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Waste Characterization and Management Strategies in Gombe, Nigeria: A Panacea Towards Sustainable Development

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Abstract

Rapid urbanization across sub-Saharan African cities has intensified municipal solid waste (MSW) management challenges, with significant implications for environmental quality, public health, and sustainable urban development. This study assessed waste characterization, generation dynamics, management practices, and resource recovery potential in Gombe, Nigeria, to identify sustainable waste management pathways. A secondary-data-based meta-analytical approach was adopted, synthesizing evidence from peer-reviewed literature, government and institutional reports, and records from the Gombe State Environmental Protection Agency. Data were analyzed using descriptive statistics, chi-square analysis, and thematic analysis. Results show that Gombe's waste stream is predominantly biodegradable, with organic food waste constituting 36–38% and agricultural waste 34.3–41.0% of total waste generated, while plastics account for 11.4–18.4%. Mean annual waste generation for 2010–2019 was estimated at 138,749.7 tonnes, and per capita waste generation reached 0.84 kg/person/day, exceeding the typical range reported for low-income urban centres. Chi-square analysis revealed no statistically significant association between population growth and waste generation ($p = 0.231$), indicating that collection, reporting, and disposal inefficiencies exert a greater influence on waste accumulation than demographic expansion alone. Resource recovery assessment demonstrated substantial circular economy potential. Composting could divert approximately 75% of biodegradable waste from disposal sites, while anaerobic digestion could generate about 67.75 million kWh of electricity annually. Co-digestion could further increase energy recovery to 81.30 million kWh/year, sufficient to supply over 44,000 households, while producing digestate valued at approximately ₦813 million annually. The study concludes that Gombe's waste management system remains predominantly linear, disposal-oriented, and environmentally unsustainable. An integrated framework encompassing source segregation, composting, recycling infrastructure, anaerobic digestion, formalization of informal waste actors, and public-private partnerships is recommended to accelerate circular economy transition and enhance urban sustainability in Gombe and comparable Nigerian cities.

Keywords

Anaerobic Digestion;
Circular Economy;
Municipal Solid Waste;
Resource Recovery;
Sustainable Waste Management

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INTRODUCTION

Global municipal solid waste (MSW) generation continues to rise, posing major environmental, public health, and governance challenges, particularly in rapidly urbanizing regions. Cities worldwide generated an estimated 2.01 billion tonnes of solid waste in 2016, equivalent to 0.74 kg per capita per day (World Bank, 2019), and nearly 3.5 billion people still lack access to adequate waste management services (UNEP, 2019). In Nigeria, MSW management remains constrained by rapid urban expansion, irregular collection, and inadequate disposal infrastructure, with consequences including soil and water contamination, blocked drainage, flooding, and disease outbreaks (Emankhu & Yamusa, 2018; Saidu & Danlami, 2018; Abba et al., 2020).

Waste characterization provides the empirical basis for technology selection, collection planning, and resource recovery optimization. In Gombe, available evidence indicates that the waste stream is dominated by biodegradable fractions, with organic and agricultural waste together exceeding 70% of the total, alongside a growing plastic fraction (Mohammed et al., 2021). Yet waste management in the city remains constrained by inadequate collection, reliance on informal and unregistered collectors, and weak data systems, leaving current practices poorly aligned with SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production).

This study evaluates waste characterization and management strategies in Gombe, examining waste composition and generation trends, current management practices, and resource recovery potential, to inform sustainable, SDG-aligned waste management strategies for Gombe and comparable Nigerian cities.

MATERIALS AND METHODS

Study Area

Gombe City, the administrative capital of Gombe State, lies within the Sudano-Sahelian belt of northeastern Nigeria (10°15′–10°19′N, 11°08′–11°12′E), covering approximately 52 km² with an expanding peri-urban fringe driven by rapid urban growth (Hashidu et al., 2019). The state's population was projected at approximately 3.47 million in 2019, with an annual urbanization rate of 3.5%. Municipal solid waste management is institutionally vested in the Gombe State Environmental Protection Agency (GOSEPA), with two principal disposal sites – the INEX and GOSEPA dumpsites – both operating as uncontrolled open dumps without engineered liners or leachate collection systems.

Method

This study employed a meta-analysis design, systematically synthesizing secondary data from peer-reviewed literature, government reports, and institutional sources, including GOSEPA and the Nigerian Bureau of Statistics, published within the past 15 years. Waste composition and generation data were analysed using descriptive statistics in SPSS v25; a chi-square test examined the association between annual percentage changes in population and waste generation over 2010–2019; and thematic analysis identified management practice patterns. Resource recovery estimates were derived using established conversion factors from Iyamu et al. (2017), IPCC (2006), and Angula et al. (2022).

RESULTS

Waste Composition

Table 1 presents the composition of municipal solid waste (MSW) at the INEX and GOSEPA dumpsites (Mohammed et al., 2021). Organic food waste was the largest single fraction at both sites (36–38%), followed by agricultural waste (34.3–41.0%); together these compostable fractions averaged approximately 75% of the waste stream, consistent with global patterns in low-income countries where organics typically account for 40–65% of MSW (Hoornweg & Bhada-Tata, 2012). Plastic waste at INEX (18.4%) exceeded the 5–15% range typical of comparable regions (Kaza et al., 2018), likely reflecting growing sachet-water and single-use packaging consumption. Paper and metal fractions were minimal, likely reflecting pre-collection scavenging by informal waste pickers rather than low generation.

Table 1: Composition of Municipal Solid Waste at INEX and GOSEPA Dumpsites (2019)

Waste Category	INEX (% Weight)	GOSEPA (% Weight)
Organic Food Waste	36.00	38.00
Agricultural Waste	34.30	41.00
Plastic	18.40	11.40
Textiles	6.02	6.90
Soil	2.70	1.20
Paper	2.05	0.71
Metals	0.83	1.43

Source: Mohammed et al. (2021)

Waste Generation Trends

Table 2 presents population and waste generation data for Gombe, 2010–2019. Population growth was stable at approximately 3.9% per annum, but waste generation was highly volatile, including a 76.29% drop in 2013 and a 65.27% surge in 2014, most likely reflecting data recording and collection inconsistencies rather than real changes in generation. A chi-square test found no statistically significant association between population growth and waste generation ($\chi^2 = 90$, $p = 0.231$), suggesting that institutional factors – erratic collection, inadequate equipment, and weak data governance – are more decisive than demographic growth alone. Average annual waste generation over the period was 138,749.7 tonnes, equivalent to a per capita rate of 0.84 kg/person/day, above the 0.45–0.65 kg/person/day benchmark typical of low-income countries (Kaza et al., 2018).

Table 2: Population Growth and Waste Generation Trends in Gombe (2010–2019)

Year	Population	Waste (Tonnes)	% Pop. Increase	% Waste Increase
2010	342,000	110,376	—	—
2011	356,000	115,920	3.93	4.78
2012	370,000	126,168	3.78	8.12
2013	385,000	71,568	3.90	–76.29
2014	401,000	206,052	3.99	65.27
2015	417,000	184,548	3.84	–11.65
2016	434,000	135,871	3.92	–35.83
2017	451,000	139,404	3.77	2.53
2018	470,000	143,028	4.04	2.53
2019	489,000	150,562	3.89	5.00

Source: Mshelia & Onuigbo (2020)

Current Waste Management Practices

Waste collection in Gombe is managed by GOSEPA, supplemented by private contractors and informal collectors, but is largely confined to monthly sanitation exercises, resulting in waste overflow and illegal dumping in drainages and waterways. The primary disposal method is unengineered landfilling at INEX and GOSEPA, with minimal segregation. Recycling infrastructure is virtually absent, and community willingness to pay for waste disposal services is low (Banjoko & Shuaib, 2023), further constraining system financing. GOSEPA itself is constrained by inadequate funding, equipment, and trained personnel.

Resource Recovery Potential

Table 3 summarises resource recovery potential across four pathways, based on 2019 MSW generation of 150,562 tonnes. Composting of the compostable fraction (approximately 112,921.5 tonnes/year) could divert 75% of waste from landfill and yield 45,168.6 tonnes of compost worth an estimated $903,372/year (Adekunle et al., 2011), while avoiding an estimated 141,152.5 tonnes CO_2e/year in landfill methane emissions. Waste-to-energy conversion could theoretically supply electricity to nearly 50,000 households daily. Anaerobic digestion of the organic fraction could generate 67.75 million kWh/year, while co-digestion with sewage sludge could raise this to 81.30 million kWh/year – enough to serve over 44,000 households – while producing digestate valued at ₦813 million/year and saving a further ₦677.5 million/year in landfill costs.

Table 3: Resource Recovery Potential from Gombe's 2019 MSW (150,562 Tonnes)

Pathway	Output	Energy (kWh/yr)	HH Served/day	Value	GHG (t CO_2e/yr)
Composting	45,168.6 t/yr	—	—	$903,372/yr	141,152.5
WtE	—	90,337,200	~49,501	—	—
AD	33,876.5 t/yr	67,752,900	~37,125	₦813.0M/yr	141,152.5
Co-digestion	33,876.5 t/yr	81,303,480	~44,550	₦813.0M/yr	141,152.5

Source: Calculated from Iyamu et al. (2017); IPCC (2006); Angula et al. (2022)

Proposed Waste Management Strategies

Seven integrated strategies are proposed. Source segregation, supported by colour-coded bins and public education campaigns, can improve separation compliance, given that perceived behavioural control and positive attitudes are the strongest predictors of compliance (Xu et al., 2017). Decentralised recycling facilities for plastics, paper, and metals would create local employment and divert Gombe's substantial plastic fraction from landfill. Formalising informal waste pickers – through licensing, training, and integration into collection routes – would improve system efficiency and worker livelihoods, following the precedent set in Enugu (Nzeadibe, 2009).

Phased waste-to-energy pilots, composting and anaerobic digestion infrastructure, stronger policy enforcement (including extended producer responsibility for plastics), and public-private partnerships would mobilise capital and technical expertise. A standardised monitoring and evaluation framework is needed to address the data-reporting inconsistencies identified in this study and to track progress against SDGs 7, 8, 11, 12, 13, and 17.

DISCUSSION

The dominance of biodegradable fractions in Gombe's waste stream – averaging 75% organic and agricultural waste – mirrors patterns reported across sub-Saharan African cities, where organics typically account for 40–65% of MSW due to limited food processing and high fresh-produce consumption (Hoornweg & Bhada-Tata, 2012; Kaza et al., 2018). This composition profile indicates substantial, largely unexploited resource recovery potential through composting and anaerobic digestion, consistent with evidence that organic-dominated waste streams in African cities offer a comparative advantage for circular economy transitions (Ezeudu & Ezeudu, 2019).

The elevated plastic fraction at INEX (18.4%), well above the 5–15% range typical of comparable contexts (Kaza et al., 2018), signals an emerging plastic pollution concern alongside an economic opportunity for targeted recycling infrastructure.

The decoupling of waste generation from population growth (χ^2 = 90, p = 0.231) challenges the assumption that urbanisation alone drives MSW accumulation, and instead points to institutional capacity, collection

infrastructure, and data governance as more decisive constraints in developing-country contexts. Gombe's current system, characterised by infrequent collection, unengineered landfilling, and negligible recycling, exemplifies the linear "collect–transport–dispose" paradigm that continues to dominate African urban waste governance, while persistent reliance on informal collectors reflects formal systems failing to keep pace with urban growth (Ferronato & Torretta, 2019).

The resource recovery analysis makes the strongest case for a paradigm shift: composting, anaerobic digestion, co-digestion, and waste-to-energy together could divert most of Gombe's organic waste from disposal, generate substantial energy and economic value, and meaningfully reduce greenhouse gas emissions, operationalising circular economy principles in a context where linear disposal has demonstrably failed (Wilson, Velis & Rodic, 2013). Realising this potential, however, will require formalising informal waste actors (Nzeadibe, 2009), strengthening source segregation (Xu et al., 2017), and mobilising public-private partnerships and policy reform – positioning Gombe's waste challenge not as a problem of demographic pressure, but of institutional design and underutilised resource recovery.

CONCLUSION AND RECOMMENDATION

This study characterised Gombe's MSW stream and found it dominated by biodegradable materials – organic food waste (36–38%) and agricultural waste (34–41%) – alongside a significant plastic fraction (11–18%). Per capita generation (0.84 kg/person/day) exceeds the low-income country benchmark of 0.45–0.65 kg/person/day, reflecting rapid urbanisation and shifting consumption patterns. The absence of a statistically significant association between population growth and waste generation ($\chi^2 = 90$, $p = 0.231$) points to institutional failures erratic collection, data governance gaps, and infrastructure deficits as more decisive constraints than demographic growth alone.

Resource recovery analysis reveals substantial untapped value: composting, waste-to-energy, anaerobic digestion, and co-digestion could collectively divert most of Gombe's organic waste from landfill while generating significant energy, economic, and climate benefits. The seven integrated strategies proposed – source segregation, recycling infrastructure, formalisation of informal collectors, waste-to-energy investment, composting and anaerobic digestion, policy reform, and public-private partnerships – form a replicable, SDG-aligned framework for mid-sized African cities facing similar urbanisation pressures. Future research should prioritise primary data collection to validate secondary data patterns, incorporate spatial analysis for hotspot targeting, and assess gender-differentiated impacts of waste management on urban livelihoods.

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