



Experimental Characterization and Seasonal Energy Potential Assessment of Municipal Solid Waste in Kano City, Nigeria

Sirajo ALHASSAN^{1*}, Abdullahi A. ADAMU², Mohammed T. JIMOH³

^{1,2,3}Department of Mechanical Engineering, Bayero University, Kano, Nigeria

^{1*}fatysira@gmail.com, ²aadamu.mec@buk.edu.ng, ³mtjimoh.mec@buk.edu.ng

Abstract

Municipal solid waste (MSW) management remains a critical environmental challenge in rapidly urbanizing regions such as Kano City, Nigeria. This study presents an experimental characterization and energy potential assessment of MSW based on seasonal variation (dry and wet seasons). Representative samples were collected from four major dumping sites: Sallari, Maimalari, Uba Gama, and Hajj Camp. Proximate and ultimate analyses were conducted to determine moisture content, ash content, volatile matter, fixed carbon, and elemental composition (C, H, O, N, and S). The results reveal clear seasonal differences in MSW properties. Moisture content ranged from $\approx 28.25\%$ in the dry season to $\approx 44.25\%$ in the wet season, while ash content varied between $\approx 28.50\%$ and $\approx 31.50\%$. Volatile matter increased from $\approx 19.75\%$ in the wet season to $\approx 28.40\%$ in the dry season, and fixed carbon ranged from $\approx 4.50\%$ to $\approx 14.85\%$. Ultimate analysis revealed relatively stable elemental composition across seasons, with carbon ($\approx 45.57\text{--}46.23\%$), hydrogen ($\approx 6.49\text{--}6.58\%$), oxygen ($\approx 45.31\text{--}46.31\%$), nitrogen ($\approx 1.42\text{--}1.43\%$), and sulfur ($\approx 0.23\text{--}0.24\%$). These results indicate moderate fuel characteristics with variability influenced by seasonal conditions. The higher heating value (HHV) was estimated to range between ≈ 16.43 and ≈ 16.95 MJ/kg, while the lower heating value (LHV) ranged from ≈ 13.92 to ≈ 14.82 MJ/kg, with higher values observed during the dry season due to reduced moisture content. The findings suggest that although high moisture and ash contents may limit the efficiency of direct combustion, the waste stream possesses moderate energy recovery potential. Overall, the findings confirm the suitability of MSW in Kano City for thermochemical conversion technologies such as pyrolysis and gasification, particularly with appropriate pre-treatment strategies. This study provides robust, seasonally resolved experimental data for supporting sustainable waste-to-energy planning and decision-making in rapidly growing urban environments.

Keywords: Calorific value; Energy recovery; Municipal solid waste; Seasonal variation; Waste-to-energy.

1. Introduction

Rapid urbanization, population growth, and changing consumption patterns have significantly increased the generation of municipal solid waste (MSW) worldwide [1], [2]. According to the World Bank, global waste generation is projected to exceed 3.4 billion tonnes annually by 2050, with developing countries experiencing the fastest growth [2]. In Nigeria, ineffective waste management practices, including open dumping and uncontrolled landfilling, remain prevalent and pose serious environmental and public health risks [3], [4].

In Kano City, one of the largest and most densely populated cities in Nigeria, the increasing volume of MSW has overwhelmed existing waste management infrastructure [5]. The predominant disposal methods, including open dumping and occasional burning, contribute significantly to environmental pollution, greenhouse gas emissions, and the proliferation of disease vectors [3], [6]. These practices have been widely reported to degrade air and water quality and pose serious public health risks in rapidly urbanizing regions [1], [5].

Waste-to-energy (WtE) technologies have gained global attention as viable solutions for managing MSW while simultaneously generating energy [7], [8]. Thermochemical conversion processes such as incineration, gasification, and pyrolysis offer significant opportunities for energy recovery from waste streams [9], [10]. However, the performance and efficiency of these technologies are highly dependent on the physicochemical properties of the waste, including moisture content, ash content, volatile matter, fixed carbon, and elemental composition [11].

Seasonal variation is a critical factor affecting MSW characteristics, particularly in tropical regions [12], [13]. During the wet season, increased rainfall leads to higher moisture content and enhanced biodegradation of organic waste, which significantly reduces calorific value and energy recovery potential [13], [14]. Conversely, the dry season is associated with lower moisture content and improved fuel characteristics, resulting in higher energy efficiency [14]. Despite its importance, limited studies have systematically investigated the seasonal variability of MSW properties and their implications for energy recovery in Kano City.

Experimental characterization of MSW through proximate and ultimate analyses provides essential data for evaluating its suitability as a fuel [15], [16]. These analyses enable the estimation of key energy parameters such as the higher heating value (HHV) and lower heating value (LHV), which are critical for the design and optimization of WtE systems [16], [17]. Empirical correlations, such as those developed by [17], are widely used for estimating calorific values based on elemental composition.

Although several recent studies have examined MSW characteristics in different regions, there remains a lack of comprehensive, seasonally resolved experimental data for Kano City. In particular, the integration of proximate analysis, ultimate analysis, and energy potential assessment within a seasonal framework remains largely unexplored, particularly in the context of integrated seasonal experimental characterization and energy assessment in Kano City. This represents a significant research gap, especially in the context of developing sustainable WtE systems for rapidly growing urban centers [18]-[21].

Therefore, this study aims to experimentally characterize municipal solid waste from selected dumping sites in Kano City and assess its energy recovery potential from a seasonal perspective. The specific objectives are to:

- Determine the proximate composition of MSW
- Evaluate the ultimate (elemental) composition
- Estimate the calorific values (HHV and LHV) and energy recovery potential

The findings of this study are expected to provide valuable baseline data for the design, optimization, and implementation of sustainable waste-to-energy systems in Kano City and similar urban environments. This study uniquely integrates seasonal experimental characterization with energy potential estimation, providing critical data for designing context-specific waste-to-energy systems in developing urban environments.

2. Materials and Methods

2.1 Study Area and Sampling Sites

This study was conducted in Kano City, Nigeria. Four major dumping sites, Sallari, Maimalari, Uba Gama, and Hajj Camp, were selected based on their representativeness of municipal waste generation sources, including residential, commercial, and mixed-use activities.

2.2 Sample Collection

Municipal solid waste (MSW) samples were collected during both the wet and dry seasons to account for seasonal variability. At each site, approximately 10–15 kg of mixed waste was collected using a random sampling approach.

To ensure representativeness, the quartering method was applied. The collected waste was thoroughly mixed, divided into four parts, and the opposite quarters were retained. This process was repeated until a representative sample size was obtained. Samples were stored in sealed polyethylene bags and transported to the laboratory for analysis.

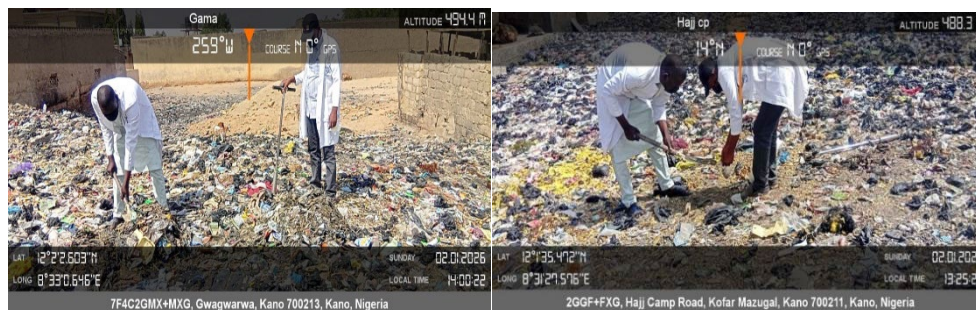


Figure 1: Field collection of representative municipal solid waste samples from major dumping sites in Kano City, ensuring spatial and seasonal coverage

2.3 Physical Composition Analysis

The physical composition of MSW was determined through manual sorting following standard procedures recommended by the American Society for Testing and Materials.

Each sample was segregated into the following categories:

- Organic waste
- Plastics
- Paper and cardboard
- Metals
- Glass
- Textiles
- Others (fines, dirt, inert materials)

Each fraction was weighed using a digital weighing balance (ADG 5000) and a spring weighing balance for larger fractions. The percentage composition was calculated using Equation (1):

$$\text{Composition (\%)} = (\text{Weight of component} / \text{Total sample weight}) \times 100 \quad (1)$$

All measurements were conducted in triplicate, and mean values were reported.

2.4 Sample Preparation

The samples were first air-dried to remove surface moisture and subsequently oven-dried at 105°C using an electric oven (Gallenkamp OHF097.XX.1.5) until constant weight was achieved.

The dried samples were then crushed, ground, and sieved to obtain a uniform particle size. The prepared samples were stored in airtight containers to prevent moisture reabsorption before analysis. All laboratory analyses were conducted at the Pollution Control Laboratory, Ministry of Environment and Climate Change, Kano State, Nigeria, using calibrated equipment and standard ASTM procedures.



Figure 2: Electric oven (Gallenkamp OHF097.XX.1.5) used for moisture determination

2.5 Proximate Analysis

Proximate analysis was conducted to determine moisture content (MC), ash content (AC), volatile matter (VM), and fixed carbon (FC) using standard ASTM procedures. Proximate analysis (moisture content, volatile matter, ash content, and fixed carbon) was conducted in accordance with standard procedures (ASTM D3173, ASTM D3175, ASTM D3174) [22-25].

- **Moisture Content (MC):** Determined by oven drying at 105°C using the Gallenkamp electric oven.
- **Ash Content (AC):** Determined by combusting the sample at 550°C in a muffle furnace (Carbolite CWF11/5, 1/98/51) using ceramic dishes.
- **Volatile Matter (VM):** Determined by heating the sample at high temperature in the absence of air using the same Carbolite muffle furnace.
- **Fixed Carbon (FC):** Calculated by difference using Equation (2) below:

$$FC (\%) = 100 - (MC + AC + VM) \quad (2)$$



Figure 3: Muffle furnace (Carbolite CWF11/5, 1/98/51) used for the determination of ash content and volatile matter with the support of ceramic dishes

2.6 Ultimate Analysis

Ultimate analysis was performed using an EMA 502 Micro Elemental Analyzer (CHNS-O) to determine the elemental composition of carbon (C), hydrogen (H), nitrogen (N), and sulphur (S). Ultimate analysis was performed in accordance with ASTM D5373 for CHNS determination.

Oxygen content was determined by difference using Equation (3).

$$O (\%) = 100 - (C + H + N + S + Ash) \quad (3)$$

All values were normalized to ensure mass balance:

$$C + H + O + N + S = 100\%$$

2.7 Calorific Value Determination

The Higher Heating Value (HHV) was estimated using the Dulong equation, which relates the elemental composition of the fuel to its calorific value [14, 17]. The HHV was calculated using Equation (4).

$$HHV (MJ/kg) = 0.338C + 1.428(H - O/8) + 0.095S \quad (4)$$

where C, H, O, and S represent the mass percentages of carbon, hydrogen, oxygen, and sulfur, respectively. This empirical correlation is widely used for estimating the energy content of solid fuels from ultimate analysis data.

The Lower Heating Value (LHV) was calculated using Equation (5).

$$LHV (MJ/kg) = HHV - 2.442 \times (9H/100 + M) \quad (5)$$

The energy recovery potential was estimated using Equation (6) below:

$$P = \frac{M \times LHV \times \eta}{3.6 \times 10^6} \quad (6)$$

where P is the power generation potential (MW), M is the mass of waste generated per day (kg/day), LHV is the lower heating value (MJ/kg), and η is the conversion efficiency of the waste-to-energy system. This formulation is consistent with standard energy balance principles and has been widely applied in waste-to-energy and fuel characterization studies [14], [17]. A conversion efficiency of 25% was assumed based on the typical performance of thermochemical conversion systems.

A daily waste generation rate of approximately 5,000 tonnes was assumed based on population estimates and typical per capita waste generation rates for urban areas in Nigeria.

2.8 Statistical Analysis

All experiments were conducted in triplicate, and results were expressed as mean \pm standard deviation. Statistical consistency was verified across sampling locations and seasonal variations.

3. Results and Discussion

3.1 Physical Composition of MSW

The physical composition of municipal solid waste (MSW) across the four dumping sites in Kano City shows clear seasonal variation, reflecting differences in waste generation patterns and environmental conditions.

During the wet season, organic waste constituted the largest fraction, with a mean of 58.25%, followed by fines and inert materials (14.50%), plastics (9.00%), and paper/cardboard (7.00%). In contrast, the dry season exhibited a reduced organic fraction (48.50%) and increased contributions from plastics (13.00%) and paper (11.00%).

The simplified physical composition of municipal solid waste in both wet and dry seasons is presented in Table 1. The table highlights the variation in waste fractions across seasons, providing insight into the influence of seasonal changes on waste generation patterns.

Table 1: Simplified Physical Composition of Municipal Solid Waste in Wet and Dry Seasons (%)

Component	Wet Season (%)	Dry Season (%)
Organic Waste	58.25	48.50
Plastics	9.00	13.00
Paper/Cardboard	7.00	11.00
Metals	3.25	4.00
Glass	3.50	4.50
Textiles	4.50	5.50
Fines/Inert	14.50	13.50
Total	100	100

Table 1. Note: Values represent mean percentage composition across the selected dumping sites.

The higher organic fraction during the wet season explains the elevated moisture content observed in the proximate analysis. Increased rainfall enhances the accumulation of food waste and biodegradable materials, leading to higher moisture retention. Conversely, the dry season is characterized by reduced biodegradation and increased presence of recyclable materials such as plastics and paper, which contribute to improved fuel characteristics.

The relatively high proportion of fines, sand, and inert materials in both seasons is consistent with the high ash content obtained from proximate analysis, indicating poor waste segregation practices.

As shown in Figure 4, the seasonal variation in MSW composition indicates a clear dominance of organic waste during the wet season, while the dry season shows increased fractions of plastics and paper. This shift reflects reduced moisture influence and improved combustibility of the waste stream during the dry season.

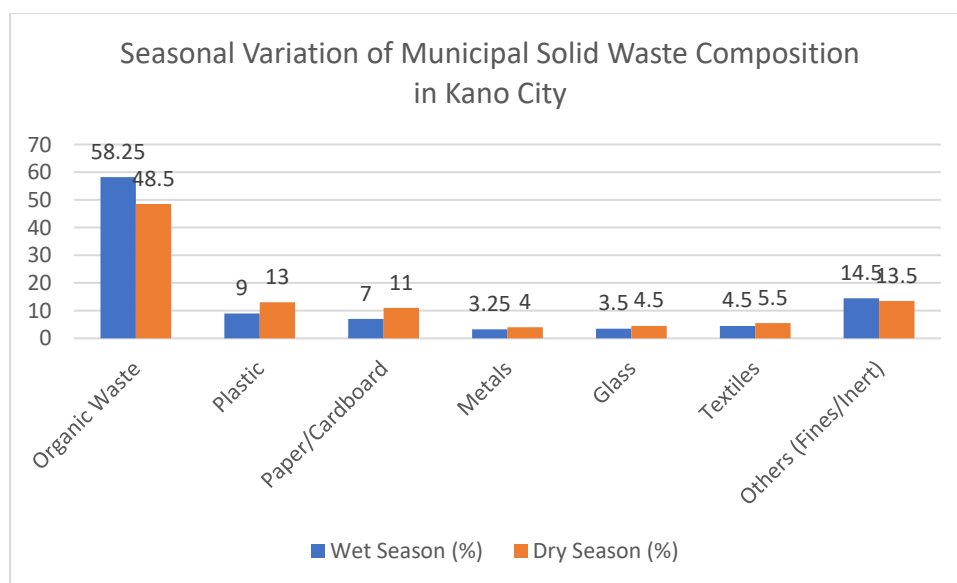


Figure 4: Seasonal variation of municipal solid waste composition in Kano City

3.2 Proximate Analysis

The proximate analysis results reveal a clear seasonal influence on the physicochemical characteristics of the municipal solid waste. The moisture content decreased significantly from 44.25% in the wet season to 28.25% in the dry season, reflecting increased water retention in organic-rich waste fractions during the wet season. These values fall within the typical range reported for MSW in developing countries [1], [12].

The volatile matter (VM) increased from 19.75% in the wet season to 28.40% in the dry season, indicating improved combustibility under drier conditions. This trend is consistent with the higher relative proportion of combustible materials such as plastics and paper observed during the dry season.

The ash content remained relatively high in both seasons, decreasing slightly from 31.50% (wet season) to 28.50% (dry season). This is attributed to the substantial presence of inert materials such as fines, sand, and debris within the waste stream. Elevated ash content is known to reduce thermal conversion efficiency and may lead to operational challenges such as slagging and fouling in thermochemical systems.

The fixed carbon (FC) content increased markedly from 4.50% in the wet season to 14.85% in the dry season, indicating enhanced potential for char formation and sustained combustion. This improvement further supports the suitability of the waste for thermochemical conversion processes during the dry season. Overall, the seasonal variation in proximate composition underscores the importance of accounting for temporal dynamics in the design and optimization of waste-to-energy systems.

The proximate analysis of municipal solid waste, including moisture content, volatile matter, ash content, and fixed carbon for both wet and dry seasons, is summarized in Table 2.

Parameter	Wet Season (%)	Dry Season (%)
Moisture Content	44.25	28.25
Ash Content	31.50	28.50
Volatile Matter	19.75	28.40
Fixed Carbon	4.50	14.85
Total	100	100

Table 2 Note: Values represent mean percentage composition across the selected dumping sites.

Figure 5 illustrates the variation in proximate parameters between seasons, highlighting a significant reduction in moisture content and a corresponding increase in volatile matter and fixed carbon during the dry season. This trend confirms the improved fuel characteristics of MSW under dry conditions.

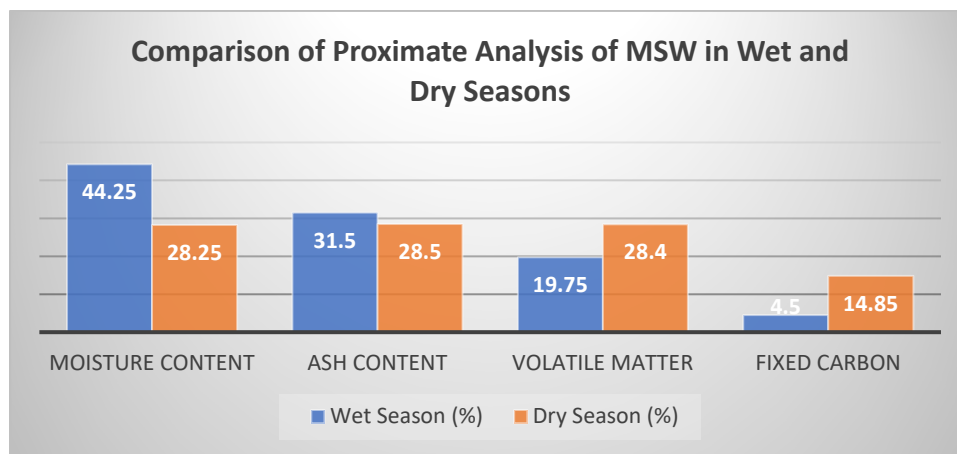


Figure 5: Seasonal variation of proximate parameters (moisture content, ash content, volatile matter, and fixed carbon) of MSW in Kano City

3.3 Ultimate Analysis

The ultimate analysis results indicate that the municipal solid waste is predominantly composed of carbon, oxygen, and hydrogen. Based on normalized values, the elemental composition shows carbon ranging from 45.57% to 46.23%, oxygen from 45.31% to 46.31%, and hydrogen from 6.49% to 6.58%, with minor contributions from nitrogen (≈ 1.42 – 1.43%) and sulphur (≈ 0.23 – 0.24%) as shown in Table 3 below.

The relatively high oxygen content reflects the dominance of biodegradable organic fractions and partially oxidized compounds within the waste stream, which contributes to a reduction in the overall calorific value. Nevertheless, the moderate carbon and hydrogen contents indicate that the waste retains appreciable energy potential for thermochemical conversion.

The low sulphur content ($<0.25\%$) suggests a minimal risk of sulphur oxide (SO_x) emissions during thermal processing, enhancing the environmental suitability of the waste for energy recovery applications. Additionally, the low nitrogen content implies limited potential for nitrogen oxide (NO_x) formation, further supporting its environmental compatibility. The relatively balanced C–H–O composition is indicative of typical heterogeneous MSW and supports its suitability for both thermochemical and biochemical conversion pathways.

Table 3: Simplified Ultimate Analysis of MSW (%)

Element	Wet Season (%)	Dry Season (%)
Carbon (C)	45.57	46.23
Hydrogen (H)	6.49	6.58
Oxygen (O)	45.31	46.31
Nitrogen (N)	1.42	1.43
Sulphur (S)	0.23	0.24
Total	100	100

Table 3 Note: Values are normalized to 100% and represent the mean elemental composition across the selected dumping sites.

As presented in Figure 6, carbon and oxygen constitute the major elements of the waste, while hydrogen contributes moderately, and nitrogen and sulphur remain minimal. This composition supports the observed moderate calorific values and indicates suitability for thermochemical conversion processes.

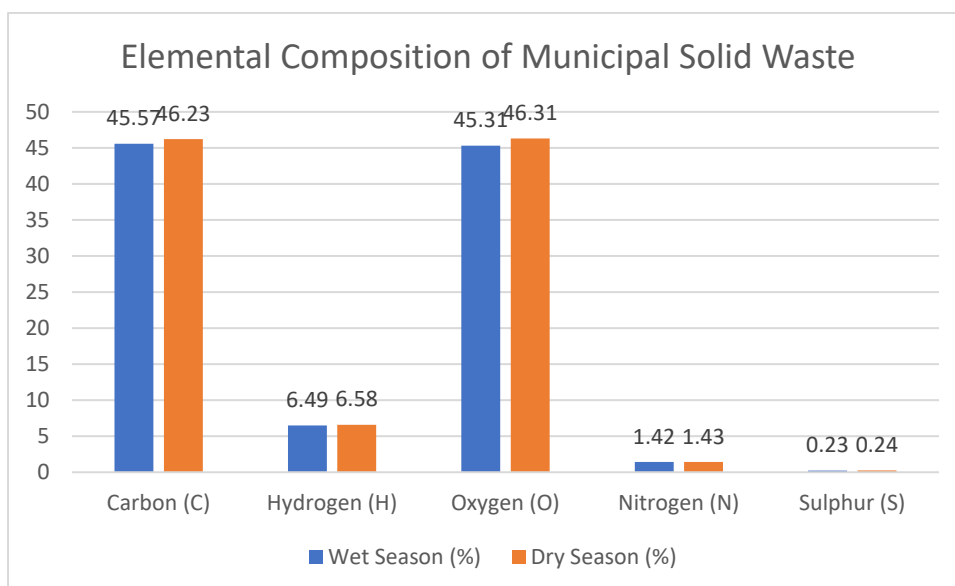


Figure 6: Ultimate analysis showing elemental composition (C, H, O, N, and S) of municipal solid waste

3.4 Calorific Value Analysis (HHV and LHV)

The energy properties of municipal solid waste in both wet and dry seasons are presented in Table 4. The parameters include Higher Heating Value (HHV), Lower Heating Value (LHV), and the estimated energy recovery potential.

The calorific value analysis indicates moderate energy recovery potential with a clear influence of seasonal variation. The higher heating value (HHV) increased from 16.43 MJ/kg in the wet season to 16.95 MJ/kg in the dry season, while the lower heating value (LHV) increased from 13.92 MJ/kg to 14.82 MJ/kg. This trend reflects improved fuel quality under drier conditions.

These values fall within the typical range of 10–20 MJ/kg reported for municipal solid waste [11], confirming the suitability of the waste stream for energy recovery applications. The relatively lower calorific values observed during the wet season are primarily attributed to the higher moisture content, which reduces the effective energy output due to the latent heat required for moisture evaporation during thermal conversion.

Furthermore, the observed calorific values are consistent with the elemental composition, particularly the moderate carbon and hydrogen contents and the relatively high oxygen fraction, which collectively influence the energy content of the waste. The higher HHV and LHV recorded in the dry season further support the enhanced suitability of the waste for thermochemical conversion processes during this period.

These results highlight the importance of incorporating seasonal variability into the design and operational optimization of waste-to-energy systems to maximize energy recovery efficiency.

Table 4: Energy Properties of Municipal Solid Waste in Wet and Dry Seasons

Parameter	Wet Season	Dry Season
HHV (MJ/kg)	16.43	16.95
LHV (MJ/kg)	13.92	14.82
Energy Recovery Potential (MW)	4.83	5.15

Table 4 Note: HHV and LHV were estimated using empirical correlations, while energy recovery potential was calculated based on the available waste quantity and calorific values.

Figure 7 shows a clear increase in both HHV and LHV during the dry season, reflecting the influence of reduced moisture content and increased combustible fractions such as plastics and paper.

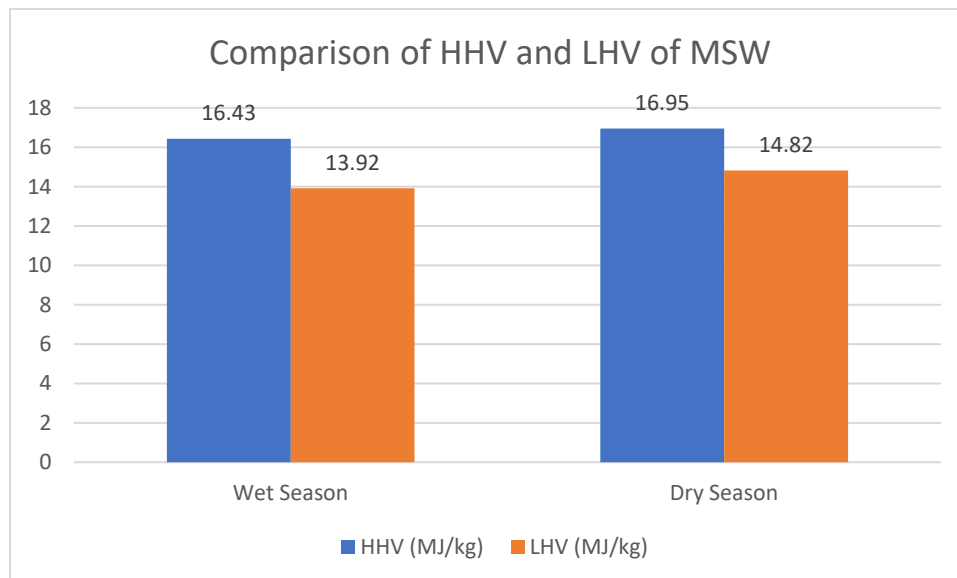


Figure 7: Comparison of higher heating value (HHV) and lower heating value (LHV) of MSW for wet and dry seasons

3.5 Energy Recovery Potential

Based on the lower heating value (LHV) and an assumed waste generation rate of approximately 5,000 tonnes per day, the estimated energy recovery potential of municipal solid waste in Kano City is approximately 4.83 MW during the wet season and 5.15 MW in the dry season, representing an increase of about 6.6%. This variation reflects the influence of seasonal changes in moisture content and combustible fractions on the overall energy generation potential.

The higher energy recovery observed during the dry season is primarily attributed to the reduced moisture content and the increased proportion of combustible materials such as plastics and paper, as reflected in the proximate analysis. Lower moisture content enhances the effective calorific value by minimizing energy losses associated with moisture evaporation during thermal conversion.

Furthermore, the increase in volatile matter and fixed carbon during the dry season contributes to improved fuel reactivity and sustained combustion, thereby enhancing overall energy output. These findings underscore the importance of incorporating seasonal variability into the design and optimization of waste-to-energy systems to ensure consistent and efficient energy generation. Energy recovery potential was estimated based on daily waste generation rates, calorific value, and assumed conversion efficiency.

The estimated energy potential indicates that municipal solid waste in Kano City can serve as a viable supplementary energy resource, contributing to sustainable energy generation and landfill diversion.

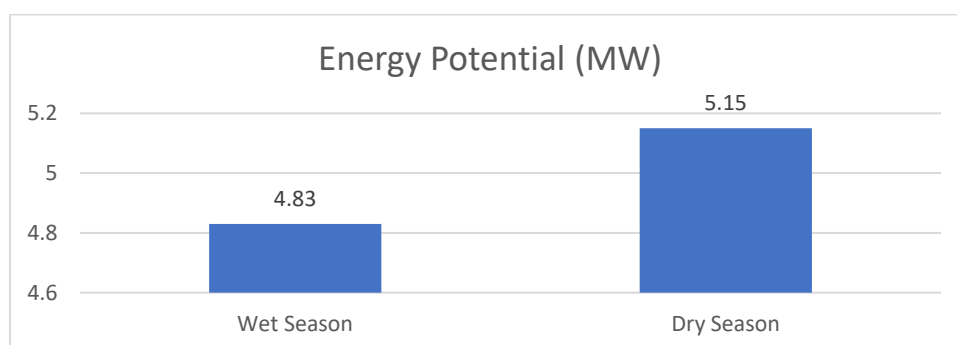


Figure 8: Estimated energy recovery potential (MW) of municipal solid waste during wet and dry seasons

As shown in Figure 8, the energy recovery potential is higher in the dry season, confirming that seasonal variation significantly influences power generation efficiency from MSW.

3.6 Integrated Interpretation

The findings demonstrate a strong interrelationship between waste composition, proximate characteristics, and energy recovery potential. A higher proportion of organic waste during the wet season contributes to increased moisture content, which in turn reduces the higher heating value (HHV) due to the additional energy required for moisture evaporation during thermal conversion.

In contrast, the dry season is characterized by a relatively higher proportion of combustible materials such as plastics and paper, resulting in increased volatile matter and improved calorific values. This enhances the overall fuel quality and energy recovery potential of the waste during this period.

Additionally, the consistently high presence of inert materials, including fines, sand, and debris, contributes to elevated ash content in both seasons. This reduces the effective energy yield and may negatively impact the performance and efficiency of thermochemical conversion systems.

Overall, the observed relationships confirm the internal consistency between the physical composition, proximate and ultimate analyses, and calorific value results. This coherence across multiple analytical parameters validates the reliability of the experimental data and supports its applicability for waste-to-energy system design and optimization.

This integrated consistency across multiple analytical parameters strengthens the reliability of the dataset for practical waste-to-energy system design.

3.7 Validation of Results with Existing Studies

The results obtained in this study are consistent with findings reported in global, regional, national, and local studies on municipal solid waste (MSW) characterization and energy potential.

At the global level, MSW in developing regions is typically dominated by biodegradable fractions ranging from 50–65%, with moderate calorific values suitable for waste-to-energy applications [26]. Similar trends have been reported in recent MSW energy modeling studies, which highlight the strong influence of moisture content and volatile matter on calorific value and overall energy recovery efficiency [27].

At the regional (African) level, studies across major urban centers indicate that organic waste constitutes the largest fraction of MSW, often exceeding 50%, alongside significant contributions from plastics and paper. For example, characterization studies in African urban centers report organic fractions typically exceeding 50% organic content, confirming the predominance of biodegradable waste streams in African cities [28].

At the national level (Nigeria), similar waste characteristics have been widely reported, with high moisture content and substantial organic fractions influencing both environmental impacts and energy recovery potential. Previous studies have also shown that increased plastic content enhances calorific value, supporting the observed increase in volatile matter and energy potential during the dry season in the present study [29].

At the local level (Kano State), several studies strongly corroborate the findings of this research. A characterization study conducted at Bayero University, Kano, reported that MSW comprises approximately 55.85% organic content and 24.99% plastics, indicating considerable potential for energy recovery [30]. Similarly, earlier investigations in Kano metropolis identified a heterogeneous waste stream dominated by organics, plastics, textiles, and paper fractions, reflecting the mixed nature of municipal waste in the city [31].

More recent studies further reinforce these observations. Analyses of waste-to-energy potential in Kano highlight the significant presence of combustible materials such as plastics, paper, and textiles, which are critical for thermochemical conversion processes [32]. In addition, investigations of incinerated MSW identified similar dominant fractions, confirming the abundance of energy-relevant components [33]. Assessments of waste management systems in Kano also report biodegradable fractions exceeding 60%, alongside poor waste segregation practices that contribute to elevated ash content [34]. Furthermore, recent composition analyses indicate increasing proportions of plastics (~22.6%) and inert materials (~18.5%), reflecting the impact of urbanization on waste characteristics [35].

Overall, the consistent between these studies and the present findings confirms that MSW in Kano City is characterized by high organic content, significant combustible fractions, and notable inert materials, all of which directly influence its energy recovery potential. This consistency validates the reliability of the experimental data and reinforces the suitability of the waste stream for waste-to-energy applications in the region.

To further validate the results, a comparison with previously reported studies in Kano is presented in Table 5.

Table 5: Comparison of This Study with Reported MSW Characteristics in Kano

Parameter	This Study	Reported Range	References
Organic (%)	48.50–58.25	50–65	[30], [34]
Plastics (%)	9.00–13.00	20–25	[30], [35]
Paper (%)	7.00–11.00	8–12	[31], [33]
Moisture (%)	28.25–44.25	30–55	[29], [34]
Ash (%)	28.50–31.50	20–35	[34], [35]
VM (%)	19.75–28.40	20–40	[29], [32]
FC (%)	4.50–14.85	5–15	[29], [32]
Carbon (%)	45–46	40–55	[29], [32]

Parameter	This Study	Reported Range	References
Hydrogen (%)	6–7	5–7	[29]
Oxygen (%)	44–45	35–50	[29]
HHV	16.43–16.95	10–20	[29], [32]
LHV	13.92–14.82	8–15	[29], [32]

Table 5 Sources: Reported ranges are synthesized from multiple studies conducted in Kano and Nigeria under varying sampling conditions and methodologies [29]–[35].

As shown in Table 5, the results of this study fall within the ranges reported in previous studies conducted in Kano and similar urban environments. Minor variations can be attributed to seasonal effects, differences in sampling locations, and evolving waste generation patterns due to urbanization. This strong agreement further confirms the reliability and representativeness of the experimental data.

4. Conclusion

This study comprehensively evaluated the physicochemical properties and energy recovery potential of municipal solid waste (MSW) in Kano City, with particular emphasis on seasonal variability. The findings revealed that moisture and ash contents were relatively high, especially during the wet season, which adversely affects the efficiency of thermochemical conversion processes. In contrast, the dry season was characterized by lower moisture content and higher volatile matter and fixed carbon, indicating improved fuel quality.

Ultimate analysis confirmed that the waste stream is predominantly composed of carbon, hydrogen, and oxygen, with minimal nitrogen and sulphur content. This composition suggests moderate fuel quality and a relatively low risk of harmful emissions, supporting the suitability of the waste for energy recovery applications.

The calorific value analysis demonstrated moderate energy potential, with higher heating value (HHV) and lower heating value (LHV) increasing from 16.43 to 16.95 MJ/kg and from 13.92 to 14.82 MJ/kg, respectively, from the wet to the dry season. Correspondingly, the estimated energy recovery potential ranged from 4.83 MW to 5.15 MW, representing improved performance under dry season conditions.

Despite this potential, elevated moisture and ash contents may limit the efficiency of direct combustion systems without appropriate pre-treatment. Therefore, process optimization strategies such as waste segregation, drying, and densification are essential to enhance fuel characteristics and overall system performance.

The seasonal variation observed suggests that waste composition and energy content are influenced by climatic and socio-economic factors, which must be considered in the design of waste-to-energy systems.

Overall, MSW in Kano City represents a viable feedstock for waste-to-energy technologies, particularly thermochemical processes such as gasification and pyrolysis. Incorporating seasonal variability into system design and operational planning, alongside appropriate pre-treatment measures, can significantly improve energy recovery efficiency. The results of this study provide critical baseline data to support sustainable waste management strategies and informed energy planning in rapidly urbanizing regions. This study provides a critical experimental foundation for integrating waste-to-energy systems into sustainable urban waste management frameworks in Nigeria and similar developing regions.

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