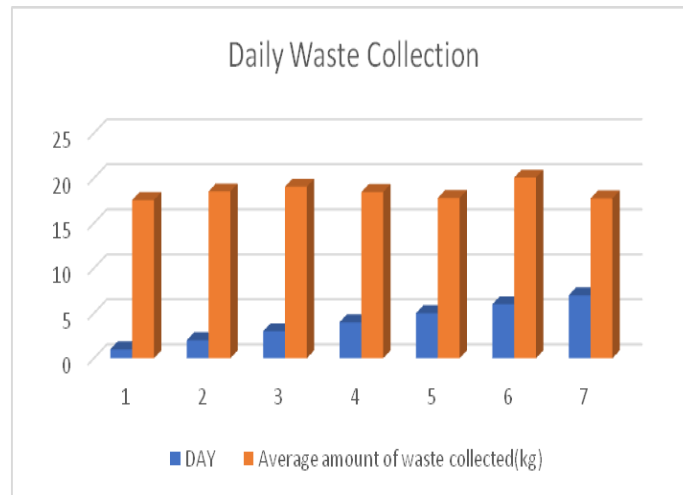


Figure 5: Bar chart of daily waste collection

The chart above shows the distribution of the amount of waste collected on each day of the WACS; 17.97 kg of waste was collected on day 1, 18.53 kg on day 2, 19.05 kg on day 3, 18.46 kg on day 4, 17.80 kg on day 5, 20.07kg on day 6 and 17.75 kg on day 7 of the WACS. A total 129.63 kg of waste was collected over 7 days and an average of 18.52 kg was collected daily.

Table 4.10: Recyclable waste composition

	Weight(kg)	% Composition
Total Amount of recyclable waste collected	36.88	100
Glass	4.29	11.65
Paper	7.55	20.46
Plastic	9.91	26.86
polythene	8.98	24.35
Metal	2.63	7.15
Textiles	3.52	9.53

Source: (Fieldwork, 2022)

The recyclable wastes were further characterized to determine the composition of all wastes classified as recyclable waste. It was found that recyclable waste has the following composition; Glass - 11.65%,

Paper - 20.46%, Plastic, 28.86%, polythene - 24.35%, Metal, 7.15% and Textiles - 9.53%.

Table 4.11: Residual waste composition

	Weight(kg)	% Composition
Total Amount of residual waste collected	21.08	100
P.H.W	7.32	34.72
Ashes/dust	2.81	13.34
Rubble	4.69	22.26
Others	6.26	29.68

Source: (Fieldwork, 2022)

The residual wastes were also further characterized at the end of the WACS. Potentially hazardous wastes (P.H.W) have the highest composition of all

hazardous waste collected with 34.72%, ashes/dust and rubbles have a composition of 13.34% and 22.26% respectively and other forms of residual waste constitute 29.68%.

Figure 6, Figure 7 and figure 8 are very essential for effective integrated waste management.



Figure 6: Options in the Waste Hierarchy

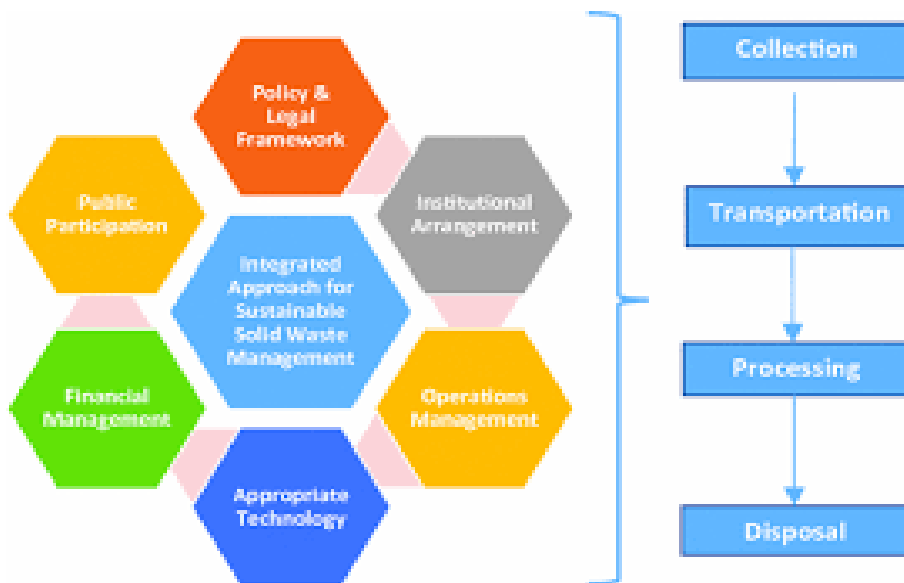


Figure 7: Important aspects of sustainable waste management

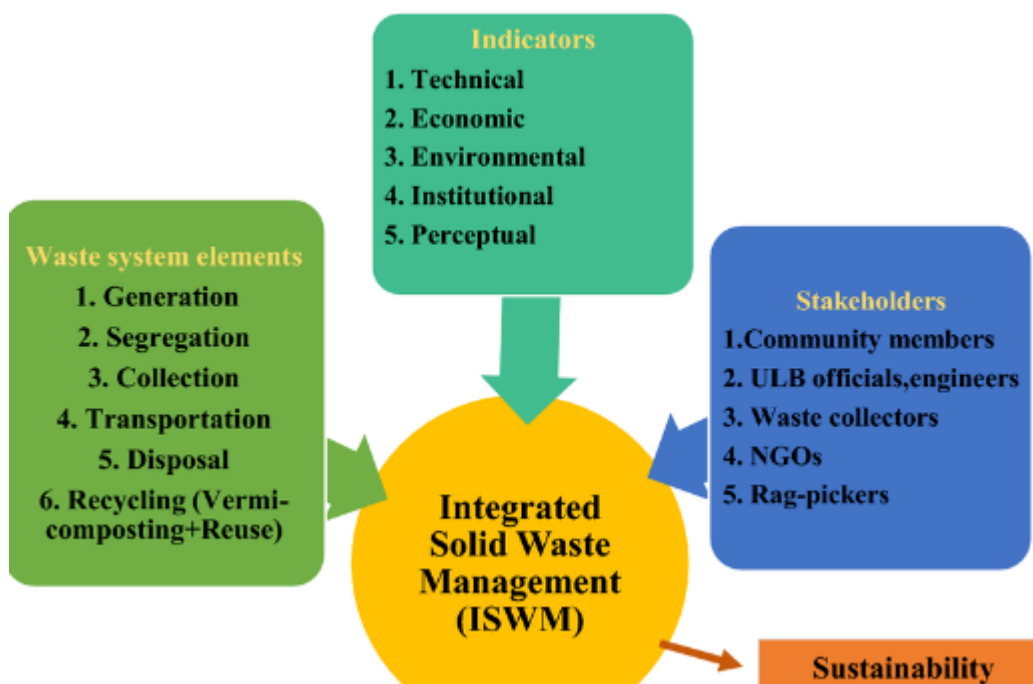


Figure 8: Dimensions of integrated solid waste management

4.4 Waste Generation

Getting data for the amount of waste generated per day in the city was not possible as the state Ministry of Environment did not have the data. A research found that the average amount of wastes generated by residents in Abuja ranges from 0.5kg – 1.5kg per day per capita (Kadafa, 2017). Another research conducted by the World Bank found that humans generate an average of 0.74kg per day but could also range from 0.11kg – 4.54kg per day. Waste

generation in Nigeria is estimated at 0.65-0.95kg/capita/day (Ike et al., 2018). With this data estimation of the total waste generated per person per day and total waste generated in Lokoja is possible. According to Macrotrends and World Population Review, Lokoja has a population of 791,580 people. This would be used to calculate the total amount of waste generated per day and per year and to provide a forecast of population increase and increase in waste production for the design of a suitable landfill.

CALCULATION:

W = Estimated waste generated per person per day = 0.80kg

P = Total Population of Lokoja = 791,580 people

Estimated total waste generated per day = P * W

= 0.80 * 791,580

Estimated total waste generated per day = 633,264kg

VOLUME-WEIGHT RELATIONSHIP:

$$V = \text{Volume of basket} = \frac{1}{4}\pi d^2 h$$

d = 0.38m, h = 0.52m

$$V = \frac{1}{4} \times 3.142 \times 0.38^2 \times 0.52$$

$$V = 0.059m^3$$

Weight of basket = 2.8kg

$$\text{Total volume of waste generated per day} = \frac{\text{Volume of basket} \times \text{Total weight of waste generated per day}}{\text{Weight of basket}}$$

$$\text{Total volume of waste generated per day} = \frac{0.059 \times 633,264}{2.8}$$

Total volume of waste generated per day = 13337.88m³/day

VOLUME DISTRIBUTION OF WASTE:

Recyclable Waste = 28.57% = 3810.63m³/day

Compostable Waste = 52.84% = 7047.74m³/day

Residual Waste = 18.59% = 2479.51m³/day

4.5 Waste Collection and Sorting

Accredited waste dumpsters in Lokoja are located along important traffic intersections, where they are transported by public waste disposal vehicles to an approved dump site on the city's outskirts. Some Lokoja residents report that they load their waste in polythene bags for days until they are full before

carrying them to the waste collection locations. Another undesirable way of waste disposal among certain Lokoja locals is the transportation of solid waste to designated dump sites on motorcycles. These waste disposal methods are unsanitary for any country attempting to attain long-term environmental progress.

The current waste collection system consists of a total of 13 accredited dumpsters and 3 waste disposal trucks that collect waste once a day.

$$\text{Average capacity of dumpster} = L \times W \times H = 4.2 \times 2.3 \times 1.2 = 11.6m^3$$

Total capacity of dumpsters = $11.6 \times 13 = 150.8m^3$

The average waste disposal truck has a capacity of $24m^3$

Total capacity of waste disposal trucks = $24 \times 3 = 72m^3$

This shows that out of a total of $13337.88m^3$ of waste generated daily, only a maximum of $150m^3$ is properly collected and disposed of at the city's final dump site. The majority of wastes generated are disposed of in unsustainable and unsanitary ways such as open burning and disposal in drainages and water bodies.

The state does not have an existent waste sorting practice. The only form of waste sorting is carried out by scavengers and waste pickers who gather scrap metals and plastic for sale.

4.6 Modal Consideration for Waste Disposal

To achieve sustainable environmental progress there has to be a shift from the various unsanitary waste transportation and disposal methods to more effective waste transportation and disposal methods. The integration of scavengers and waste pickers into the state waste management system would help in the safe, efficient and daily transportation of municipal wastes from houses,

Capacity of 1 dumpster = $11.6m^3$

Capacity of 1 waste disposal truck = $24m^3$

Total waste generated per day = $13337.88m^3$

Estimated number of truck runs per day = 3

Therefore, the dumpster is emptied 3 times a day

Estimated amount of waste a dumpster can hold in 1 day = $3 \times 11.6 = 34.8m^3$

The estimated amount of waste disposed by a single truck per day = $3 \times 24 = 72m^3$

Total number of dumpsters needed = $\frac{13337.88}{34.8} \approx 385$ dumpsters

Total number of disposal trucks needed = $\frac{13337.88}{72} \approx 190$ trucks

Waste sorting is achieved by means of environmental awareness where the citizens are sensitized on how to characterize and package their waste before disposal and at every dumpsite there are 3 different bins labelled; 'Recycle', 'Compost', and 'Residual'.

4.7 Landfill Design Capacity

The estimation for the capacity of a landfill (area/height/volume) is carried out using the following steps;
Active life of landfill = $n = 10$ years

Waste generation rate (per year) = $W = 365 \times 2479.51 = 905021.15m^3$

Assuming a 5% increase in population and waste production;

Total volume of waste = $V = (W \times n) + 5\%(W \times n)$

$V = (905021.15 \times 10) + \frac{5}{100} \times (905021.15 \times 10) = 9502722.075m^3$

offices and other institutions to the accredited waste dumpsters. Current waste dumpsters can only collect $150m^3$ of the $13337.88m^3$ of waste generated; therefore, there is a need for more dumpsters in the city. There is also a need for an increase in the number of waste disposal trucks. Waste sorting can also be achieved on-site.

Volume of daily cover = $0.1V = 950272.2075m^3$

The volume of liner and final cover = $0.25V = 2375680.519m^3$

Total volume (landfill capacity) = $C = V + 0.1V + 0.25V$

$C = 950272.2075 + 950272.2075 + 2375680.519 = 12828674.8m^3$

Assume $C = 13000000 m^3$

The recommended capacity for any landfill to be constructed is $13000000 m^3$.

5.0 Conclusions

Today, solid waste management is a major concern in most developing nation and this can be handled by integrated and sustainable waste management. The high rate of industrialization and population growth has resulted in a large increase in solid waste generation, with the government exhibiting little interest in the environmental consequences of poor solid waste management. In waste management, characterization and composition investigations are significant because they help to identify and plan for the most appropriate system of solid waste transportation, storage, and disposal. Meanwhile, characterization is required to identify any potential environmental consequences, particularly those affecting nature and society. With effective environmental awareness, motivation, and commitment campaigns (environmental sanitation), all stakeholders must support a proper collection system (which could include door-to-door waste pickup from houses and institutions to approved waste dumpsters throughout the city). Reduction, Reuse, and Recycling (the 3Rs) of an efficient and effective sustainable waste management are among the key techniques that comprise the Integrated Solid Waste Management (ISWM) strategy. A significant concern facing several countries worldwide is the sustainable and appropriate management (SWM) of generated solid wastes (SW). Interventions for managing solid waste in developing nations include enhancing technology, accessibility, and service operations; utilizing recycling programs and improving disposal techniques; and establishing landfills. Poor waste management can have serious implications, with death being the worst-case scenario. During this study, many challenges, problems, and positives were discovered. My findings have led me to the following conclusions:

1. Although the amount of waste generated could not be obtained from the state's Ministry of Environment, studies estimate a range of 0.5 – 1.5kg/day/capita, for the sake of this study 0.80kg/day/capita was adopted.
2. Households, commercial facilities, institutions, municipal services and medical facilities are the major sources of waste generation in Lokoja.

3. The results of the waste composition clearly show that Lokoja is mostly residential which means waste management should be taken with utmost importance, as biodegradable waste makes up 52.84% and is the most frequent waste, with recyclable and residual wastes making up 28.57% and 18.59% respectively.
4. Improper collection, storage and disposal methods were responsible for some secondary problems such as open burning, disposal into canals, drainages and water bodies, and feeding of stray animals.
5. Waste is mostly disposed of by open burning, collective wastes in a particular street, close or crescent is gathered and at a particular point and burnt, this is done by those who practice burning. Others give their waste to scavengers most of which have no idea where the scavenger disposes of the waste finally. Waste trucks only collect a negligible amount of waste generated in the city.
6. Recycling/reuse is generally a strange term to Nigerians, it's no surprise that only a few practices this in Lokoja and most of which practice to get monetary value for their waste.
7. There is little or no government involvement in the management of solid waste in Lokoja.
8. From the average composition of waste, environmental degradation, pungent odours, contamination of groundwater and also the release of greenhouse gas from open burning are the environmental impacts of the current waste management system.

5.1 Recommendations

The following are the key recommendations resulting from the waste analysis and characterization study conducted:

1. Waste sorting by individuals and on site is key, as in the later stage it will save time, cost and stress of sorting by waste disposal facilities.
2. In an attempt to reduce littering and encourage segregation and recycling. Appropriate bins for separate waste can be provided, and segregated waste collection at various communal points.
3. Environmental sanitation should be introduced and supervised by the Ministry of Environment

for more ecofriendly results, as this can also help in creating awareness.

4. From estimations calculated in this study, an average of 385 dumpsters and 190 trucks are needed to effectively manage waste in Lokoja. A landfill with an estimated capacity of $13000000m^3$ should also be constructed.
5. New recycling plants should be set up to cater for the amount of recyclable materials.
6. Introduce solid waste and recycling function which has a clear point of accountability in the organogram and one clear budget section, this is to be monitored at regular time intervals and should be modified accordingly.
7. Scavengers and waste pickers should be integrated into the state's waste management plan to help with door-to-door waste collection and to avoid cutting off their source of income.
8. Since Lokoja is mostly populated by low and average-income earners, financial tools systems and incentives that promote affordability and burden sharing between the people and government should be developed.

STATEMENTS AND DECLARATIONS

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest:

The authors declare no conflict of interest.

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