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Original Article

Urban food waste for digestate production: Implications for soil health and circular economy in Benin Metropolis, Nigeria

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ABSTRACT

Food waste poses a significant environmental and socio-economic concern in urban areas of Nigeria, where disposal methods remain largely unregulated and underutilized. This study investigates food waste generation, composition, and disposal practices across four Local Government Areas (LGAs) of Benin Metropolis: Ovia North-East, Ikpoba Okha, Oredo, and Egor with a view to assessing its viability as feedstock for digestate production. A structured questionnaire was employed in the survey via a multistage sampling of a total of 143 respondents, and these data were analyzed using descriptive statistics and chi-square tests (χ^2). Results revealed that food waste originated predominantly from residential sources (mean = 64.43%, SD = 9.06), with significant variation across LGAs ($\chi^2 = 10.75$, $df = 3$, $p = 0.013$). Non-cooked food waste (44.32% residential, 45.28% commercial) constituted the bulk of organic waste, though segregation practices were limited (only 16% segregated waste). Disposal was primarily via public dumpsites (41%) and commercial sanitation services (35%). The study highlights the untapped potential of food waste as an input for digestate-based soil fertility enhancement. It recommends improved waste segregation, decentralized composting infrastructure, and policy reform as pathways to advancing sustainable organic agriculture, improving soil health and food security and achieving circular economy goals in urban Nigeria.

KEYWORDS: *Digestate, Food waste, Organic agriculture, Urban sustainability, Waste management*

INTRODUCTION

Rapid urbanization and population growth have led to a substantial increase in municipal solid waste generation worldwide, with organic waste; particularly food waste constituting a large proportion of urban waste streams. In many developing countries, organic waste accounts for up to 60% of municipal solid waste, making its management a critical environmental challenge. Improper disposal of food waste through open dumping or landfilling contributes to greenhouse gas emissions, environmental pollution, and the loss of valuable nutrients that could otherwise be recycled into productive systems (Kolawole, 2024). Consequently, sustainable strategies for food waste management and resource recovery are increasingly gaining attention in environmental and agricultural research.

One promising approach for the valorization of food waste is anaerobic digestion (AD), a biological process that decomposes organic materials under oxygen-free conditions to produce biogas and a nutrient-rich by-product known as digestate. While biogas serves as a renewable energy source, digestate contains essential plant nutrients such as nitrogen, phosphorus, potassium, and organic matter, making it a valuable soil amendment (Zhang *et al.,* 2019). The recycling of digestate in agricultural systems can improve soil fertility, enhance nutrient

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availability, and reduce dependence on synthetic fertilizers (Edosa, 2024).

The utilization of food-waste-derived digestate aligns with the principles of the circular economy**,** which emphasizes resource efficiency by converting waste streams into valuable inputs for other production systems (Sarangi *et al*., 2024). Through anaerobic digestion, urban organic waste can be transformed into renewable energy and nutrient-rich soil amendments, thereby closing nutrient loops and reducing environmental burdens associated with waste disposal. Such resource recovery strategies contribute to climate change mitigation and sustainable urban waste management.

Beyond waste management, digestate application has important implications for soil health**.** Organic amendments derived from anaerobic digestion can enhance soil physical, chemical, and biological properties by increasing soil organic matter, improving nutrient availability, and stimulating microbial activity (Edosa *et al*., 2021). These improvements are particularly relevant in tropical soils, which often experience declining fertility due to continuous cultivation and low organic matter inputs.

In Nigeria, urban centers generate significant quantities of food waste that are often poorly managed through open dumping or uncontrolled landfills. In cities such as Benin Metropolis, Edo State**,** the underutilization of organic waste resources presents both an environmental challenge (Ikpe, 2020) and an opportunity for sustainable waste valorization. Converting urban food waste into digestate through anaerobic digestion could provide an integrated solution for waste management, renewable energy production, and soil fertility improvement.

Hence, this study evaluates the potential of urban food waste as a feedstock for digestate production and examines its implications for soil health and circular economy development in Benin Metropolis, Edo State. Specifically, the study assesses the characteristics of food-waste-derived digestate and its potential role in promoting sustainable waste management and nutrient recycling within urban environments.

MATERIALS AND METHOD

The study was conducted in four LGAs which constituted the Benin Metropolis: Ovia North-East, Ikpoba-Okha, Oredo, and Egor. In total, 143 questionnaires were administered, with 47 (32.87%)**,** 21 (14.68%)**,** 36 (25.17%), and 39 (27.27%) obtained from the respective LGAs. These areas differ in population size, income levels, and waste disposal infrastructure, making them suitable for comparative food waste analysis. The data reveal a fairly even distribution of respondents across these LGAs, providing a comprehensive overview of food waste generation in the Benin Metropolis.

Survey Design and Data Collection

The study adopted a cross-sectional survey design**,** with data collected using structured questionnaires administered to 143 respondents in total**.** A multistage sampling technique was applied, whereby each Local Government Area (LGA) was divided into sections, and the four most densely populated areas within each LGA were selected for the survey. The participants included both residential and commercial food waste generators. Information was gathered on the following:

- Household size and demographic profile
- Source and type of food waste
- Quantity generated
- Collection and disposal methods
- Challenges associated with waste handling

Data Analysis

Descriptive statistics (percentages, means, and standard deviations) were computed to summarize the data. Chi-square tests were conducted to determine significant differences in waste generation across LGAs in the metropolis and their sources ($p < 0.05$). Graphs and error bars were used to visualize key findings.

Results

Distribution of Food Waste Sources

Figure 1 shows that residential areas were the predominant source of food waste in all the LGAs, contributing 61.70% in Ovia North-East, 71.43% in Ikpoba Okha, 52.78% in Oredo, and 71.79% in Egor. The majority of households generating food waste had between 1-5 persons. Notably, the highest percentage contributing to food waste in the metropolis was observed in Ikpoba Okha (57.14% residential) and Egor (51.28% residential) which has smaller households. This suggests that smaller households are more likely to generate food waste, which could be due to inadequate meal planning or overestimation of food needs.

This trend highlights the significant contribution of households to food waste, suggesting that interventions targeting residential areas could effectively reduce overall waste generation.

The average residential contribution across LGAs was 64.43% (SD = 9.06). A chi-square test revealed a significant difference in food waste sources across LGAs ($\chi^2 = 10.75$, df = 3, $p = 0.013$).

Type of Food Waste Generated

Results in figure 2 of the food waste in both residential and commercial settings showed that non-cooked food waste constituted the largest proportion, accounting for 44.32% in residential areas and 45.28% in commercial areas. Cooked food waste represented 37.50% of the total waste in residential settings and 41.51% in commercial settings, indicating a substantial presence of post-consumption organic residues. In contrast, fruit waste contributed less than 2% of the total food waste in both residential and commercial areas suggesting that fruit residues are a relatively minor component of the waste stream.

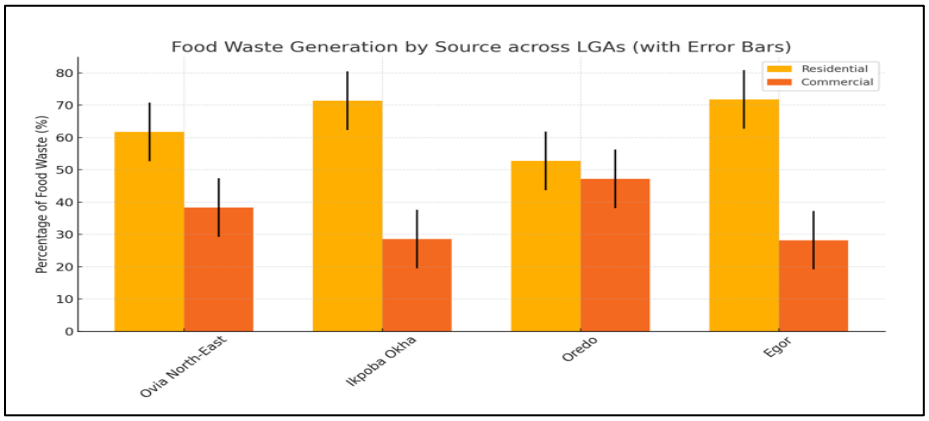

Figure 1: Generation of food waste in residential and commercial areas across the four LGAs

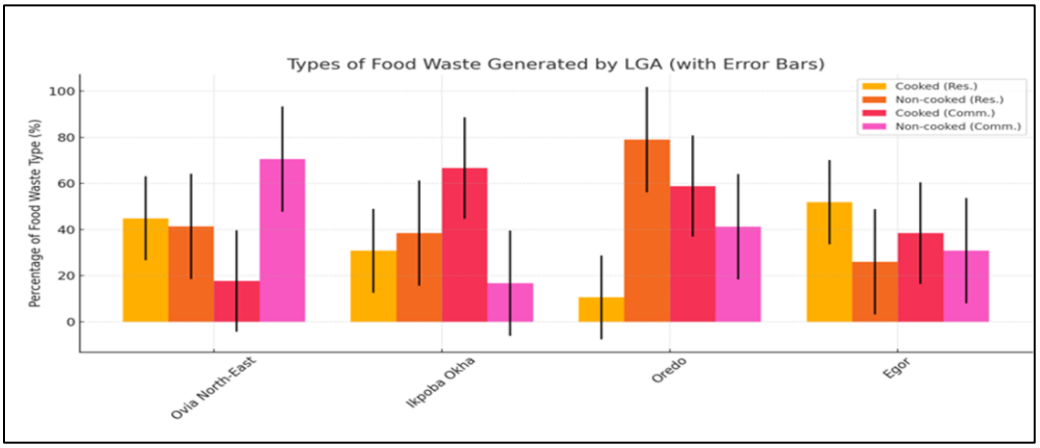

Figure 2: Types of food waste generated in residential and commercial areas across the four LGAs

Quantity and Collection Practices

In figure 3, it was observed that in the four local government areas surveyed, the predominant method of food waste collection involved the use of disposable plastic "take-away" packs. This collection approach was reported by 65.22% of residential respondents and 39.22% of commercial respondents in the metropolis, reflecting its widespread availability and convenience for short-term waste storage. The second most common collection method was the use of 4-liter paint rubber containers, adopted by 27.17% of residential respondents and 41.18% of commercial respondents, likely due to their durability, reusability, and capacity to store moderate quantities of waste.

In contrast, the use of 20L containers for waste collection was reported far less frequently in both residential and commercial settings across all four local government areas, indicating a preference for smaller, more portable storage options. This trend suggests that waste storage capacity is generally limited, potentially necessitating more frequent disposal and influencing the overall waste management cycle.

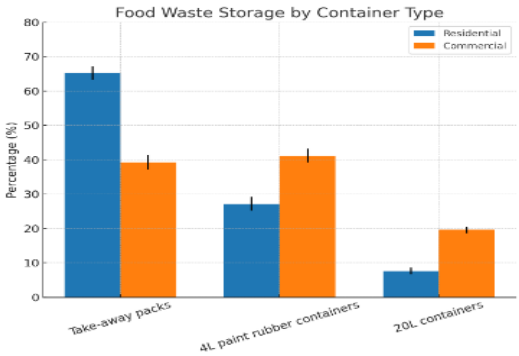

Figure 3: Types of food waste storage by container types in residential and commercial areas

Disposal Methods and Segregation

In the four local government areas assessed, food waste disposal practices varied considerably, reflecting a combination of formal, semi-formal, and informal waste management approaches. The largest proportion of respondents (41%) reported disposing of their food waste at public refuse dumpsites, a method that, while easily accessible, often lacks adequate containment and management measures, thereby

posing risks of leachate generation, environmental contamination, and public health hazards. Commercial sanitation services, which involve the collection and transportation of waste by registered private or municipal contractors, were utilized by 35% of respondents, representing a relatively more structured waste management pathway that could facilitate better control over disposal processes if effectively regulated.

Figure 4 shows that a smaller proportion of respondents (7%) in the metropolis reported the use of incineration as a disposal method. While incineration can significantly reduce waste volume, its effectiveness and environmental safety are contingent on the use of controlled, high-temperature facilities with adequate emission control technological conditions that may not be met in many local contexts, potentially resulting in air quality deterioration and the release of toxic byproducts. Informal collection, locally referred to as the "dirty man" system, accounted for 17% of reported disposal practices. This method typically involves unregulated waste pickers or collectors transporting waste to undefined or unauthorized disposal points, which may contribute to indiscriminate dumping and the associated environmental consequences.

Notably, only 16% of the total respondents reported practicing waste segregation at source before disposal. This low level of segregation significantly compromises the efficiency of downstream waste management processes, particularly those aimed at material recovery, recycling, or resource valorization such as composting and anaerobic digestion. The absence of systematic segregation not only hampers the extraction of high-quality organic fractions but also results in contamination by non-biodegradable and hazardous materials, thereby limiting the potential for sustainable waste-to-resource conversion and posing challenges to achieving circular economy objectives.

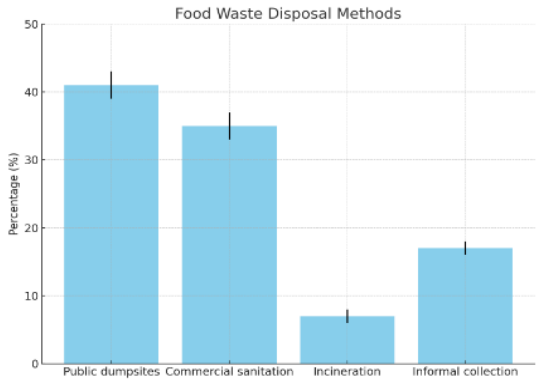

Figure 4: Types of food waste disposal methods in the local government areas.

Challenges in Food Waste Management

The challenges of food waste management in these localities include inadequate waste collection services, poor public awareness and attitudes toward waste disposal, insufficient infrastructure and equipment, and the widespread practice of open dumping and burning. In the four local government areas assessed, respondents consistently reported a range of environmental and public health concerns directly associated with food waste mismanagement. The most frequently cited issues included the emission of offensive odors, which were attributed to the decomposition of the wastes, increased pest infestation, particularly by vectors such as rodents, flies, and cockroaches, which pose potential risks for disease transmission; and visual pollution resulting from the unsightly accumulation of waste in public and residential areas. These adverse outcomes were observed to be more pronounced and recurrent in locations where waste was not collected promptly or was disposed of through informal and unregulated means, such as open dumping or indiscriminate roadside disposal. Such practices not only exacerbate aesthetic and sanitary challenges but also create conditions conducive to environmental degradation, the proliferation of disease vectors, and the impairment of community well-being.

Digestate as a Sustainable Solution

The study confirms that food waste generated in Benin Metropolis is largely composed of biodegradable organic fractions, particularly cooked and uncooked food residues. Such organic materials are well-suited for anaerobic digestion, a process that converts biodegradable substrates into biogas and digestate. Digestate, the residual slurry produced after anaerobic digestion, is widely recognized as a valuable soil amendment in organic and regenerative farming systems (Edosa *et al*., 2021). It typically contains essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), as well as organic matter and beneficial microorganisms that enhance soil fertility and biological activity. These properties improve soil structure, water retention, and nutrient availability, thereby supporting sustainable crop production (Zhang *et al*., 2019).

Beyond its agronomic benefits, digestate also presents important implications for food security. The application of digestate as an organic fertilizer can provide a cost-effective alternative to synthetic fertilizers (Barzee *et al*., 2019; Edosa *et al*., 2024), which are often expensive and inaccessible to many smallholder farmers operating in peri-urban and rural zones (Doyeni *et al*., 2021). By replenishing depleted soil nutrients and stimulating microbial activity, digestate can enhance crop productivity, particularly in degraded or nutrient-deficient soils. These improvements contribute to sustainable crop yields while reducing input costs, thereby improving food availability and affordability for low-income populations.

Moreover, the valorization of food waste through digestate production offers an integrated solution to several urban environmental challenges. By converting organic waste into valuable agricultural inputs, anaerobic digestion supports circular economy principles that promote resource recovery and nutrient recycling Chojnacka & Chojnacki (2024). Instead of being disposed of in landfills where it may generate methane emissions, food waste can be transformed into a productive

resource that sustains soil fertility and agricultural output (Edosa *et al*., 2024). This waste-to-resource approach strengthens the resilience of local food systems and contributes to broader sustainability goals. In particular, it aligns with Sustainable Development Goals (SDGs) 2 (Zero Hunger), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production). As urban populations continue to grow, decentralized anaerobic digestion systems could therefore play an important role in reducing urban food waste while supporting peri-urban agricultural productivity (Doyeni *et al*., 2021).

Constraints to Resource Recovery

Despite the considerable potential of food waste as feedstock for digestate production, several operational and systemic constraints currently limit effective resource recovery in Benin Metropolis. A major barrier identified in this study is the low level of waste segregation at the household and commercial levels. Most respondents reported that food waste is rarely separated from general municipal waste. The mixing of organic materials with plastics, metals, and other non-biodegradable components reduces the quality of feedstock available for anaerobic digestion and may compromise both process efficiency and the safety of the resulting digestate (Li *et al*., 2019).

Infrastructural deficiencies also present significant barriers. Many residential and commercial zones lack access to structured waste collection systems or designated organic waste bins. Informal waste disposal methods such as dumping in open spaces or reliance on unregulated collectors remain prevalent in the Benin metropolis. These practices not only hinder centralized recovery efforts but also increase the environmental burden through methane emissions, pest infestations, and land degradation.

Another critical barrier is the limited public awareness and behavioral inertia. Many respondents expressed unfamiliarity with composting or digestate use, perceiving food waste merely as a nuisance rather than a resource. Cultural attitudes toward waste, lack of incentives, and absence of community education programs have collectively stifled innovation in organic waste valorization Justice *et al*. (2021).

These constraints mirror findings from similar urban contexts in sub-Saharan Africa, where informal waste economies and fragmented governance systems challenge the implementation of sustainable waste management strategies (Adegbite *et al*., 2020; Debrah *et al.,* 2022; Ndam, 2023). Without deliberate intervention, these bottlenecks will continue to undermine the transition toward a circular, regenerative food economy.

Strategic Policy Recommendations

To realize the full potential of food waste as a feedstock for digestate production and its subsequent application in organic agriculture for enhanced soil health, an integrated and multi-pronged strategy is required. Based on the study's findings and aligned with global best practices in sustainable urban waste management, the approach should begin with the mandatory segregation of organic waste at both household and commercial levels (Kumar & Rana 2024), supported by the efficient collection infrastructure, and strict enforcement mechanisms, including penalties for non-compliance. This step will ensure a clean and uncontaminated organic fraction suitable for anaerobic digestion, thereby maximizing nutrient recovery Chojnacka & Chojnacki (2024). The establishment of decentralized composting and anaerobic digestion hubs in urban and peri-urban areas, through joint investments by municipal authorities and private sector actors, will facilitate localized processing of food waste, minimize transportation costs, and enable the direct supply of nutrient-rich digestate to nearby farms. Concurrently, sustained public awareness and education campaigns are necessary to foster behavioral change by emphasizing the value of food waste as a resource, the importance of segregation, and the agronomic and environmental benefits of digestate; these campaigns should be disseminated via local media, and implemented through community sensitization programs. The integration of digestate into agricultural policies, coupled with agricultural extension programs promoting its use in soil fertility enhancement, will bolster its adoption. Finally, strengthening institutional coordination among environmental, agricultural, and urban planning agencies, alongside the development of robust data systems to track food waste flows, monitor environmental and agronomic outcomes, and evaluate policy impacts, will provide the necessary feedback mechanisms for continuous improvement, ensuring that food waste valorization contributes meaningfully to soil health restoration, sustainable crop production, and circular economy objectives.

CONCLUSION AND RECOMMENDATIONS

The findings demonstrated that residential areas are the predominant source of food waste across the four LGAs of Benin Metropolis, contributing an average of 64.43% of total waste in the metropolis. Smaller households contributed disproportionately to waste generation, emphasizing the need for targeted behavioral and policy interventions. The dominance of both cooked and non-cooked food residues in residential and commercial streams highlights the strong potential for organic waste valorization via anaerobic digestion, which can convert biodegradable waste into renewable energy (biogas) and nutrient-rich digestate. However, current practices characterized by small disposable storage containers, low source segregation (16%), and largely informal disposal impede effective segregation and resource recovery, thereby limiting downstream recycling or energy recovery and exacerbating public health and environmental impacts such a odour, pests, and visual pollution. Despite the biodegradable nature of the food waste stream, systemic constraints such as inadequate segregation, infrastructural deficiencies, and limited public awareness continue to constrain implementation of sustainable treatment pathways like anaerobic digestion.

Based on the survey findings, sustainable food waste management in Benin Metropolis requires mandatory source segregation, improved waste collection infrastructure, public awareness initiatives, integration of digestate into agricultural policies, and stronger institutional coordination to enhance resource recovery and support efficient anaerobic digestion and nutrient recycling.

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Authors' Contributions

VIOE: Conceptualization, methodology, investigation, data collection, formal analysis, interpretation of results, writing, original draft preparation, and manuscript revision. IO: Data collection, critical review of the manuscript and intellectual contributions. Both authors read and approved the final version of the manuscript

Ethical statement

Not applicable.

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