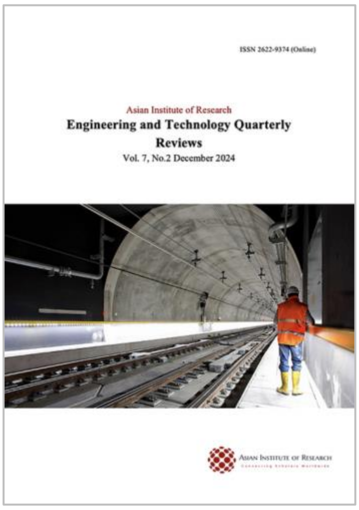

Engineering and Technology Quarterly Reviews

Batagarawa, R. L., Saleh, D., Ahmed, S., Sani, J. E., & Muazu, A. I. (2024), Status of Solid Waste Management in Kaduna and Bauchi of Nigeria. In: *Engineering and Technology Quarterly Reviews*, Vol.7, No.2, 26-40.

ISSN 2622-9374

Published by:
The Asian Institute of Research

Asian Institute of Research
Connecting Scholars Worldwide

The Asian Institute of Research
Engineering and Technology Quarterly Reviews
Vol.7, No.2, 2024: 26-40
ISSN 2622-9374

Status of Solid Waste Management in Kaduna and Bauchi of Nigeria

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Abstract
Reliable database is a requirement to support policies and decision-making for efficient solid waste management. The aim of this study is to establish the status of solid waste management by assessing solid waste generation and composition, characterization, collection methods and the effectiveness of existing practices and strategies in Kaduna and Bauchi State. A structured questionnaire was employed to gather data on waste management practices and awareness, willingness to sort at source and to pay for proper waste management. Solid waste generation, composition and characterization including bulk density, moisture content, were established by site and laboratory analysis. 100 houses per city were surveyed in Bauchi and Kaduna with the population of 669 and 675 respectively. 0.25kg/capita and 0.35 kg/capita were recorded in Bauchi and Kaduna respectively. The waste is predominantly food waste for both Bauchi (47.1%) and Kaduna (53.5%) and recyclable fractions of 29.4% and 26% respectively. Bulk density was established at 412.3 kg/m3 and 407.8 kg/m3 for Kaduna and Bauchi with moisture content at 40% and 60%. Calorific values and volatile solids obtained were 10.3MJ/kg and 46% for Kaduna and 18MJ/kg and 50% for Bauchi. 2% of the households in Kaduna partially sort waste and 13% and 27% of the households in Bauchi and Kaduna reuse the plastic bottles. Meanwhile, 35% and 41% of the residents showed willingness to separate waste at source in Bauchi and Kaduna respectively. Although treatment at household level was nonexistent, 60% of the residents indicated a willingness to treat with adequate technical knowledge. The predominant disposal methods of open dumping and burning pose environmental and health risks, emphasizing the urgent need for improved waste management infrastructure and awareness campaigns. Despite these challenges, the community's willingness to engage in proper waste management practices underscores the potential for positive change through education and implementation of effective waste management.

Keywords: Solid Waste, Solid Waste Management, Nigeria

1. Introduction

1.1 Solid Waste Management

Solid waste management is a multi-faceted process that encompasses waste generation, waste collection, recycling, and treatment to final disposal of unwanted solid material (Allesch & Brunner, 2014). Solid waste management is a critical aspect of environmental sustainability, necessitating comprehensive strategies for minimizing waste generation, promoting recycling, and ensuring proper disposal of residual waste (Mwanza et al., 2018). Effective management of solid waste is crucial for mitigating environmental pollution, conserving resources, and safeguarding public health (Awasthi et al., 2019).

The global volume of solid waste generation has been escalating due to population growth, urbanization, and industrialization, posing significant challenges for waste management systems worldwide (Adedara et al., 2023). In low-income countries, such as Nigeria, the predominant methods of disposal are uncontrolled open dumping and burning with the severe environmental health and safety consequences – climate change, spread of diseases and encouraging urban violence (Mama et al., 2021; Voukkali et al., 2024). Addressing this issue requires integrated approaches that encompass waste reduction, reuse, recycling, and appropriate treatment methods (Babaei et al., 2015).

Promotion of waste minimization and resource recovery is an important aspect of solid waste management. Research highlights the importance of adopting sustainable consumption patterns and encouraging the reuse of materials to reduce the overall burden on waste management infrastructure (Wang et al., 2020). Implementing policies and initiatives that encourage manufacturers to design products with recyclability and durability in mind can contribute to minimizing the generation of waste at the source, thus promoting a circular economy model (Wang et al., 2020).

Furthermore, the adoption of advanced technologies and innovative waste management practices is essential for enhancing the effectiveness and sustainability of waste treatment processes. Recent studies highlight the potential of technologies such as waste-to-energy conversion, anaerobic digestion, and composting in diverting organic waste from landfills and harnessing its energy potential. Integrating these technologies into solid waste management systems can help reduce greenhouse gas emissions, mitigate environmental contamination, and recover valuable resources from waste streams (Young, 2010).

Reliable database is a requirement to support policies and decision-making for efficient solid waste management (Harir et al., 2017). Furthermore, solid waste management requires a diversified approach that encompasses policy interventions, public awareness campaigns, technological innovations, and stakeholder collaboration (Harir et al., 2017).

1.2 Solid waste generation

Solid waste generation and composition are critical components in the development of effective waste management strategies aimed at mitigating environmental pollution and promoting sustainable resource utilization (Pujara et al., 2019). Solid waste generation refers to the solid left over of all processes where materials are used (Lagerkvist & Dahlén, 2012). Solid wastes are generated from extraction of raw materials, manufacture of products and consumption (Abdel-Shafy & Mansour, 2018). Urban areas generate a significant portion of solid waste, with per capita waste generation rates influenced by socio-economic factors, cultural practices, and waste management infrastructure (Louati et al., 2019).

1.3 Solid waste composition

Municipal solid waste physical and chemical composition varies geographically and is influenced by factors such as population demographics, consumer behavior, food habits, standard of living, degree of commercial activities, and seasons (Wang et al., 2020; Kolekar et al., 2016). While organic waste, paper, plastics, and packaging materials remain predominant components of municipal solid waste, the proportion of certain materials, such as electronic waste and single-use plastics has been steadily increasing in recent years (Wang et al., 2020; Kolekar et al., 2016). By conducting detailed compositional analyses, waste management authorities can identify priority materials for recycling, composting, or energy recovery initiatives (Louati et al., 2019). Alabdraba & Al-Qaraghully (2013) summarized ranges of waste composition and characteristics for high, middle and low-income countries as shown in Table 1.

Table 1: Waste composition of high, middle and low income countries

Components	High income	Middle income	Low income
Food waste	7 - 55	20 - 65	40 - 85
Paper and cardboard	15 - 50	15 - 40	1 - 10
Plastics	2 – 20	2 - 13	1 - 11
Leather and rubber	2 - 12	1 - 5	1 - 3
Glass	4 - 10	1 - 10	1 - 10
Metals	3 - 13	1 - 5	1 - 5
Ash and dirt	5 - 20	15 - 40	15 - 50
Moisture (%)	20 - 35	40 - 60	40 - 80
Density (kg/m^3)	120 - 200	170 - 330	250- 500

1.4 Solid Waste Management

Solid waste management encompasses; temporary storage, collection, transportation, treatment and disposal (Muthuraman & Ramaswamy, 2019). Temporary storage facilities can vary from simple waste bins or containers at households and businesses to larger transfer stations or depots where waste is consolidated before further transportation (Kulkarni & Anantharama, 2020). The duration of temporary storage is commonly based on waste generation rates, collection schedules, and the capacity of the storage facility. Typically, waste remains in temporary storage for a few hours to a few days (Nanda & Berruti, 2021).

Solid waste collection is the critical and capital-intensive aspect of solid waste management covering about one-third of the total waste management capital expenditure aimed at efficiently gathering and managing various types of waste generated by residential, commercial, and industrial activities (Sharma & Jain, 2020; Hannan et al., 2020). The types of solid waste collection include curbside, communal collection (Pérez et al., 2020; Pires et al., 2019).

In recent years, advancements in technology, policy frameworks, and community engagement have reshaped approaches to waste treatment and disposal, offering innovative solutions to address environmental concerns and resource conservation (Malinauskaite et al., 2017). Waste to Energy (WtE) is a process in solid waste management where the energy content of waste materials is converted into usable energy forms such as electricity, heat, or fuel (Kumar & Samadder, 2017). This approach aims to address two critical challenges: waste disposal and energy generation. By converting waste into energy, WtE facilities help alleviate the strain on landfills, reduce greenhouse gas emissions, and contribute to the diversification of energy sources (Moya et al., 2017).

Waste to Energy facilities typically employ various technologies such as mass burn incineration, gasification, pyrolysis, and anaerobic digestion to convert solid waste into energy (Kumar & Ankaram, 2019). Examples of such facilities are the SEMASS Resource Recovery Facility in Massachusetts, USA, processes municipal solid waste (MSW) through mass burn incineration to produce electricity and the Edmonton Waste Management Centre in Alberta, Canada, integrates anaerobic digestion technology to process organic waste to produce biogas (methane) and nutrient-rich digestate (Khan et al., 2016; Giraud et al., 2021).

Recycling and Material Recovery play pivotal roles in sustainable solid waste management by diverting valuable materials from landfills, conserving natural resources, and reducing environmental impacts (Scarlat et al., 2019). Materials such as paper, plastics, textile, glass, metals, and organic waste are collected, sorted, and processed to be used as raw materials in the production of new products (Scarlat et al., 2019).

The Sims Municipal Recycling Facility in New York City, USA, one of the largest MRFs in North America, utilizes advanced sorting technologies like optical scanners and automated conveyor systems to segregate and recover recyclables (Li et al., 2022).

Landfills are a cornerstone of solid waste management systems, serving as primary disposal sites for non-recyclable and non-compostable waste materials. They represent engineered facilities designed to safely contain and manage waste while minimizing environmental impacts (Owusu-Nimo et al., 2019). The Puente Hills

Landfill in California, USA implemented a landfill gas (LFG) recovery system to capture methane emissions generated from decomposing organic waste within the landfill, which is then converted into renewable energy (Lau, 2023).

1.5 Solid waste characterization

Solid waste characterization is crucial in establishing waste management strategies, enabling authorities to devise efficient disposal methods, recycling programs, and energy recovery systems (Miezah et al., 2015). Parameters such as Total solids, volatile solids, moisture content, bulk density, and calorific value are used to characterize solid waste (Zoroufchi Benis et al., 2019).

Total Solids represent the total mass of solids in a waste sample, including both organic and inorganic components (Igoni et al., 2008). Volatile Solids (VS) refer to the portion of solids that can be volatilized at a specific temperature, typically around 550°C. VS analysis helps identify the organic component of solid waste, which is crucial for evaluating its biodegradability and potential for anaerobic digestion or composting (Tokmurzin et al., 2020).

Moisture Content influences waste handling processes and treatment efficiency. High moisture content in waste increases transportation costs, leachate production, and landfill space requirements. Conversely, low moisture content enhances the potential for incineration and energy recovery (Tupsakhare et al., 2020). Accurate moisture content analysis enables waste managers to optimize storage, transportation, and treatment operations effectively (Fatimah et al., 2020).

Bulk Density represents the mass of solid waste per unit volume, indicating its compactness or porosity (Shinners & Friede, 2018). Understanding bulk density is critical for waste storage, transportation, and landfill design. Higher bulk densities imply greater material compaction, reducing storage space and transportation costs (Shinners & Friede, 2018).

Calorific value (heating value or energy value) is the amount of energy released during the complete combustion of a substance. It is typically expressed in units such as kilojoules per kilogram (kJ/kg) or British thermal units per pound (BTU/lb) (Ozyuguran et al., 2018). The calorific value of solid waste varies significantly depending on its composition, generally, materials with higher organic content, such as food waste, paper, and wood, tend to have higher calorific values compared to non-organic materials like plastics and metals (Nwoke et al., 2020).

1.6 Solid waste management in Nigeria

The solid waste management status in Nigeria is marked by several challenges, including deficient policy frameworks, inadequate financing, and a lack of waste data and institutional arrangement (Ezeudu, et al., 2021). The current system suffers from inefficiency due to uncoordinated and poorly planned waste management strategies (Salami et al., 2019). In Lagos State, the rate of waste generation exceeds the capacity of the existing management strategies (Chidiebere et al., 2018). While the present solid waste management strategy is widely employed, it faces challenges such as population growth, urbanization, and industrialization (Nwosu & Chukwueloka, 2020). Despite these challenges, there is potential for adopting a circular economy and utilizing thermochemical conversion to convert waste-to-energy, thereby generating electricity (Salami et al., 2019; Ezeudu, et al., 2021).

Nigeria generates an estimated annual waste of 32 million tonnes annually with a 20 – 30% collection rates and a suggested per capita waste generation of 0.5kg per day (Adeniran et al., 2019; Gbadebo et al., 2022). High population increase in the country has led to an increase in solid waste generation due to housing, manufacturing industries and trade where some cities (Ibadan, Onitsha and Lagos) in Nigeria have been listed as the dirtiest places to live in the world (Ike et al., 2018). The low collection rates evidenced by waste piles on properties, drains and streets are the jurisdiction of the local authorities (Ike et al., 2018).

1.7 Solid waste management status, perception and awareness

Fereja & Chemeda, (2022) conducted a research on the status, quantification and characterization of municipal solid waste in Dilla town of southern Ethiopian as a measure towards effective solid waste management. Data collection was achieved via structured questionnaires on waste management practices from households. On-site investigations, waste segregation, and quantification were conducted. Per capita waste generation rate of 0.475 kg/capita/day was recorded, with organic waste comprising 68.40% by weight, recyclables of 5.5% and 19.60% inert fraction. Challenges identified included poor waste segregation, unsanitary landfill disposal and awareness deficit among residents. Barriers to effective Solid Waste Management (SWM) included inadequate waste fee systems, lack of trained personnel, improper collection routes, vehicle shortages, illegal disposal, and improper community container placement.

Household waste practices and perceptions of solid waste management in Panji, sub-district in Kota Bharu, Kelantan, Malaysia was assessed using a questionnaire survey across 338 households. The results of the study indicate that 95.9% of the respondents have awareness of the improper solid waste management repercussions and 50.3% of the households separate their waste at source for treatment purposes (Fadhullah et al., 2022).

Ike et al. in 2018 carried out an assessment of the status of solid waste across three cities in Nigeria – Enugu, Birnin Kebbi and Minna. Interviews, observations and questionnaires were administered to determine physical composition, collection and disposal situation. It was found that disposal methods adopted were predominantly placing at the government designated containers and sites (52%) and open dumping on roads, drainages and other open spaces. 53% of the waste is collected and transported by the private informal sector using carts while 47% was achieved by the local authorities.

A study by Bundhoo in 2018 assessed the current status of solid waste management in least developed countries and the findings show average generation of 0.56 kg/capita/day with the highest waste stream of 52% being organics and 26% recyclables. Illegal practices of open dumping and burning are recorded due to low and irregular waste collection rates. The few existing landfills were severely lacking in effective leachate or gas collection systems, with a few existing small scale composting and biogas plants, while recycling is carried out for exportation.

Kumar & Agrawal (2020) conducted a research on Municipal Solid Waste Management (MSWM) in India. They highlighted challenges arising from exponential population growth, urban density, cultural diversity, and changing lifestyles. The study identified challenges such as unsorted waste, societal attitudes, poor assessment, and inadequate strategies. The study emphasized the importance of centralized and decentralized solutions involving municipalities, informal sectors, and private agencies to achieve sustainable MSWM in Indian cities by adopting treatment and recycling strategies tailored to India's waste composition.

In a study by Olukanni et al. (2020), the public perception and attitudes towards local waste management practices in five Local Government Areas of Ogun State, Nigeria, were examined. The research utilized a survey to analyze socio-demographics, household characteristics, and solid waste disposal practices. Findings highlighted the influence of factors such as age, income, and education on perceptions and practices, with 36.6% disposing waste at open dumps. The study emphasizes the need for enhanced enforcement of environmental laws and awareness campaigns to promote proper waste management practices.

Mbah et al. (2017) assessed the active role of the informal waste economy based on an 8-year engagement in Nigerian cities. They advocate for integrating informal waste workers into Municipal Solid Waste Management (MSWM) policies, highlighting the significance of social acceptance and inclusion in post-2015 development goals. The paper called for a coherent MSWM policy in Nigeria aligned with the sustainable development goals (SDGs) to enhance livelihoods and sustainability.

In a similar finding by Olukanni & Nwafor (2019), partnerships between local governments and private operators were evaluated. The study highlighted that successful public-private partnerships relied on effective monitoring by the public sector to ensure private operators prioritized service quality over profit while stressing the importance of stakeholder engagement. Legislation and enforcement were also identified as crucial aspects of Solid Waste Management (SWM), ensuring proper waste disposal practices in Nigeria. The public sector played a vital role in facilitating private sector engagement through legislation, enforcement, and public awareness campaigns.

Several studies conducted on solid waste management in Nigeria, Ethiopia, India, and other regions emphasize the need for comprehensive research on the status of solid waste management in Nigeria looking into solid waste quantification, and characterization as well as the existing practices. Despite numerous insights into the challenges and potential solutions, there remains a critical gap in understanding the current state of waste management practices, particularly in Nigerian cities. This gap calls for focused research efforts aimed at assessing waste generation rates, composition, collection methods, and the effectiveness of existing practices and strategies.

Based on the study by Bundhoo (2018), waste generation and composition; waste transport, transfer and collection; waste management techniques; recycling and disposal need to be assessed to establish solid waste management status. Also, perceptions, practices and awareness are an integral part of the solid waste management status for modeling and prediction in the case of scarce data for proper management (Kolekar et al., 2016; Harir et al., 2017; Fadhullah et al., 2022).

2. Materials and Methods

2.1 Study Area

The status of solid waste management was assessed in Bauchi and Kaduna metropolis as 2 of the 19 states in Northern Nigeria. Bauchi state is located at latitude 10^o 17’ and longitude 09^o 49’ E, with a total land area of 49,119 km^2. The population of Bauchi State in 2015 was estimated at 6,275,523, derived from the 2006 census figure of 4,653,066, indicating a growth rate of 3.6%. (Ori et al., 2021). Bauchi states consists of 20 local government areas of which Bauchi town is among. The major economic activities of Bauchi town are retail and whole sale trading, peasant and commercial agriculture, infrastructural investment such as hotels, construction, factories, private and government firms among others, small scale businesses and other informal trades such as street hawking.

Kaduna state is located at latitude 09^o 02'N and 11^o 32'N and longitude 06^o 15'E and 08^o 38'E with a total land area of 46,053 square kilometers. Based on the population projection for the year 2021, Kaduna State is estimated to have a population of 9.4 million individuals, constituting approximately 4.3% of Nigeria's entire population (Abdussalam et al., 2023). The state was ranked number four by total area of land and number three by population. Kaduna state has 23 local government areas with Kaduna city being the capital of the state and described as 8th largest city in the country as of 2006. Farming and other forms of agriculture, small and medium scale businesses are the major economic activities taking place in the city with other manufacturing and processing businesses.

2.2 Sample size determination

Statistical technique was used to determine the sample size at 95% confidence level with 0.05 allowable error. The sample size (n) of households selected to participate in the survey was calculated using the widely utilized equation established by Cochran (1977), which is commonly adopted by numerous researcher (Fereja & Chemeda, 2022).

$$n = \frac{NZ^2pQ}{d^2(N-1) + Z^2pQ} \qquad Eq. 1$$

Where n = sample size of housing units
p = Variable of residential housing unit
Q = nonresidential houses (offices, schools, etc.) = 1 – p
N = Number of housing units (total)

Z = Standard normal variable and its value that corresponds to a 95% confidence interval equals 1.96
d = Allowable error (0.05)
10% contingency was added to allow for non-complying housing units (Fereja & Chemeda, 2022).

2.3 Sampling technique and data collection

Stratified random sampling as used by Fereja & Chemeda, (2022) was adopted, with the study area divided according to household income levels in both Kaduna and Bauchi. The households were categorized into low (65%), middle (20%), and high-income (15%) groups.

2.3.1 Generation rate

Bin bags (Fig.1) were distributed for daily generated waste collection for eight days. The waste collected for the first day was discarded to account for the waste that was generated prior to the commencement of the study. Each household population was recorded as well. Solid waste samples were taken from all households and transported to selected sorting station for waste segregation and composition analysis daily (Fig. 2)
Daily per capita waste generation was determined using Equation 2

$$waste\ generated\ per\ \frac{capita}{day} = \frac{Total\ weight\ of\ waste\ generated\ by\ each\ household}{Total\ population\ of\ the\ households} \left(\frac{\frac{kg}{capita}}{day}\right) \qquad Eq. 2$$

Figure 1: Bin bags collection

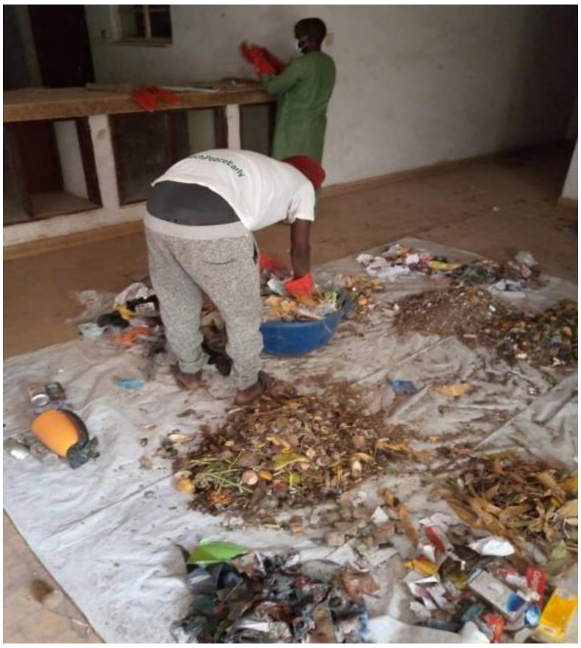

Figure 2: Solid waste sorting

2.4 Solid waste composition and characterization analysis

2.4.1 Solid waste composition

The composition of the waste was determined with a 50kg of thoroughly mixed solid waste on approximately 24m^2 polythene sheet placed on the ground to avoid loss of moisture. The waste was sorted into food waste, green waste plastics, textile, paper, glass, metals and other waste (Sand, fine organics, ash, and dust, Construction and demolishing waste, batteries, paints, and any other waste fraction that did not fit in other categories). Each waste fraction was weighed to determine its mass and consequently its percentage using equation 3;

$$Percentage\ of\ the\ waste\ fraction\ = \frac{weight\ of\ the\ waste\ fraction}{Total\ weight\ of\ the\ sorted\ waste} \times 100 \qquad Eq. 3$$

2.4.2 Bulk density

The bulk density of the waste was determined by obtaining the mass of 25 bin bags containing the waste in a container of 0.12 m^3 volume. After obtaining the mass, the density was determined using an equation; $Bulk\ density = \frac{mass}{volume} \qquad Eq. 4$

2.4.3 Moisture content

Moisture content was measured from mass loss of sample after 2 hours at 105^0C in an oven under nitrogen purge. Solid waste sample was weighted before and after oven drying to establish the moisture content using Eq 5

$$\%MC = \frac{Wc - Dc}{Dc - W} \times 100 \qquad Eq. 5$$

Where
Wc is the weight of the wet sample + container
Dc is weight of sample (oven dried) + container
W is the weight of the container
MC is the Moisture Content

2.4.4 Volatile solids

Volatile solid was determined by heating the oven dried samples covered with lid in a muffle furnace at 850^0C. N_2 purge line and thermocouple were inserted through the top of the furnace and down into the stainless steel box through a small hole in the box cover. The box was purged with N_2 for about 5mins at a flow rate of $5Lm^{-1}$. After the initial purge, the N_2 flow rate was decrease to 3 Lm^{-1}, the furnace was set to the desired peak separation temperature of 850oC. The temperature in the furnace was measured every 60s during the heating period and the furnace switched off once the separation temperature is attained. The sample was weighed and the VS determined using Eq. 6

$$Volatile\ solid = \frac{Wtotal - Wvolatile}{Wtotal - Wdish} \times 100 \qquad Eq. 6$$

Where
Wdish = Dish Weight in mg
Wtotal = dried residue Weight and dish weight in mg
Wvolatile = Residue weight and dish weight after ignition in mg

2.4.5 Total solids

Total solid was determined by heating the sample in an evaporating dishes at 550^0C for 1 hour in a muffle furnace purged with N_2 for over 10 minutes at a 1 L min^{-1} flow rate of to ensure removal of all oxygen, the sample was transferred immediately to desiccator, left to cool for 10 minutes and weighed. This was done continuously until constant weight was realized then the oven was turned off.

$$Total\ solids = \frac{Wtotal - Wdish}{Wsample - Wdish} \times 100 \quad Eq. 7$$

Where;
Wdish = Weight of dish (mg)
Wsample = Wet sample Weight and dish weight in mg
Wtotal = dried residue Weight and dish weight in mg

2.4.6 Calorific value

The Bomb Calorimeter (Model 6100, Bomb Calorimeter, Parr Instrument, and Moline, Illinois) was used to calculate the sample's Calorific Value. By burning a known mass of standard benzoic acid, which has a known heat of combustion of 26.453 Kj/g, the Bomb calorimeter was calibrated. Using an oxygen bomb calorimeter, the gross heat of combustion was determined in accordance with ASTM D2382-88 standard technique. One milliliter of deionized water and a weighted sample weighing roughly 0.1 grams were added to the calibrated adiabatic bomb calorimeter. In order to ignite the sample, a Chromel (chromium nickel alloy) wire was attached to the two electrodes in the pressure vessel (bomb) and brought into contact with it. The bomb was then put together, sealed, and purified twice by pressurizing it to 0.5 MPa with pure oxygen (99.99%), venting it afterwards, then pressurizing it to 2.0 MPa for the test using pure oxygen. Finally, it was placed inside an insulated jacket-clad bath that held two liters of water. To maintain a consistent temperature throughout the water around the bomb, a motorized stirrer was inserted into the water bath. After that, an electric current was run through the Chromel wire to ignite the sample, which caused it to burn completely in the high-pressure oxygen. Then, to act as a thermal shield, the bomb and the bucket were placed inside a calorimeter jacket. Depending on the unit used, the result was shown in either (Cal/g) or (MJ/kg) on the display.

2.4.7 Current practices, awareness and perception of solid waste management

A structured questionnaire was administered in a structured survey to household residents. This method was employed to gather data on the prevailing waste management practices and awareness by evaluating sorting of waste at source, practices of temporary storage, types of waste disposal, willingness to sort at source, re-use, in situ treatment, waste management awareness, and willingness to pay for proper waste management. Other data encompass gender, age, educational level, marital status, family size, income level. These questionnaires consisted of both open-ended and closed-ended questions. Physical field observation was carried out to assess the current practice of solid waste management in the area.

3. Results and Discussion

3.1 Sample size

100 houses were identified for the survey in both Bauchi and Kaduna with the population of 669 and 675 respectively

3.2 Solid Waste Quantity and Composition

The daily waste generation ranges from 0.18 kg/capita to 0.28 kg/capita in Bauchi and 0.33 kg/capita to 0.36 kg/capita in Kaduna with an average of 0.25kg/capita and 0.35 kg/capita in Bauchi and Kaduna respectively. These generated rates are in close range with the suggested waste generation value of 0.5kg/capita.day in Nigeria by Adeniran et al., (2019) and Bakare (2022). Also similar to the findings in Dilla (Southern Ethiopia) of 0.475kg/capita day, 0.35 kg/capita day in Bonga town of Ethiopia, 0.18 kg/capita day from Bishoftu town, 0.43 kg/capita day from Gondar town of Ethiopia and 0.233 Kg/capita day for East African cities developed by WHO (Fereja & Chemeda, 2022).

Table 2: Waste Generation in Kaduna and Bauchi

Kaduna			**Bauchi**	
Days	Daily total weight (kg)	Daily per capita generation (kg/capita.day)	Daily total weight (kg)	Daily per capita generation (kg/capita.day)
Day 1	239.03	0.35	173.78	0.26
Day 2	239.95	0.36	129.93	0.18
Day 3	226.46	0.34	173.01	0.26
Day 4	228.23	0.34	163.95	0.25
Day 5	232.28	0.34	161.91	0.24
Day 6	224.42	0.33	184.33	0.28

Day 7	245.65	0.36	186.32	0.28
Average		0.35		0.25

The generated solid waste in Kaduna (Fig 3) is predominantly food waste at 53.5%, other fractions include plastics (18.24%), textile (4.48%), paper (2.14%), green waste (2.02%), metals (0.62%), glass/ceramics (0.61%) and other waste (18.41%). Similarly, solid waste generated in Bauchi was found to be food waste (47.1%), plastics (16.5%), green waste (2.5%), paper (3.3%), textile (7.7%), metals (0.9%), glass/ceramics (1%) and other waste (21%) as shown in Figure 3

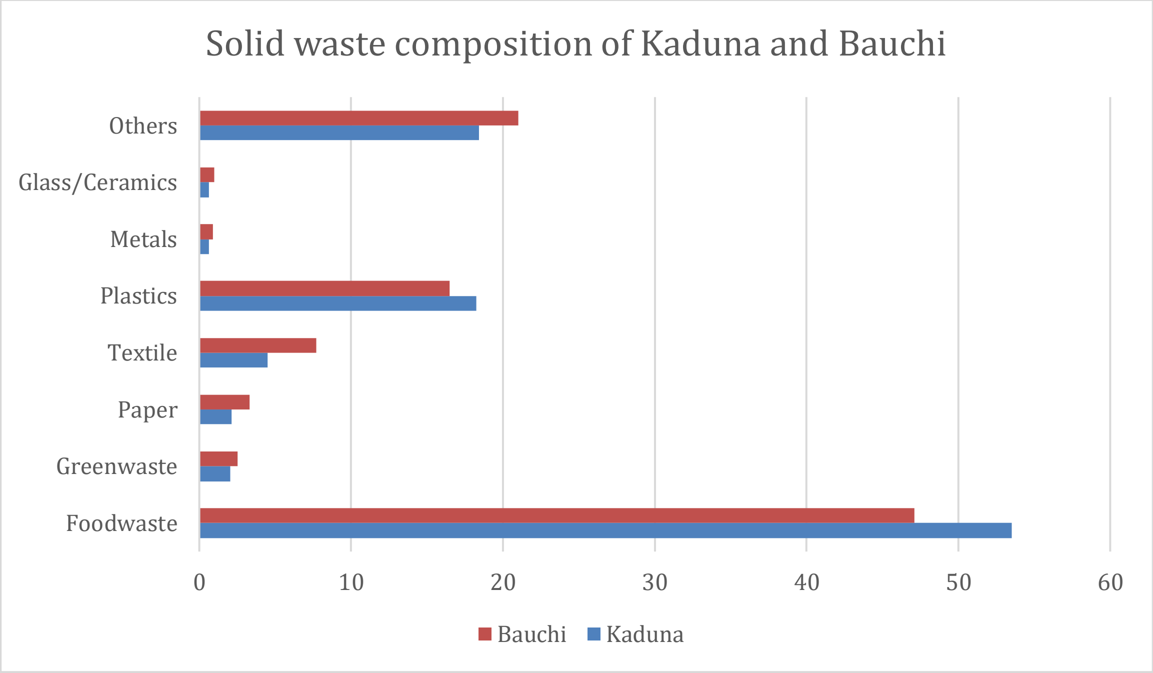

Figure 3 Solid waste composition Kaduna and Bauchi

3.3 Solid Waste Characterization

3.3.2 Bulk density

Table 3: Bulk density of solid waste in Kaduna and Bauchi

	Bulk density (kg/m3)	**Weight of solid waste (kg)**		**Bulk density (kg/m3)**	**Weight of solid waste (kg)**
Kaduna	408.7	49.04	**Bauchi**	398.5	47.82
	357.7	50.08		436.3	52.35
	459.7	55.16		415.2	49.82
	458.8	55.06		408	48.96
	385.1	46.21		398.3	47.8
	410.3	49.23		388.7	46.64
	418.6	50.23		409.3	49.12

*Average bulk density is 412.3 kg/m^3 and 407.8 kg/m^3 for Kaduna and Bauchi respectively
*volume of the solid waste is 0.12m^3

The uncompacted bulk densities of solid waste in Kaduna range from 357.1 kg/m^3 to 459.7 kg/m^3 with an average of 412.3 kg/m^3 (Table 2). That of Bauchi is in the range of 388.7 kg/m^3 to 436 kg/m^3 and 407.8kg/m^3 average. These values are higher than bulk density obtained in Dilla town Ethiopia of 317 kg/m^3, and lower than

480kg/m^3 reported by Singh et al., (2021). That may be as a result of different compositions of waste fractions of the various sources.

3.3.3 Moisture content

The moisture content of the waste is 60% and 40% in Bauchi and Kaduna respectively, these values fall within the ranges of typical solid waste moisture content of middle and low income countries established at 40-60% and 40-80% respectively.

3.3.4 Volatile solids

The average values of volatile content of the waste in Kaduna is 46% and that of Bauchi is 50%, these values indicate the potentials of the waste for energy generation, and close to what was obtained by Singh et al., (2022) with volatile content value of 65%.

3.4.5 Calorific value

The calorific values obtained are similar to works by previous researchers such as Franjo, et al. (1992) with 10.36 MJ/kg from unsegregated solid waste, Nwoke, et al., (2022) with 13.9MJ/kg, 16.3MJ/kg, 26.9MJ/kg and 17.8MJ/kg from sorted solid waste separated into Food waste, paper, plastics and textile respectively. Values of 10.3MJ/kg and 18MJ/kg were obtained in Kaduna and Bauchi respectively. Therefore, a reasonable amount of energy can be obtained through thermal conversion of the waste.

3.5 Practices, awareness and perception of solid waste management

From the result of the survey, only 2% of the households in Kaduna partially sort their waste while no source separation was recorded in Bauchi. However, responses from the households' show 35% and 41% of the respondent that are willing to separate waste at source in Bauchi and Kaduna respectively.

In Kaduna, 20% of the household temporarily store their waste in plastic bags, 75% in bins/drums, while 5% dispose their waste directly into rivers behind their houses. Similarly, 80% of the households in Bauchi store their waste in bins/drums, while 17% use bin bags and 3% dispose waste directly at nearby dump site.

Analysis of the survey shows that 13% and 27% of the households in Bauchi and Kaduna reuse the plastic bottles in their waste. The research considered responses from households and physical observation to ascertain the level of solid waste treatment. While zero waste treatment was recorded at household levels, willingness to treat waste was found to be 60% that may be due to lack technical knowhow recorded at 95%. Also, 86% of the respondents show readiness to make financial commitments towards proper management of their waste. Results of the survey indicate 95% community's eagerness to learn more about waste management.

30% of the households employ the services of private waste collectors to dispose their waste, while 60% dispose their waste at communal dump sites that are often evacuated by large trucks to the central dump site of the town. The remaining households dump their waste in the streams waiting for storm water to transport it somewhere, and the lesser percentage open- burn their waste in their houses. Uncontrolled open dumps, open burning, dumping of refuse by road side or in streams are some common practices of disposal in the study area as seen in figures 4, 5, 6 & 7, causing bad odour, poor aesthetic, health and safety challenges

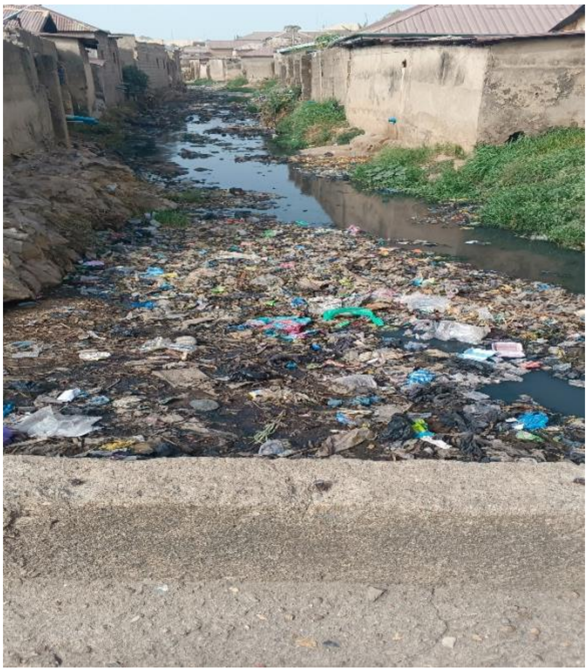

Figure 4: Dumping in stream in Kaduna

Figure 5: Open waste disposal site in Bauchi

Figure 6: uncontrolled waste disposal in Kaduna

Figure 7: dumping in streams in Kaduna

4. Conclusion

The study sheds light on the solid waste generation rates and composition in Kaduna and Bauchi, revealing an average daily waste generation of 0.3 kg/capita/day, aligning closely with national and international findings. The densities of un-compacted solid waste of 412.3kg/m^3 and 407.8kg/m^3 were slightly higher than observed in Dilla town, Ethiopia, indicating variations influenced by waste composition. Food waste emerged as the predominant component in both towns' waste streams, underscoring the need for targeted management strategies.

Furthermore, analysis of parameters such as Total Solid (TS), Volatile Solids (VS), Moisture content, and Calorific Value provided insights into potential energy recovery and handling.

The status of solid waste management highlighted significant challenges, including low rates of waste sorting at the source, inadequate temporary storage methods leading to environmental hazards, and limited waste re-use and treatment practices. The predominant disposal methods of open dumping and burning pose environmental and health risks, emphasizing the urgent need for improved waste management infrastructure and awareness campaigns. Despite these challenges, the community's willingness to engage in proper waste management practices underscores the potential for positive change through education and implementation of effective waste management.

Author Contributions: All authors contributed to this research.

Funding: Not applicable.

Conflict of Interest: The authors declare no conflict of interest.

Informed Consent Statement/Ethics Approval: Not applicable.

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