

Physicochemical Properties, Resource-Recovery Potential and Heavy-Metal Content of Market-Generated Waste in Bwari Area Council, Nigeria

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ABSTRACT

Market-generated solid waste contains substantial recoverable material but may also contain metals that can constrain safe reuse. This study characterised the physical composition, physicochemical properties, nutrient content and heavy-metal concentrations of solid waste from Kubwa, Bwari and Dutse markets in Bwari Area Council, Abuja, Nigeria. Field sampling was conducted in June, October and November 2024. Within each market, waste was collected from different dumpsite positions, including upper and lower portions, and four coded field samples per market were used for laboratory characterisation. A 10 kg waste sample was manually sorted into organic/food waste, plastics and rubber, paper and cardboard, metals, glass, textiles, and grit/gravel. Proximate properties and nutrients were determined using the documented laboratory procedures, while Pb, As, Hg, Cd, Cu and Fe were quantified by atomic absorption spectrometry after aqua-regia digestion. Organic/food waste dominated the three waste streams (55.70-60.20%). Kubwa recorded the highest mean calorific value (2,877.85 kJ/kg), while Dutse had the highest volatile matter, phosphorus and potassium values. Mean Pb and Hg concentrations were highest in Kubwa. The results indicate opportunities for composting, recycling and energy recovery, but the detected metal concentrations show that recovered materials should be chemically assessed before soil application or other reuse. The findings provide baseline evidence for market-specific segregation, recovery and monitoring strategies in Bwari Area Council.

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INTRODUCTION

Urban and peri-urban markets are major sources of heterogeneous solid waste due to intensive commercial activities, food handling, and extensive use of packaging materials. Solid waste refers to useless, unwanted, or discarded materials generated from human activities in residential, commercial, and industrial settings (Nathiya & Thandapani, 2019). Globally, the rapid rate of urbanization, population growth, and economic development has significantly increased municipal solid waste (MSW) generation, posing serious environmental and public health challenges (Zhang et al., 2024). It is estimated that over 2.01 billion tons of municipal solid waste are generated annually worldwide, with a large proportion not managed in an environmentally sound manner (Ibimode et al., 2023; United Nations Environment Programme, 2024).

In developing countries, including Nigeria, ineffective solid waste management systems are characterized by inadequate infrastructure, insufficient funding, lack of waste segregation at source, and low public awareness (Anokye et al., 2024). These challenges often result in environmental pollution, blockage of drainage systems, flooding, and the spread of diseases (Ibimode et al., 2023). In Abuja, the Federal Capital Territory (FCT), rapid urban expansion and population influx have intensified waste generation, frequently exceeding the management capacity of agencies responsible for waste collection and disposal (Dabis et al., 2023; Ibimode et al., 2023).

The composition of solid waste is a crucial factor in the planning and implementation of effective waste management systems. Solid waste typically consists of organic materials such as food and yard waste, as well as inorganic materials including plastics, paper, metals, and glass, with variations influenced by socio-economic conditions, culture, and consumption patterns (Hamid et al., 2015). Studies have shown that organic waste constitutes the largest proportion of municipal waste streams, particularly in areas with intensive food-related activities such as markets. For example, organic waste accounted for as high as 81% to 96% of total waste in food-service environments, indicating its dominance and potential for composting and other recovery options (Hamid et al., 2015; Manea et al., 2024).

Understanding the physical composition of solid waste is essential for identifying recyclable and biodegradable components, selecting appropriate treatment technologies, and minimizing environmental impacts. A well-functioning solid waste management system involves several interrelated elements, including waste generation, storage, collection, transportation, processing, resource recovery, and final disposal (Nathiya & Thandapani, 2019). However, in many Nigerian markets, the absence of proper waste segregation limits the recovery of valuable materials and reduces the efficiency of waste management practices (Omokaro et al., 2026).

Despite the economic and social importance of markets within the Federal Capital Territory, there is limited empirical data on the physical composition of market-generated solid

waste, particularly in Bwari Area Council. Existing studies in Abuja have primarily focused on household waste generation and general waste management practices, with little attention given to market-specific waste streams (Ibimode et al., 2023). Given that markets generate large quantities of organic and recyclable waste, there is a need for localized studies to provide detailed information on waste composition.

Characterizing waste streams through chemical and toxicological assessment is essential for designing effective waste management and resource recovery systems (Trivedi et al., 2024). Market waste differs from typical municipal solid waste due to its high organic fraction, heterogeneous composition, and potential contamination from mixed commercial activities (Adeleke et al., 2021). With the transition of the waste industry from disposal practices to resource recovery approaches, the need for detailed information on waste composition has become increasingly important (Burnley, 2006).

Despite increasing attention to waste management, limited empirical studies have focused specifically on the chemical and heavy metal characteristics of market-generated waste in semi-urban councils such as Bwari. Understanding proximate composition (moisture, ash, volatile matter, fixed carbon, calorific value) and nutrient content is necessary to determine suitability for waste-to-energy or composting. Equally important is the assessment of toxic metals, which may constrain safe reuse (Sani et al., 2026).

This study aims to characterise the physical and physicochemical properties of market-generated waste in Kubwa, Bwari and Dutse markets and evaluate its resource-recovery potential and heavy-metal contamination.

MATERIALS AND METHODS

Study Area

Bwari Area Council is one of the six area councils in the Federal Capital Territory (FCT), Nigeria. The council is

located approximately 45 km north-west of Abuja, the capital city of Nigeria. Geographically, it lies between latitude 9°05'N and 9°25'N of the equator and longitude 7°10'E and 7°35'E of the Greenwich meridian. The area council covers an estimated land area of about 1,362 square kilometers (FCTA, 2020).

Bwari Area Council is bounded to the north by Kaduna State, to the south by Abuja Municipal Area Council (AMAC), to the west by Niger State, and to the east by Nasarawa State. The council is characterized by rapid population growth and increasing urban expansion due to its proximity to the Abuja city center. Administratively, the area council is divided into ten political wards, namely: Bwari Central, Byazhin, Dutse Alhaji, Igu, Kawu, Kubwa, Kuduru, Shere, Ushafa, and Usuma. Each ward is represented by elected councilors responsible for local governance and development.

The area is predominantly inhabited by the Gbagyi (Gwari) ethnic group, alongside other ethnic groups due to migration and urbanization. Traditional institutions also play significant roles in governance and cultural preservation. The paramount traditional ruler is the Esu (also known as Sabwaya) of Bwari, currently His Royal Highness (Dr.) Ibrahim Yaro. In addition, the Sarkin Bwari, Alhaji Awwal Ijakoro II, serves as a second-class traditional ruler in the area.

This study was conducted in three major markets within Bwari Area Council, namely Kubwa Market, Bwari Market, and Dutse Market. These markets are located within Kubwa, Bwari Central, and Dutse Alhaji wards respectively, and serve as major commercial centers characterised by high population density and intensive trading activities. Consequently, they generate significant quantities of solid waste, making them suitable for the assessment of the physical composition of market-generated solid waste in the study area.

Overview of Selected Markets in Bwari Area Council

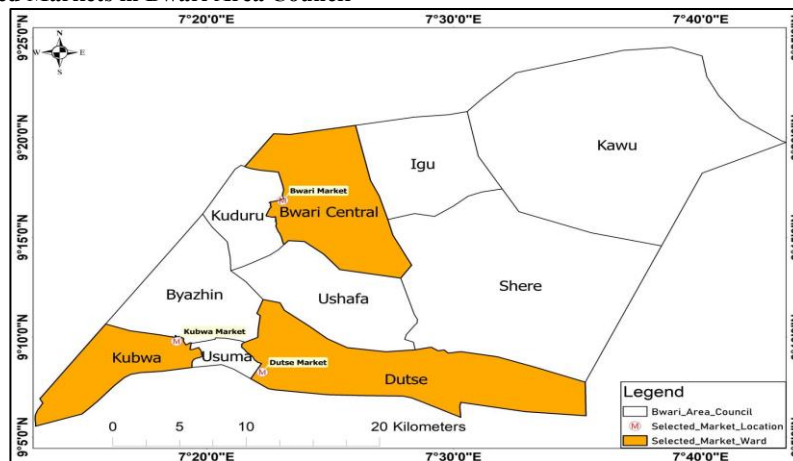


Figure 1: The wards of the selected market and the market location in Bwari A.C

Source: Urban and Regional Planning, University of Abuja (2025)

Waste Sampling and Physical Characterization

Waste sampling was conducted in Kubwa, Bwari and Dutse markets during June, October and November 2024. Samples were obtained from the market dumpsites where waste from the different trading sections accumulated. To capture within-dumpsite variability, four field samples were obtained per market from different sampling positions, including upper and lower portions of the deposited waste. Sample codes identified the market and sampling position (for example,

D1a, D1b, D2a and D2b for Dutse, with equivalent coding for Kubwa and Bwari). For physical characterization, a 10 kg waste sample was manually separated into organic/food waste, plastics and rubber, paper and cardboard, metals, glass, textiles, and grit/gravel. Each fraction was weighed with a digital scale and expressed as a percentage of the total sample mass. The component weights were checked against the initial sample mass. Gloves, boots and face masks were used throughout sampling and sorting.

Physicochemical and Nutrient Analysis

Physicochemical and nutrient analyses were conducted at the Sheda Science and Technology Chemistry Laboratory, Kwali, FCT, Abuja. The field samples included material taken from upper and lower portions of the market dumpsites. The manuscript reports the laboratory procedures actually used; the laboratory record available for this revision did not specify formal standard-method numbers for the proximate analyses.

Moisture content was determined by weighing 5 g of sample into a pre-weighed dish and drying at 105 °C to constant mass. The sample was cooled in a desiccator and reweighed. Moisture content was calculated from the loss in mass relative to the initial sample mass.

Moisture content (%) = [(mass before drying - mass after drying) / initial sample mass] × 100

Determination of Volatile Matter

For volatile matter determination, 1 g of sample was placed in a pre-heated and pre-weighed silica crucible, covered and heated in a muffle furnace at 925 °C for 7 min. The crucible was cooled first in air and then in a desiccator before reweighing, and volatile matter was calculated from the mass loss.

Determination of Ash Content

For ash determination, 1 g of sample was placed in a pre-heated, pre-weighed silica crucible. The sample was heated at 450 °C for 30 min and then at 850 °C for 1 h. After cooling in a desiccator, the residue was weighed and ash content was expressed as a percentage of the initial sample mass.

Ash content (%) = [(mass of ash residue) / (initial sample mass)] × 100

Determination of Fixed Carbon

Fixed carbon was calculated by difference from moisture, volatile matter and ash content.

Fixed carbon (%) = 100 - [moisture (%) + volatile matter (%) + ash content (%)]

Determination of Calorific Value

Gross calorific value was determined using a bomb calorimeter and is reported as kilojoules per kilogram (kJ/kg).

Determination of Nitrogen

Total nitrogen was determined by the Kjeldahl procedure. One gram of sample was digested with CuSO₄, K₂SO₄ and H₂SO₄ until the digest became clear. After cooling and dilution, ammonia was distilled following addition of NaOH, collected in boric acid and titrated with 0.1 M HCl. A reagent blank was processed using the same reagents.

Determination of Phosphorus

For phosphorus determination, 0.50 g of sample was digested in a closed microwave system with 0.5 mL H₂O₂ and 9.5 mL HNO₃ at 140 °C for 25 min and a microwave power of 1,250 W.

Heavy-Metal Analysis and Analytical Quality Control

All plastic and glassware used for metal analysis were washed with detergent, rinsed with deionized water, soaked in 10% HNO₃ for 24 h, rinsed again with deionized water and dried at low temperature before use.

For heavy-metal determination, 5 g of well-mixed, air-dried waste sample was digested in 20 mL aqua regia (HCl: HNO₃, 3:1) in a covered 250 mL glass conical flask on a hotplate for 3 h at 110 °C. After evaporation to near dryness, the digest was treated with 20 mL of 2% (v/v) HNO₃, filtered through Whatman No. 42 filter paper and made up to 100 mL with deionized water. Pb, Cd, As, Hg, Fe and Cu were measured using a Thermal Scientific iCE 3000 series atomic absorption spectrometer. The digestion approach followed the aqua-regia procedure described by Chen and Ma (2001). Digestions were performed in triplicate for analytical repeatability; these analytical replicates were not treated as independent field samples.

Documented quality-control measures included acid-cleaning of laboratory ware, use of deionized water and replicate digestion. The laboratory records supplied for this revision did not report certified reference material recoveries, metal-analysis blanks, limits of detection (LOD) or limits of quantification (LOQ); these values are therefore not reported in the manuscript.

Statistical Analysis

Laboratory results were organized by market and field-sample code in SPSS version 26. For each market, the four field samples were summarized using means and standard deviations for physicochemical and nutrient variables and using ranges and means for heavy-metal concentrations. Physical-composition data were summarized as percentages. Given the small number of independent field samples and the heterogeneous sampling design, comparisons among markets are presented descriptively in this manuscript. Analytical replicate measurements were used to assess repeatability and were not entered as independent observations in statistical comparisons

RESULTS AND DISCUSSION

Physical Composition of Waste Generated in the Markets

The physical composition of waste generated in the three markets is presented in Figures 2-4

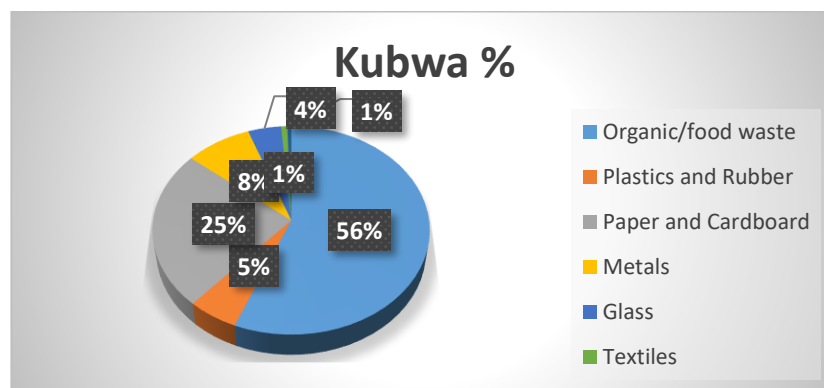


Figure 2: Physical composition of waste in Kubwa Market

In Kubwa Market, Organic/food waste constituted the largest fraction at 55.70% of the total waste generated. Paper and cardboard followed at 24.30%, while plastics and rubber

accounted for 5.40%. Metals and glass contributed 8.40% and 4.20%, respectively. Textile waste (0.80%) and grit/gravel (0.50%) represented the least components.

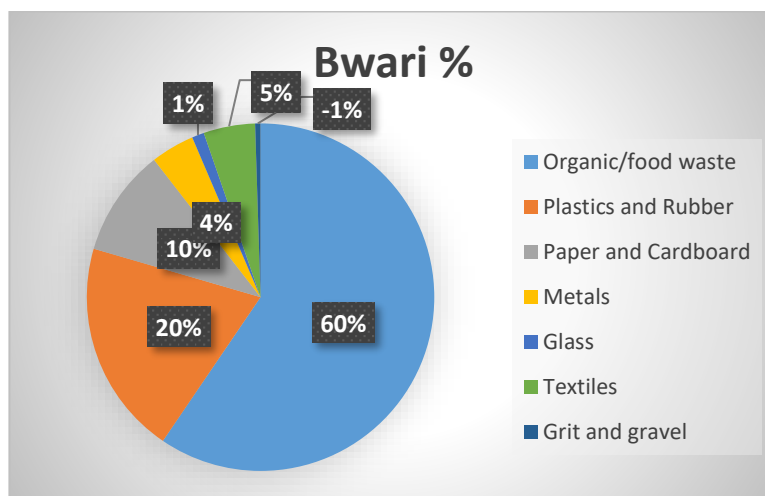


Figure 3: Physical composition of waste in Bwari Market

Bwari Market shows Organic/food waste was the dominant component at 59.50%. Plastics and rubber formed a significant proportion at 20.00%, the highest among the three markets. Paper and cardboard accounted for 10.00%, while

metals and glass contributed 4.07% and 1.13%, respectively. Textile waste was 4.80%, and grit/gravel remained low at 0.50%.

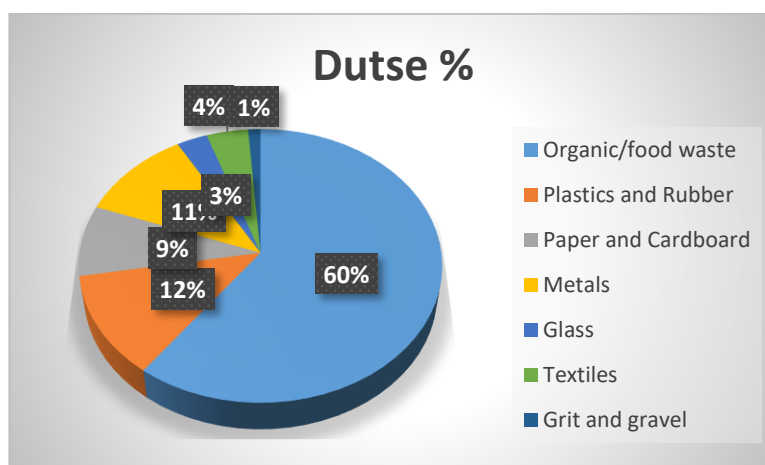


Figure 4: Physical composition of waste in Dutse Market

Dutse Market recorded the highest proportion of organic/food waste at 60.20%. Plastics and rubber accounted for 12.10%, while metals contributed 11.07%, the highest among the three markets. Paper and cardboard made up 8.37%, and glass accounted for 3.00%. Textile waste and grit/gravel were 4.07% and 1.20%, respectively.

Comparative Pattern

Across the three markets, organic/food waste consistently

constituted the largest fraction, exceeding 55% in all locations. Bwari Market recorded the highest proportion of plastics and rubber (20.00%), while Kubwa Market had the highest proportion of paper and cardboard (24.30%). Dutse Market exhibited the highest levels of metals (11.07%) and grit/gravel (1.20%).

Figure 5 presents a comparative overview of the physical composition of waste across the three markets.

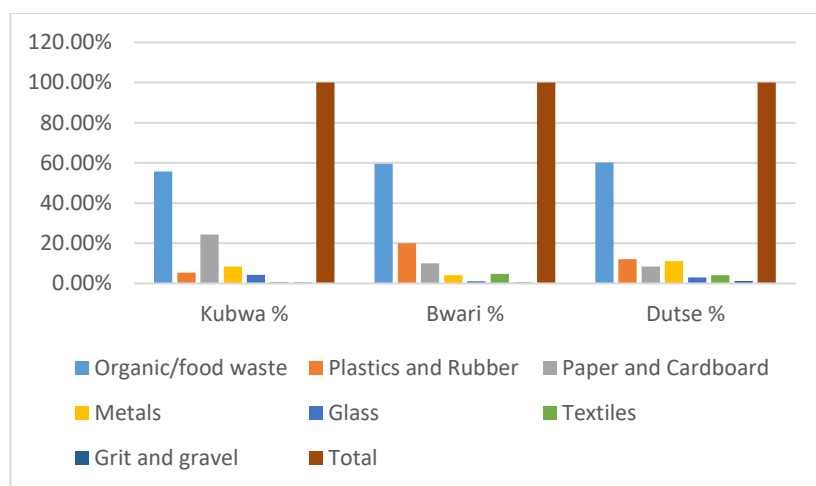


Figure 5: Physical composition of waste in the three markets

Physicochemical Properties and Nutrient Content

The results obtained for chemical characteristics of waste

generated across selected markets are shown in Table 1.

Table 1: Physicochemical Properties and Nutrient Content of Market Waste (Mean $\pm$ SD; N = 4 Field Samples Per Market)

Parameter	Kubwa	Bwari	Dutse
Moisture content (%)	25.00 $\pm$ 27.79	21.58 $\pm$ 22.68	8.66 $\pm$ 6.32
Ash content (%)	19.38 $\pm$ 17.59	49.67 $\pm$ 15.68	29.08 $\pm$ 5.71
Volatile matter (%)	41.31 $\pm$ 24.10	20.10 $\pm$ 5.07	56.23 $\pm$ 10.06
Fixed carbon (%)	19.94 $\pm$ 7.41	9.66 $\pm$ 3.71	13.37 $\pm$ 6.37
Calorific value (kJ/kg)	2877.85 $\pm$ 2059.05	1617.99 $\pm$ 717.06	2545.09 $\pm$ 1083.86
Total Nitrogen (%)	0.29 $\pm$ 0.03	0.17 $\pm$ 0.02	0.21 $\pm$ 0.02
Total Phosphorus (mg/kg)	3.22 $\pm$ 0.36	4.95 $\pm$ 0.10	5.66 $\pm$ 0.50
Potassium (mg/kg)	68.69 $\pm$ 6.14	48.78 $\pm$ 2.01	99.49 $\pm$ 2.11

Kubwa had the highest mean moisture content (25.00%) and fixed carbon content (19.94%), with a mean calorific value of 2,877.85 kJ/kg. Its mean nitrogen content was 0.29%, while phosphorus and potassium were 3.22 mg/kg and 68.69 mg/kg, respectively.

Bwari had a mean moisture content of 21.58% and the highest mean ash content (49.67%). Its mean volatile matter (20.10%), fixed carbon (9.66%) and calorific value (1,617.99

kJ/kg) were lower than those observed in Kubwa and Dutse. Mean nitrogen, phosphorus and potassium values were 0.17%, 4.95 mg/kg and 48.78 mg/kg, respectively.

Dutse recorded the lowest mean moisture content (8.66%) and the highest mean volatile matter (56.23%). The mean calorific value was 2,545.09 kJ/kg. Dutse also recorded the highest mean phosphorus (5.66 mg/kg) and potassium (99.49 mg/kg) values among the three markets.

Heavy-Metal Concentrations**Table 2: Heavy-Metal Concentrations in Market Waste (Mg/Kg; N = 4 Field Samples Per Market)**

Parameter	Kubwa (Min–Max)	Kubwa (Mean)	Bwari (Min–Max)	Bwari (Mean)	Dutse (Min–Max)	Dutse (Mean)
Lead (Pb)	14.69 – 199.50	107.10	12.00 – 45.00	28.50	14.69 – 98.16	56.43
Arsenic (As)	0.59 – 6.00	3.30	0.99 – 4.00	2.49	0.46 – 6.90	3.68
Mercury (Hg)	0.02 – 4.23	2.13	0.06 – 1.75	0.91	0.03 – 3.25	1.64
Cadmium (Cd)	0.25 – 0.32	0.29	0.97 – 1.03	1.00	0.01 – 0.02	0.02
Copper (Cu)	0.49 – 0.55	0.52	2.44 – 2.80	2.62	0.95 – 1.05	1.00
Iron (Fe)	1338.55 – 1495.23	1416.90	1987.56 – 2099.08	2043.32	2231.54 – 2567.23	2399.39

Heavy metals were detected in samples from all three markets, with distinct concentration patterns. Kubwa recorded the highest mean Pb concentration (107.10 mg/kg) and mean Hg concentration (2.13 mg/kg). Mean as, Cd, Cu and Fe concentrations in Kubwa were 3.30, 0.29, 0.52 and 1,416.90 mg/kg, respectively.

Bwari recorded mean concentrations of 28.50 mg/kg Pb, 2.49 mg/kg as, 0.91 mg/kg Hg, 1.00 mg/kg Cd, 2.62 mg/kg Cu and 2,043.32 mg/kg Fe. Among the three markets, Bwari had the highest mean Cd and Cu concentrations.

Dutse recorded mean concentrations of 56.43 mg/kg Pb, 3.68 mg/kg as, 1.64 mg/kg Hg, 0.02 mg/kg Cd, 1.00 mg/kg Cu and

2,399.39 mg/kg Fe. Dutse had the highest mean as and Fe concentrations among the three markets.

These results show spatial variation in metal concentrations within the mixed market-waste stream. Because no formal human-health or ecological risk assessment was undertaken and no matrix-specific regulatory benchmark for raw mixed market waste was established in this study, the concentrations are reported descriptively rather than classified as regulatory exceedances.

Discussion

Physical Composition

The findings of this study revealed that organic/food waste constitutes the dominant component across all three markets Kubwa (55.70%), Bwari (59.50%), and Dutse (60.20%). The high proportion of organic waste across the markets can be attributed to the predominance of agricultural produce and food-related trading activities within the study area. This result is consistent with previous studies conducted in Nigerian urban markets, which similarly reported a high prevalence of biodegradable waste due to the dominance of food items (Adeniran et al., 2017).

Comparable findings have also been reported in other developing countries; for instance, Monney et al. (2013) observed that organic waste constituted the largest fraction of municipal solid waste in Ghana, accounting for approximately 61%. The high organic content observed in this study suggests significant potential for composting and bio-energy recovery if properly harnessed.

Furthermore, the study revealed variations in the proportion of plastic and rubber waste across the markets, with Bwari Market recording the highest percentage (20.00%), compared to Kubwa (5.40%) and Dutse (12.10%). This variation may be attributed to differences in consumption patterns, packaging practices, and levels of regulatory enforcement across the markets. The relatively high proportion of plastic waste in Bwari supports earlier findings by Adeolu et al. (2014), who reported increased use of non-biodegradable packaging materials in semi-urban markets. Similarly, Abubakar et al. (2019) also documented increasing plastic waste generation in Nigerian urban and semi-urban environments.

Metal waste was found to be most prominent in Dutse Market (11.07%), followed by Kubwa (8.40%) and Bwari (4.07%). This pattern may be associated with the presence of metal-packaged goods and inadequate waste segregation practices within the market. This finding aligns with Kihila et al. (2021), who noted that poor segregation systems often result in higher quantities of recyclable materials being mixed within the general waste stream.

In addition, paper and cardboard waste were most prevalent in Kubwa Market (24.30%), indicating a higher reliance on carton-based packaging materials and a relatively structured trading system. Textile waste was more noticeable in Bwari (4.80%) and Dutse (4.07%), which may reflect the presence of second-hand clothing and fabric-related trading activities. This observation is consistent with the findings of Oyelola and Babatunde (2008), who emphasized that the composition of market waste is strongly influenced by the types of goods sold within the market environment.

Minor components such as grit and gravel were generally low across all markets but were slightly higher in Dutse Market (1.20%). This may be linked to environmental factors such as unpaved surfaces and open market conditions that facilitate the accumulation of dust and soil particles in the waste stream.

Overall, the variations observed in the composition of waste across the three markets highlight differences in trading activities, material usage patterns, and waste management practices. These findings underscore the need for tailored waste management strategies that consider the specific characteristics of each market, particularly in promoting waste segregation, recycling, and resource recovery.

Physicochemical Properties and Resource-Recovery Potential

The proximate analysis demonstrates that waste from Kubwa and Dutse markets possesses favorable characteristics for energy recovery. Their relatively high volatile matter and calorific values indicate the presence of substantial combustible fractions. The particularly low moisture content in Dutse further enhances its suitability for waste-to-energy applications.

Conversely, the high ash content observed in Bwari suggests a greater proportion of inert materials, which may reduce thermal efficiency and increase residue generation. This indicates that Bwari waste may be less suitable for direct thermal conversion and may instead benefit from material recovery approaches.

From a nutrient perspective, the moderate nitrogen content and relatively higher phosphorus and potassium values especially in Dutse indicate potential for composting if proper source segregation is implemented. However, the overall nutrient levels suggest that enrichment or co-composting may be required to produce high-quality compost.

Heavy-Metal Concentrations and Management Implications

The detection of Pb, Hg and other metals is important when considering recovery pathways for market waste. Kubwa recorded the highest mean Pb and Hg concentrations, whereas Dutse recorded the highest mean as and Fe concentrations and Bwari the highest mean Cd and Cu concentrations. These patterns indicate that mixed market waste can contain metals that may constrain direct reuse of the organic fraction. However, the present study did not conduct a formal human-health or ecological risk assessment, and the results should not be interpreted as evidence of regulatory exceedance without a benchmark that is explicitly applicable to the same waste matrix.

Before composting, soil application or other valorization of the organic fraction, source segregation and appropriate chemical quality testing are therefore advisable. This is particularly important because mixing food waste with metallic, plastic and other commercial wastes can alter the quality of the recoverable organic fraction.

Overall, the findings confirm that market waste streams in Bwari Area Council are heterogeneous and site-specific. Therefore, uniform waste management strategies may be ineffective. Instead, tailored interventions based on waste characterization are required.

Study Limitations

This study provides baseline information on the physical composition, physicochemical properties and heavy-metal concentrations of market-generated solid waste in Kubwa, Bwari and Dutse. Sampling was conducted in June, October and November 2024 and included multiple positions within the market dumpsites; nevertheless, the three-month period does not represent a complete annual or seasonal cycle, and the findings should not be generalized to all markets in Bwari Area Council or the wider FCT.

Physical sorting and weighing are also subject to classification and measurement error, particularly where waste is not segregated at source. In addition, although the laboratory procedure documented replicate digestion and basic contamination-control measures, the laboratory records available for this revision did not provide certified reference material recoveries, metal-analysis blanks, LOD or LOQ values. This limits the extent to which analytical accuracy and detection performance can be independently evaluated.

Despite these limitations, the dataset provides a useful baseline for designing more extensive seasonal sampling and for developing market-specific waste segregation and resource-recovery strategies.

Conclusion

This study provides baseline evidence on the physical composition, physicochemical properties, resource-recovery potential and heavy-metal content of market-generated waste from Kubwa, Bwari and Dutse markets. Organic/food waste constituted more than half of the characterized waste in each market, indicating substantial potential for biological recovery where effective source segregation is established. Differences in paper, plastics, metals and other fractions also show that recovery strategies should reflect the specific waste profile of each market. The physicochemical results indicate possible material and energy-recovery opportunities: Kubwa recorded the highest mean calorific value, while Dutse combined relatively high volatile matter with the highest phosphorus and potassium values. Heavy metals were detected in all three markets, with the highest mean Pb and Hg concentrations in Kubwa. These measurements do not constitute a formal risk assessment, but they demonstrate the need for chemical quality control before waste-derived materials are used for composting, soil application or other recovery purposes. Future work should extend sampling across a full seasonal cycle, increase independent field replication and report complete analytical QA/QC, including blanks, recoveries, certified reference materials, LOD and LOQ where available. For management practice, source segregation, routine chemical monitoring and market-specific recovery systems are recommended to improve the safe utilization of recoverable waste fractions in Bwari Area Council.

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