

Conversion and analysis of incinerated Kano municipal solid wastes for management and control

Shaba Idris Hassan ¹, Ojong Elias Ojong ², Wosu Chimene Omeke ^{3,*} and Dagde Kenneth Kekpugile ⁴

¹ Strive Prime Consulting Solutions Limited Abuja, Number 35 Julius Nyerere Crescent Asokoro, Abuja, Nigeria.

² Department of Chemical and Petrochemical Engineering, Faculty of Engineering and Technology, University of Calabar, P.M.B. 1115 Calabar, Cross River State, Nigeria.

³ Department of Chemical Engineering, Faculty of Engineering, Federal University Otuoke, Bayelsa State, Nigeria.

⁴ Chemical/Petrochemical Engineering, Faculty of Engineering, Rivers State University, Port Harcourt, Nigeria.

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Abstract

The study of conversion and analysis of incinerated Kano Municipal Solid Waste (MSW) for management and control has been successful. The work considered Kano Metropolis City with eight (8) Local Government Areas and three (3) major dumpsites (Court Road, Maimalari and Kuka Bulukiya) for collection and discharging of Municipal Solid Waste. Laboratory analysis was conducted for sampled size of waste generated streams, field analysis and investigation of different types of solid waste streams, MSW were analysed and characterized. Compositional analysis of the different types of combustible MSW was carried out after been incinerated in a Laboratory. The results of the waste characterization study revealed that food wastes, plastic paper, cardboard, metal tins/cans, thin film (nylon) and leather, and textile materials were the most common MSW generated at the three selected dumpsites in Kano metropolis. The thin film (nylon) and leather, paper/cardboard and textile wastes were the most produced solid wastes in that order at Court Road, Maimalari and Kuka Bulukiya dumpsites after characterization process. The combustible solid wastes paper, wood, textiles and food waste were also characterized and compared. The comparative analysis showed that Court Road has the highest quantity of paper/cardboard and textile waste, while Kuka Bulukiya has more content of wood and food waste. Non-combustible wastes i.e., plastic & rubber, glass, ferrous metal, and aluminum were also studied. The proximate and ultimate analyses of the different types of the selected combustible solid wastes was conducted and a comparative analysis revealed that kitchen waste has more of %moisture content (21.14), paper has more % ash content (10.15), wood has more carbon content (25.54), and textile has more % sulphur content (2.73) and calorific value of 28.82). The gas emissions analysis yield revealed that textile wastes produce more of CO₂, CO and total volatile organic compound (TVOC) of values 0.005, 0.00034, and 4.932mg/m³ respectively, while wood gave more of H₂S, HCHO, and PM_{2.5} of values 0.06ppm, 1.185mg/m³ and 227µg/m³ respectively. Also, the analysis showed that kitchen wastes produce more of oxygen of value 19.57ppm compared to other samples. Based on the result, the analysis of ultimate gave more of carbon (0.542) and more of volatile matter (0.55), while proximate gave more of fixed carbon (0.272) of the biomass and 100% of ash was present in the ash proximate and ultimate analysis.

Keywords: Conversion; Analysis; Incineration; Solid Wastes; Control

1 Introduction

Since the beginning of the oil boom of the 1970s, Nigeria has become an increasingly urbanized and urban-oriented society. During the 1970s, Nigeria had possibly been the fastest urbanization growth rate in the world [1] [2]. Because

* Corresponding author: Wosu. Chimene Omeke

of the great influx of people into urban areas, the growth rate of urban population in Nigeria in 1986 was estimated to be close to 6 percent per year, more than twice that of the rural population [3].

Besides, cities are recognized as engines of social modernization and economic growth but are also areas where globalization impacts are manifested. For Nigeria this reflects in fueling the already unprecedented urban growth that outstrips available infrastructures many times over. Other impacts include the increased volume and variety of solid waste generated, resulting from growing Industrialization and manufacturing activities, increased flow of goods and services, and changed lifestyle and consumption pattern.

However, a study by the European Environment Agency (EEA) indicated that the amount of solid waste is expected to grow by 25 % from 2005 to 2020 and that limiting or avoiding growth in waste volumes would reduce greenhouse gas emissions from the waste sector and deliver other benefit to society and the environment [4]. Also, according to the Environmental Protection Agency (EPA) rising levels of gases in the Earth's atmosphere are causing changes in our climate, and some of these changes can be traced to solid waste. The result of a study conducted by Prof. Aliyu Baba Nabegu of the Kano State University of Science and Technology Wudil on the Role of Refuse Management and Sanitation Board (REMASAB) in Solid Waste Management in Kano Metropolis indicated that the current solid waste management system in Kano can only cover 30% of the solid wastes generated daily in the city due mainly to inappropriate institutional arrangement of management of solid waste, poor state of infrastructure and the lack of adequate funding [5].

Serval researches have been conducted on the impact of solid wastes on health and environment and thus;

[6], in their study of Solid Waste Management Application and Its Dilemma in Kano Metropolis-Nigeria, stated that municipal solid waste (MSW) in Kano is handled centrally by a single agency of the state government, and this is believed to have limit solid management efficiency in the area. Kano Metropolis itself is spread over eight (8) autonomous Local Government Area, yet the management of waste is still under the responsibility of a single agency. In most parts of the world where waste management has been efficient it has always been a local affair. The research findings showed that the Kano Metropolis produces 5,150 gallons of liquid waste and 180 tons of solid trash every day from its industrial sectors. Approximately 72% of the solid trash and 78% of the liquid waste produced in the research region are the result of urban residents. 80% and 20%, respectively, of the trash produced in Kano Metropolis is made up of solid and liquid wastes. Solid trash accounts for the majority (70%) of the waste produced in the Kano Metropolis. It is made up of water bags, sachets, polytene materials (45%), plastic (25%), paper (22%), and other materials such broken wood pieces (7%). Finally, the study concluded that only 25% of all solid waste produced is handled well.

[5], in his research reviewed the current municipal solid waste management in Kano metropolis by Refuse Management and Sanitation Board (REMASAB). Data for his study was obtained from published documents and questionnaire he administered to the government agency responsible for waste management and a random selection of the users of the service covering three zonal land uses of the city. The result of this research indicated that the current management system can only cover 30% of the solid wastes generated daily in the city due to inappropriate institutional arrangement of management of solid waste, poor state of infrastructure and the lack of adequate funding. Possible solutions that can improve the services such as involvement of stakeholders identified as the generators of waste; managers of the waste; the informal sector; community-based organizations and private sector participation were explored.

Nabeul has shown that localization of waste management has serious implications for the disposal, transport and economic of waste management. However, of recent solid waste management has taken a new dimension in Kano Metropolis more especially with the introduction of more solid waste stakeholders such as the private registered waste companies, and the German based private waste company known as CAPE GATE.

[7], researched on sustainability appraisal of waste management in Nigeria, development and Evaluation of an index-based tool. The decision makers are continuously in search of a comprehensive yet simple means of assessing solid waste management to make effective and informed decisions. In this study, an in-depth investigation of solid waste management in Nigeria is conducted by quantifying sustainable development to develop an assessment tool.

[8], researched on analyzing municipal solid waste treatment scenarios in rapidly urbanizing cities in developing countries, case of Dares Salaam, Tanzania. Large quantities of municipal solid waste (MSW) in many cities of the developing countries are being dumped in informal or formal but unregulated dumpsites that threaten the ecological environment and general public health.

[9], researched on sustainability of municipal solid waste management in Nigeria, a case study of Lagos. Waste generation is an unavoidable product of man's activities; however, sustainable management of such waste is a challenge faced in many countries today. Nigeria, a developing country in Africa, has been in a quandary of how to efficiently manage the municipal solid waste its population generates. Many states in the country lack adequate plans and infrastructure required for efficient and sustainable management of municipal solid waste. For Lagos, the most populous and popular state in Nigeria, the problem is further compounded by its rather large and still increasing population. Yetunde concluded that waste reduction, reuse, recycling and composting are potential management options for the state. Landfilling will remain an important option for final disposal but reliance on this method could be significantly reduced if management options are exploited to the maximum in a sustainable solid waste management structure.

[10], researched on evaluation of solid waste generation, categories and disposal options in developing countries, a case study of Nigeria. The quantity and generation rate of solid wastes in Nigeria have increased at an alarming rate over the years with lack of efficient and modern technology for the management of the wastes. The generation rate, collection and disposal of solid wastes are functions of several factors which if well considered and appropriated could bring the desired solution to the waste management problems in Nigeria. The quantity and rate of solid waste generation in several cities in Nigeria, factors influencing the generation, solid waste types and categories, collection, disposal, reuse and recycling, and environmental problems were investigated. The results indicated large generation at high rate without a corresponding efficient technology to manage the wastes. Of 201 respondents to questionnaire in Abeokuta, 35.8% used waste collection services, 64.2% used other waste disposal options, 16.4% used both, 68.7% and 58.7% were aware of waste collection service and waste management regulations, respectively, while 28.4% separated their solid wastes at source.

[11], researched on transforming trash, reuse as a waste management and climate change mitigation strategy. Waste reflects the culture that produces it and affects the health of the people and environment surrounding it. As urbanization and waste production increase on a global scale, cities are faced with the challenge of how to manage their waste effectively to minimize its negative impacts on public and environmental health. The review emphasized that source reduction and anaerobic digestion is best to control wastes and manage greenhouses.

[12], researched on evaluation of improvement priorities for municipal solid waste management in Ogun State, Nigeria using experiences from Finland. Municipal solid waste management (MSWM) is still at its starting phase in most developing countries. This phase consists of low municipal solid waste (MSW) re-use, inadequate collection, minor recycling, improper waste treatment and immense waste disposal prior to appropriate treatment. The contents of present MSW generated around the world has become more hazardous than in the past, making it necessary for proper collection, re-use, recycling, treatment and disposal. Also, as population growth continues to increase enormously in these countries, it has become necessary for them to develop a MSWM structure that utilizes the waste management hierarchy, the sustainable development principles and the integrated solid waste management approach. This study evaluated MSWM practices in Finland. The evaluation was structured around the legislations and practices that paved way to the present day admirable MSWM system in the country. The study also considered key performance indicators such as waste treatment and recovery technology level, actors/responsibilities of waste, the technical requirements of landfills and the extended producer responsibility (EPR) that influences the effective waste management in Finland. The goal of this research was to plan a MSWM framework that applies the bottom-up approach for Ogun state (Nigeria). Nevertheless, the framework could be applicable to other developing cities/countries that are in the same situation as Ogun State as they witness economic, technological and social growth. The study revealed that any MSWM framework development plan for developing countries should consider how to effectively merge scavengers and SMEs into the MSWM system. The growth and development of MSWM system for developing countries would be time consuming without an EPR scheme. The standard of living and the citizen's awareness to environmental protection in Nigeria needs to be improved in order to ensure a speedy and effective MSWM system.

[13], worked on potential impacts of climate change on waste management in Ilorin City Nigeria. Ilorin is one of the major cities in Nigeria today and its growing capacity in both socioeconomic affiliations is commendable. However, the city is potently polluted with heaps of refuse that occasionally caused traffic hold-up in places in the urban center. A lot of health incidence resulting from water, air and pest borne diseases are not uncommon within areas where prevalence of effluents prevailed. The problems of poor waste management upon the government efforts are as a result of the potential impacts of climate change on the natural world, and with wide effects resulting from these changes has its implications in Ilorin city. This work examines the management of waste in the city of Ilorin which has been the sole responsibility of the Kwara State Environmental Protection Agency (KWEPA) and other health management sectors. Worldly wise, there are evidence that climate change and its due, at least in part to human activities, gives rise to emissions of Greenhouse gases (GHGs) which invariably is disturbing the world [14].

[15], researched on waste management system in low-income areas of Jos, Nigeria. The challenges and waste reduction. He stated that over two (2) billion people do not have access to waste collection services, and 3 billion do not have access to controlled waste disposal. This lack of services and infrastructure has a detrimental impact on public health and the environment with waste being dumped or burnt in communities.

[16], researched on the review of municipal solid waste management in Nigeria, the current trends. The management of municipal solid waste (MSW) is essential for every community; and it is currently a major challenge in Nigeria. An overview of the current MSW management trends in Nigeria and proposes new sustainable MSW management systems was discussed. Across Nigerian cities, MSW management is characterized by inefficient collection and transportation to disposal sites. Collection services do not reach some unplanned areas and slums due to poor street network. Even some planned areas are not reached by collection services. The informal sector contributes to waste collection, resource recovery and recycling; however, their activities are not recognized by the governments. Markets exist for recovered materials, but more efforts need to be geared towards intensive recovery of materials and expansion of these markets. Despite the high proportion of putrescible matter in MSW, the only form of treatment commonly used currently is open burning for volume reduction. The high organic fraction presents a great opportunity for composting and anaerobic digestion. Ultimate disposal is currently done in open dumpsites. This needs to be upgraded to engineered landfills that are properly sited and adequately operated by well-trained personnel. There is an emerging waste stream of concern, electronic waste (e-waste), that requires urgent sustainable management as e-waste are currently co-disposed with other waste streams or burnt in the open posing detrimental health impacts.

[17], Stated that waste management has become a common issue of discourse among individuals, groups and governments. This study which assessed urban solid waste management in Ebonyi state with focus on Abakaliki urban specifically sought to find out why indiscriminate solid waste disposal/dumps has persisted in Abakaliki urban, investigate the measures put in place to curtail the tide and ascertain the extent to which indiscriminate waste disposal affects people's health and environment. Four null hypotheses were formulated, and Human Capital Theory was adopted as the theoretical framework. The study used survey design whereby data were collected from the sample considered to be representative of the population. The study concluded that, the Ebonyi State Environmental Protection Agency (EBSEPA) currently have no required manpower, technical skills and competences to curtail the tide of waste and therefore made the following recommendations: Ebonyi state government should strengthen the already established departments of Environmental and Health Sciences in Ebonyi State University (EBSU) and the School of Health Technology, Ezzamgbo, by providing and equipping them with modern waste management equipment for students to be exposed to practical methods of waste management, Government should contract foreign-based private firm through Public-Private-Partnership (PPP) arrangement to establish waste management industry in Ebonyi state, immediate provision of permanent waste dumpsites by the government, among others.

[18], Stated that the prevailing waste management strategy, especially in developing countries such as Nigeria, is far below standard, resulting in environmental contamination and pollution which hampers sustainability. How waste-to-energy can serve as a circular economy tool towards climate mitigation that will ensure environmental sustainability, is a key challenge related to moving beyond the perception of 'waste as a problem' to 'waste as a resource'. Ultimately, both waste prevention, as well as a widespread growth in circular economy activities, will require a coherent and holistic approach that takes recovery options into account at every stage of the product life cycle. They explored the potential inherent in Waste-to-Energy (WtE) as a tool. The work is qualitative and involves a synchronic evaluation of previous research works relevant to the study to ascertain the viability of WtE as a circular economic tool for scaling back adverse environmental impact

[19], researched solid waste management options for Africa. Waste generation, both domestic and industrial, continues to increase worldwide in tandem with growth in consumption. In developed countries, per capita waste generation increased nearly three-fold over the last two decades, reaching a level five to six times higher than that in developing countries. With increases in populations and living standards, waste generation in developing countries is also increasing rapidly, and may double in volume in the current decade. If current trends continue, the world may see a five-fold increase in waste generation by the year 2025. A high proportion of the waste could be recycled by the urban poor generating income for themselves and protecting the environment. There is a need to develop an integrated approach where the public, private and community sectors work together to develop local solutions promoting sustainable solid waste management the Sustainable Development and Poverty Reduction Unit (PSDU) of the African Development Bank (ADB) has commissioned a study on solid waste management options for Africa. The study encompasses a literature review of municipal waste management options in African countries and close examination of current waste management practices in the four main African municipalities of Cairo (Egypt), Nairobi (Kenya), Accra (Ghana) and Cape Town (South Africa).

The work target is to contribute to the improvement of municipal solid waste (MSW) management systems in Africa, to promote appropriate management policies on national, regional, local and sectorial levels in order to enable the integration of suitable management practices and to guide the African Development Bank's Task Managers in the design of waste management practices or in the integration of waste management concerns into sanitation or urban development projects.

[20], researched waste mismanagement in developing countries, a review of global issues. This paper reviews the main impacts due to waste mismanagement in developing countries, focusing on environmental contamination and social issues. Results reported that the environmental impacts are pervasive worldwide: marine litter, air, soil and water contamination, and the direct interaction of waste pickers with hazardous waste are the most important issues.

[21], researched on chemical recycle of plastic. Various chemical processes currently prevalent in the chemical industry for plastic recycling. Possible future scenarios in chemical recycling, analysed are the effects on the environment, the risks, costs and benefit of PVC recycling and listed plastics are safe to use and which not after recycling.

[22], researched on management of PET plastic bottles waste through recycling in Khartoum state. The target is to assess the general waste management the PET plastic bottles by identifying practical means and introducing recycling as cleaner production tool to achieve sustainable development goals. The information necessary were gathered during the period of June to July 2010 through questionnaires, interviews, meetings and visits to various sites, in addition to the official information and documents collected from reliable sources, mainly Sudan central bank, customs authorities, ministry of industry, soft drink and water bottling factories. The analysis of data in tables, graphs and charts provides information for the future forecast and result showed that consumption in PET bottles and the PET consumption in year 2015 estimated to be 6000 tons, twice the estimate in the year 2010. This simulation will create serious environment problems that require much more effort to be exerted by all stakeholders to look for scientific and practical solution for the disposal of plastic waste through recycling.

[23], researched on plastic waste management effectiveness in Indonesia industries. Waste management in Indonesia is less effective and Indonesia statistics in 2016, revealed that the population in Indonesia of about 261, 115, 456 people can produce 65, 200,000 tons of waste plastics annually. Additionally, the economic growth has an impact in industrial establishment. The activity of industries leads to the increase of waste production from the total waste pile 85,000 tons per year are plastic waste. The waste pile will increase along with the projected increase in population and industrial growth. The considerable amount of plastic waste in Indonesia will be dangerous to the environment. Therefore, a strategy is needed to prevent the increasing amount of plastic waste in Indonesia.

This research examined the Solid Waste Management in Kano Metropolis with emphasis on the on the characterization of different solid waste generated in Kano Metropolis comprising of eight (8) Local Government Areas namely; Dala, Fagge, Kwale, Kano Municipal City, Nasarawa Tarauni, Gumborts and Ungag. Kano Metropolis is the capital city of Kano State in northern Nigeria. It is one of the largest cities in the country and serves as a major economic/commercial, cultural, and educational center. The selection of Kano Metropolis is based on its rapidly growing status, quantity of solid waste generation, population growth, industry localization and of course its commercial activities

2 Materials and method

The materials utilized in this research are survey questionnaires, municipal solid wastes, laboratory pyrolysis plant, sampling equipment, waste disposal trucks, Aspen plus software, interview guides, refuse trucks, data sheets, Measuring cylinders and beakers of various sizes, conical flasks, and separators.

The glass wares used during the experimentations are measuring cylinders of various sizes, beakers of various sizes, conical flasks, separating funnel. The specific equipment for MSW characterization is presented in Table 1.

The research involves experiment, qualitative and survey approach. The procedures adopted includes solid wastes sample collection from the three major dumpsites in Kano metropolis, sample characterization, sample sorting, preparation and incineration in the laboratory for detail analysis.

Table 1 Equipment List for the Characterization of MSW

Property	Equipment and Manufacturer
Incineration Chamber	Refer to Incinerator Plate as embedded in this project.
Drying	Vaucher VT 6025 Air-Dry Vacuum Oven. Thermon Scientific NJ, USA
Calcination	Anoscope SM9080 Muffle Furnace. Surgi friend, England
Density	SVM 3000 50 millilitre Pycnometer (Density Bottles) Anton Paar, UK
Water Bath	B-Brian HH-4 Water Bathe, Guangdong, China
Weighing Balance	OHAUS AV264 Adventurer Pro Analytical balance. $\pm$

2.1. Characterization of different Municipal Solid Wastes in Kano Metropolis

To achieve waste characterization at the Metropolis level, three (3) selected major dumpsites were sampled to obtain first-hand information on rate of waste generation, physical composition of waste, sorting and separation efficiency.

The steps utilized to carry out the waste categorization during this study are as follows

- Setting the characterization protocols.
- Carry out selection and sampling of the three major dumpsites as the reference for this project.
- Segregate and weigh solid waste samples collected from the selected dumpsites.
- Processing and comparative analysis of the characterization results for the selected dumpsites.

The step-by-step protocol used for the waste characterization at the selected dumpsites are as follows

- The Waste Pickers (waste managers) collected waste samples from refuse tipped by refuse trucks at the dumpsites.
- The samples collected were thoroughly mixed using a mechanical shovel and a minimum of 150kg was collected in sampling bags.
- The sample bags were weighed before sorting for actual mass calculation.
- After weighing, the contents of the bags were emptied on a clean floor and sorted into various categories by the waste pickers under my direct supervision (see Figure 1 - 3)
- Collection of the fines left which include dust, dirt, soil etc is also weighed.
- Findings/results values are entered in the data Sheets.

Considering the hazards associated with solid waste handling generally, adherence to health and safety procedures were properly followed throughout the data collection processes.

The use of Personal Protective Equipment (PPE) protocols was strictly mandated.



Figure 1 Waste Segregation-Pure Water Packs Separated for Recycling



Figure 2 Waste Samples in Readiness for Characterization

2.2. Data Collection Instruments

- Majorly the instruments adopted for this exercise were observational checklist and interview guide.
- Checklists were used to record waste components after sorting and refuse truck information.
- In addition, information on household heads and population of members was captured in data sheet after each brief interview.



Figure 3 Waste Categorization Process



Figure 4 A Portion of Solid Waste Sample Categorized

2.3. Other Data/Information Gathering Checklist

Other data/information gathering tools utilized are data sheets templates developed for recording data for the number of people and waste collection in a household (Figure 5), Waste Sample data sheet developed for waste categorization in Kg (Figure 7) and Refuse Truck Information Sample data sheet developed for waste truck records (Figure 6).

ID	Number of people in the household	Day of the Week (Thick appropriately)							Comments
		Mon	Tue	Wed	Thur	Fri	Sat	Sun	
A1									
A2									
A3									

Figure 5 A Sample Data Sheet Developed for Recording the Number of People and Waste Collection in A Household

Observation	Industrial	Municipal /Domestic	Market/Co mmercial	Institutional/ Schools	5 th Truck
Source of waste					
Size of the trucks (tonnage capacity)					
Tonnage per day					
Population served					
Any other comments					

Figure 6 Refuse Truck Information Sample of Data Sheet Developed for Records

S/N	WASTE CATEGORIES	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1	Food waste							
2	Yard/garden wastes							
3	Paper/ Cardboard							
4	Hard Plastics							
5	Thin film (Nylon)							
6	Textiles							
7	Rubber							
8	Leather							
9	Wood							
10	Nappies (disposable diapers)							
11	Glass (pottery and china)							
12	Aluminum							
13	Ferrous metals							
14	Ceramics							
15	Electronic wastes							
16	Healthcare waste							
17	Others- dust, dirt, soil, ash							

Figure 7 Waste Sample Data Sheet Developed for Waste Categorization (Kg)

2.4. Compositional Analysis of the Solid Wastes

- A critical part of this study work was the Laboratory Incinerator Experiment conducted to carry out Proximate and Ultimate Analysis and Incineration Gas emissions.
- The objective of the laboratory experiment is to analyses and determine the % Moisture content, Volatile matter, Ash content, Carbon content, Sulphur content, Hydrogen content, Nitrogen content and Calorific value via the Proximate and Ultimate Analysis.
- The Incineration Gas Emissions analysis was conducted to determine the composition of the exhaust gas i.e. ppm of O², CO², CO, H₂S, and mg/m³, Total Volatile Organic Compounds TVOC, Formaldehyde HCHO, and µg/m³, Particulate Matter PM2.5 and Particulate Matter 10.
- The Laboratory Experiment was conducted with the support of LUCO SCIENTIFIC CHEMICAL LABORATORY LTD Benin City, Nigeria. Luco Scientific Chemical Laboratory specializes in chemical synthesis/analysis, soil analysis, Biofuel synthesis/characterization and Biomass pyrolysis.

2.4.1 Proximate and Ultimate Characteristics

Procedure

Exactly, 1kg of sample was sun dried for 2 hours to remove loose moisture and then ground and sieved through 500µm sieve. The obtained fine powder was then analyzed by the methods approved by the American Society for Testing and Material (ASTM) and International Organization for Standard (ISO) for the proximate and ultimate characteristics.



Figure 8 Pyrolysis Reactor used for Incineration Process

2.5. Method of Incineration Experiment

A constant-temperature electric-powered incineration vessel was used for the combustion of waste materials with a heating rate of 15°C/min. It consists of a 20 L reactor vessel where the thermal degradation occurs at high temperatures under an airflow for the decomposition of waste materials. The size of the material was reduced by cutting into pieces smaller than 10cm by 6cm in size. About 500g of the prepared material pieces were loaded into the vessel and covered tightly with a lid containing a metal pipe of about 3cm diameter. A mini vacuum pump was connected to blow air into the chamber through the gas inlet. The gas exit pipe was then connected to the product exit pipe which passes through a gas analyzer which detects the composition of the exhaust gas. The system was powered on from the controller and allowed the temperature to rise to a constant value of about 500°C on the digital display for a time of about 60 minutes.

2.5.1 Ash Content

Exactly 2.0 g each of pulverized samples were weighed into three separate platinum crucibles and subjected to a temperature of 600°C in a muffle furnace for about 2 hours. The furnace was then switched off and the sample was left inside for about 60 minutes for the temperature to drop and then removed and placed in a desiccator where the temperature was allowed to drop into ambient temperature.

$$\%Ash = \frac{Mass.of.Ash}{Mass.of.Sample} \times 100 \quad \dots\dots\dots (1)$$

2.5.2 Moisture Content

Moisture content was determined in an air-dry oven. Exactly 2.0 g of the powdered sample of each saw dust was placed in an evaporating-dish and subjected to a temperature of 105 - 110°C for 3 hours in the absence of air, until a constant weight was attained. The moisture content was estimated thus:

$$\% \text{Moisture} = \frac{A - B}{A} \times 100 \quad \dots\dots\dots (2)$$

where, A is the initial mass (2.51g) and B is the final mass (2.336g)

2.5.3 Volatile Matter

This is the material that is driven off when saw dust is heated to a high temperature in the absence of air under specified conditions. This was therefore determined by weighing One gram of powdered sample of the saw dust was weighed and covered in a 50 mL platinum crucible. The sample was subjected to a temperature of 500°C in a muffle furnace for 7 min. the weight loss was practically estimated from before and after it was placed in the furnace.

$$\%V_m = \frac{(M_s - M_v)}{M_s} \times 100 \quad \dots\dots\dots (3)$$

where, V_m is the volatile matter, M_v is the mass after volatile matter removed (1.23g), and M_s is the mass of sample (2g)

2.5.4 Carbon Content

The carbon content was determined by carbonization method. About 5g of sample was weighed into a 100ml crucible and placed into a muffle furnace set to heat at 400°C and allowed to carbonize for 60minutes. The crucible placed into a desiccator until the temperature reduces to ambient and mass of carbon weighed and recorded. The carbon content was then estimated as follows:

$$\text{Total Carbon \%} = \frac{M_s - M_c}{M_s} \times 100 \quad \dots\dots\dots (4)$$

where, M_s is the initial mass (5.1g) and M_c is the final mass (1.963g)

2.5.5 Fixed Carbon

The fixed carbon content of the sample is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate carbon content of the saw dust because some carbon is lost in hydrocarbons with the volatiles. Therefore, fixed carbon was estimated according to the equation below.

$$\%FC = 100 - (M + V + A) \quad \dots\dots\dots (5)$$

where, FC is the Fixed Carbon, M is the mass of moisture content, V is the mass of the volatile matter, and A is the mass of the ash content

2.5.6 Hydrogen and Oxygen

Total hydrogen content of sample was determined by weighing 2g of sample into a 100ml evaporating dish and placing into an air-dry oven and the weight of moisture driven off noted. The estimation of hydrogen content was conducted using the formular

$$\text{Hydrogen content } \% = \frac{\text{weight of } H_2O \times 0.1119 \times 100}{\text{mass of sample}} \quad \dots\dots\dots (6)$$

where, weight of water driven off = 0.86g

N/B

$$\text{Oxygen content} = 100 - (C + H + N + S + \%Ash) \quad \dots\dots\dots (7)$$

where, C is carbon element, H is hydrogen atom, N is nitrogen element, and S is Sulphur element

2.5.7 Total Nitrogen

Total nitrogen (TN) was determined by Kjeldahl method. 2g of sample was weighed into a 250ml conical flask and added 5g CuSO₄ as a catalyst and 20ml H₂SO₄. The mixture was swirled gently and placed on a hot plate set to maximum temperature for several minutes until a clear solution is obtained. It was cooled and diluted with 100ml distilled water. The content was stirred with a glass rod and transferred into a 500ml flat bottom flask and connected to a distillation unit and a conical flask containing 25ml of 4% boric acid solution was attached to the condenser outlet. 50ml of 40% NaOH was carefully dispensed into the flask containing the sample and distillation carried out for 10 minutes. The ammonium borate solution formed was titrated with 0.1M HCl to a purplish – grey end point using methyl red as indicator. Total nitrogen content was estimated from

$$\%TN = \frac{(S-B)N(1.4007)}{w} \quad \text{..... (8)}$$

where, N is normality of acid (0.1M), S is titre value of sample (12.5), B is titre value of blank (0.4ml), and W is mass of sample digested (2.5g),

2.6. Sulphur (Uncombine Sulphur)

Exactly 6 ml of bromine water was added to 0.5g of the sample in a 500ml capped beaker. After 10 minutes at this temperature, 15 cc of concentrated nitric acid was added. The mixture was heated slowly and then boiled to remove bromine and nitric acid after the strong reaction. After adding 2.5 g of sodium chloride to prevent sulphuric acid loss, the mixture was evaporated to half its content. Evaporation was repeated three times with 5 ml of strong hydrochloric acid added after each evaporation, allowed to dry, and heated gradually. The residue was taken up with 5ml of weak hydrochloric acid and 10ml of water, and the insoluble stuff was filtered using a Whatman filter and washed on filter paper with hot water. In a 500ml volumetric flask, the filtrate was diluted and mixed. 100ml aliquot was measured into a beaker, heated to boiling, then 100ml barium chloride solution was added drop by drop with steady stirring. After stirring and standing overnight, the solution was filtered and calcined at 700°C in a crucible with a muffle furnace. Wash clean of chlorides with boiling water, dry, and weigh as barium sulphate.

$$\%Sulphur = 100 \times \frac{0.1375 M_1}{M} \quad \text{..... (9)}$$

where M₁ = mass in g of the carbon di-sulphide insoluble residue (0.023g), and M = mass in g of the sample taken for the test (0.5g),

3 Results and Discussion

The results of the analysis and findings on solid waste management in Kanu metropolis are presented in the Figures and Tables below.

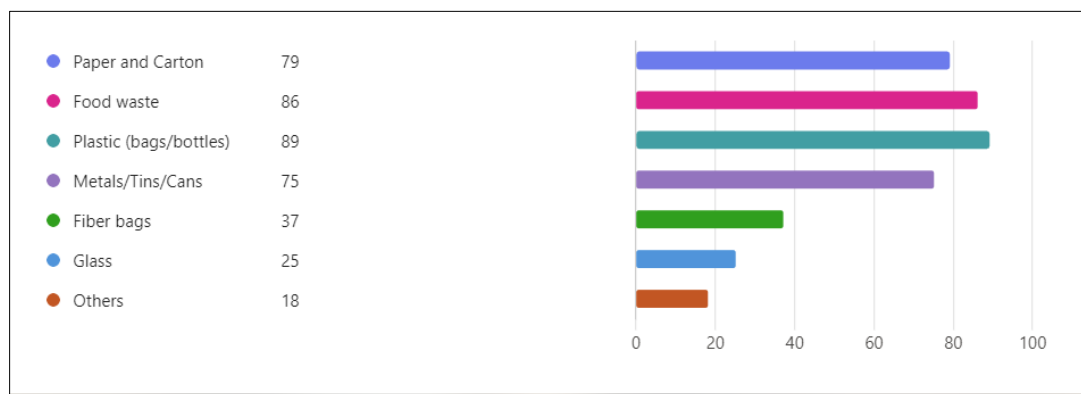


Figure 9 Types of MSW Generated from Household

The solid waste for household characterization showed that plastics comprises of bags/bottles is generated most, followed by food waste, paper and carton, metals/tins/cans, fibre bags, glass, and others in this order as shown in Figure 9. Comparing these wastes into combustible and none combustible, the household produces more of the combustible waste (0.494), none combustible waste (0.462) and others (0.044). Thus, the reason for incinerating the combustible wastes as a way of solid waste management approach implementation.

3.1. Solid Waste Composition in Kano Metropolis

The results of the surveys and interviews showed that the solid waste compositions presented in Tables 2, 3 and 4 shows the results/outcome of the characterization process to ascertain the waste streams component observed at the three (3) major dump sites in Kano metropolis. From the results analysis of the samples taken, eleven (11) different types of wastes components were discovered. These components include food scarp, paper cardboard, textile, rubber, plastic material, glass, metal, ash and dirt and vegetables.

Table 2 Court Road Dumpsite

Component	Weight (Kg)	% By Weight
Paper/Cardboard	550	28.3
Plastic & Rubber	15	0.8
Organic or vegetables	12	0.6
Thin film (Nylon) & Leather	900	46.3
Glass	75	3.9
Ferrous metal	10	0.5
Aluminium	2	0.1
Wood	50	2.6
Textile	300	15.4
Food waste	13	0.7
Others- dust, dirt, soil,	16	0.8
Total =	1,943	100%
Combustible Only		
Paper/Cardboard	550	28.3
Wood	50	2.6
Textile	300	15.4
Total Combustible	900	46.3

Table 3 Kuka Bulukiya Dumpsite

Component	Weight (Kg)	% By Weight
Paper/Cardboard	472	24.3
Plastic & Rubber	53	2.7
Organic or vegetables	67	3.5
Thin film (Nylon) & Leather	777	39.9
Glass	120	6.2
Ferrous metal	44	2.3
Aluminium	22	1.1
Wood	81	4.2

Textile	227	11.7
Food waste	34	1.8
Others	46	2.4
Total =	1,943	100%
Combustible Only		
Paper	472	24.3
Wood	81	4.2
Textile	227	11.7
Total Combustible	780	40.2

Table 4 Maimalari Dumpsite

Component	Weight (Kg)	% By Weight
Paper/Cardboard	506	26.0
Plastic & Rubber	66	3.4
Organic or vegetables	48	2.5
Thin film (Nylon) & Leather	801	41.2
Glass	89	4.6
Ferrous metal	33	1.7
Aluminium	16	0.8
Wood	66	3.4
Textile	258	13.3
Food waste	22	1.1
Others	38	2.0
Total	1,943	100%
Combustible Only		
Paper	506	26.0
Wood	66	3.4
Textile	258	13.3
Total Combustible	830	42.7

The first dumpsite field visited was the Maimalari Dumpsite located in Dakata Ungogo Local Government Area. At the Maimalari dumpsite, thirty (30) scavengers (waste managers) were used as support staff to help in carrying out this assignment and later on interviewed at random alongside four (4) waste truck drivers were also interviewed. The next step was the characterisation of the solid waste at each dumpsite to classify the waste using manual separation techniques with the help of the scavengers into various physical components, followed by weighing each specific components of the categorized waste. The tables and the graphs below illustrated the results/findings of the waste components by Kg, and also the results of the comparison of waste component by %weight of the three (3) major dumpsites in Kano Metropolis. The findings indicated that there are more paper/cardboard components in Court Road dumpsite when compared to the other two dumpsites, while organic waste at Kuka Bulukiya dumpsites is higher than the other 2 dumpsites, and Maimalari dumpsite has the highest plastic/rubber components when compared with the other two dumpsites.

Analysing thin film & leather components, Court Road dumpsite recorded the highest weight component of thin film & leather, while Kuka Bulukiya dumpsite recorded the highest wood component when compared with the other two

dumpsites. Also, in terms of textile waste, Court Road dumpsite recorded the highest component by weight when compared with the other two dumpsites.

The most probable reasons for the differential waste compositions from one dumpsite to another might be because of the following:

Due to the population of the area where the dumpsite is located,

- Income per head of the populace,
- Whether the area is mainly residential, commercial or industrial area and
- The occupation of the people living in the area.

Table 5 Characterization of MSW in Dumpsites of the LGAs

Waste Components	Court Road	Kuka Bulukiya	Maimalari
Paper/cardboard	550	472	506
Plastic and Rubber	15	53	66
Organic or Vegetables	12	67	48
Thin film (Nylon) and Leather	900	777	801
Glass	75	120	89
Ferrous metal	10	44	33
Aluminium	2	22	16
Wood	50	81	66
Textile	300	227	258
Food waste	13	34	22
Others	16	46	38
Sample Size	1943	1943	1943

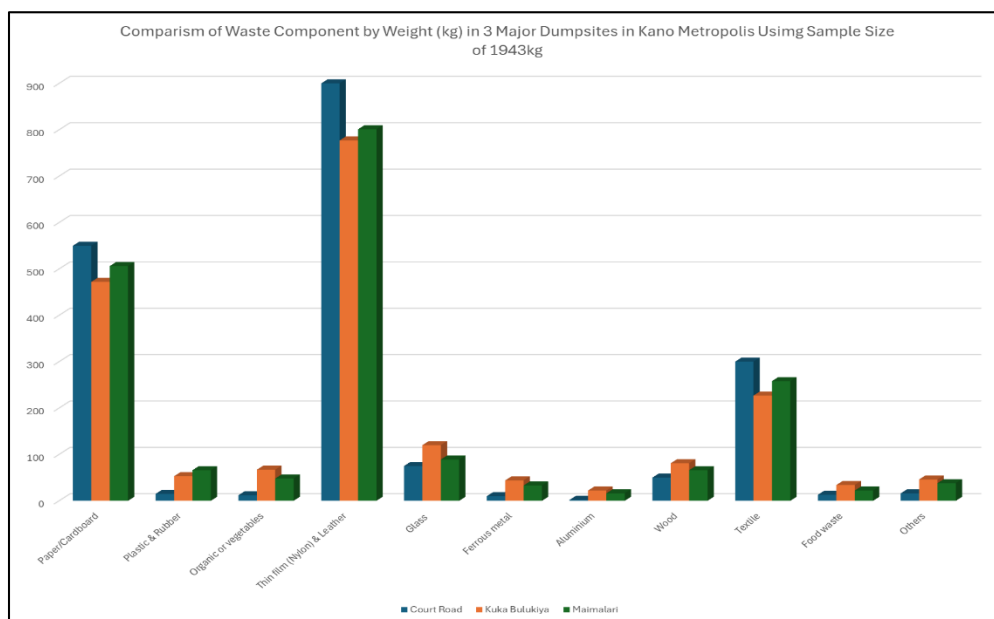


Figure 10 Analysis of Comparison of Waste Component by Weight

The 3 dumpsites investigated as shown in Table 5, nylon type of solid waste is the most produced in the area but the highest produced is in the dumpsite of court road, followed by Maimalari and then Kuka Bulukiya. Paper/cardboard is the next type of solid waste that is generated and textile solid waste coming in that order. Similar to the dumpsite with more waste generated as discussed earlier, Court Road generate more due to the population of the people compared to Maimalari and Bulukiya. Further analysis of Comparison of waste component by %weight in the 3 major dumpsites is also illustrated in the table and graph below.

Table 6 Characterization of MSW in percentage by Weight

Waste Components	Court Road	Kuka Bulukiya	Maimalari
Paper/cardboard	28.3	24.3	26
Plastic and Rubber	0.8	2.7	3.4
Organic or Vegetables	0.6	3.5	2.5
Thin film (Nylon) and Leather	46.3	39.9	41.2
Glass	3.9	6.2	4.6
Ferrous metal	0.5	2.3	1.7
Aluminium	0.1	1.1	0.8
Wood	2.6	4.2	3.4
Textile	15.4	11.7	13.3
Food waste	0.7	1.8	1.1
Others	0.8	2.4	2

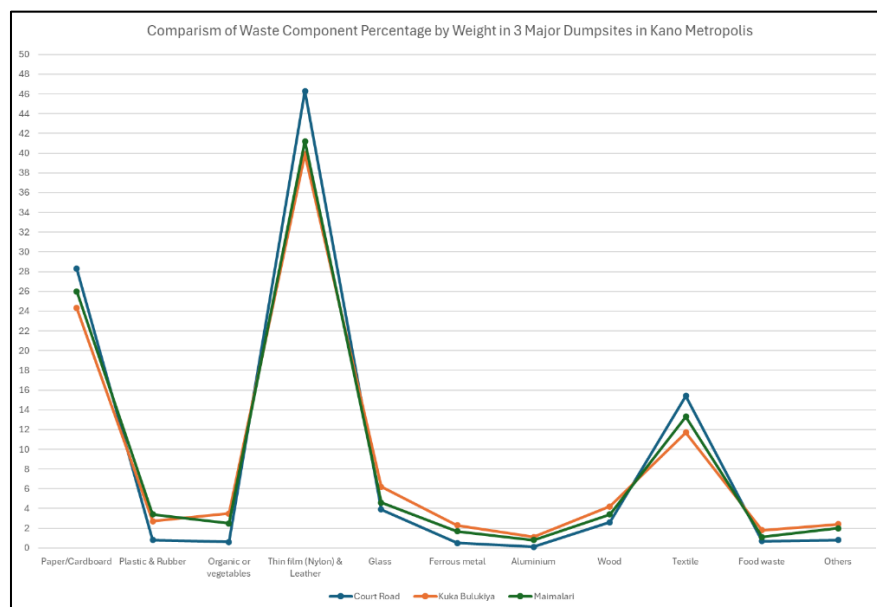


Figure 11 Analysis of MSW in the Dumpsites by Weight Percent

The weight percent analysis of solid wastes generated in the dumpsites with same sample size showed that thin film (nylon) and leather are most generated, followed by paper/cardboard and then textile waste in percentage conversion as shown in Figure 11. Also, the dumpsite found in court road of KSME is the one with the most solid wastes by weight % as explained in Figure 10. The results and findings clearly indicate that in all the 3 major dumpsites, thin film & leather accounts for the highest percentage by weight followed by paper/cardboard and textile waste respectively.

3.2. Analysis of Combustible Solid Waste

For the specific purpose of this research which included the modelling, design and simulation of a municipal solid waste incinerator, the combustible waste (paper/cardboard, wood and textile) were further analysed separately and compared among the 3 dumpsites.

The table and chart below indicate the analysis of the proposed selected combustible waste components of the Incinerator.

Table 7 Combustible MSW in the 3 Dumpsites Investigated

Combustible Only	Court Road	Kuka Bulukiya	Maimalari
Paper/cardboard	550	472	506
Wood	50	81	66
Textile	300	227	258
Total Combustible	900	780	830

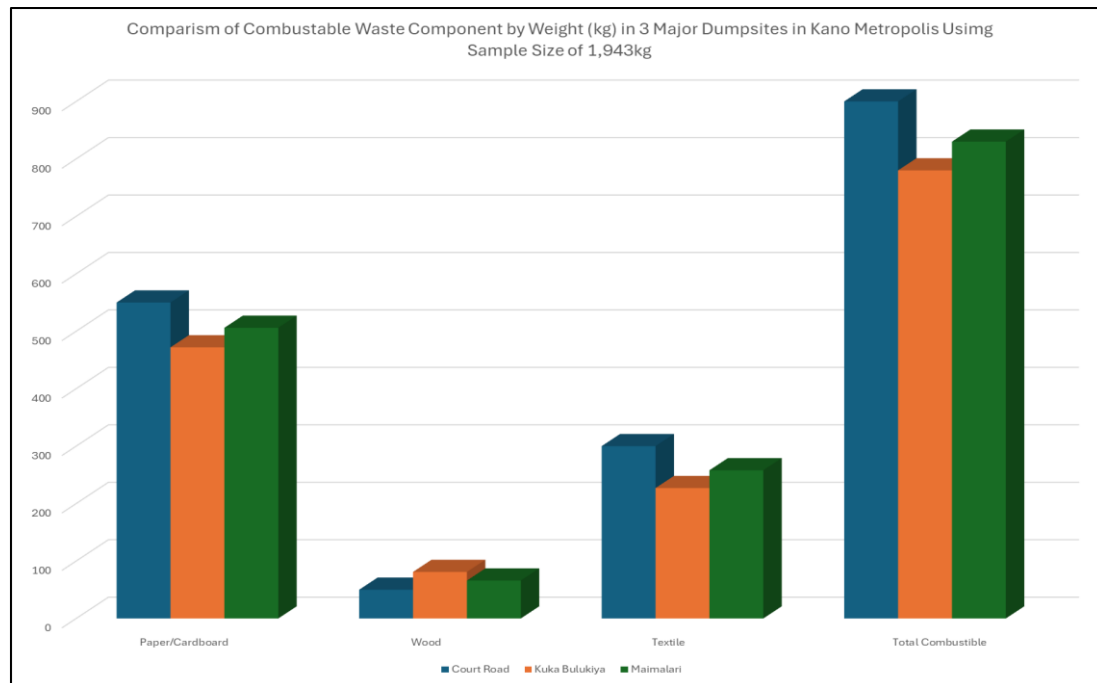


Figure 12 Characterization of Combustible MSW in the 3 sites of KSME

From Figure 12, it clearly shows that Court Road dumpsite has the highest amount of combustible waste, followed by Maimalari and Kuka Bulukiya respectively. Therefore, in the consideration of the design of the municipal solid waste Incinerator, the capacity for each location will differ for each dumpsite.

3.3. Compositional Analysis of the MSW in Kanu Metropolis

The proximate and ultimate analyses of the MSW generated in the KSME are shown. This is possible as the combustible solid waste is incinerated and the products analyze as shown in Tables and Figures.

The graphical representation below shows the comparison of the four (4) selected solid waste materials (paper, wood, textiles and kitchen waste) analyzed during the Proximate and Ultimate analysis to ascertain the moisture content, volatile matter, ash content, Sulphur content, hydrogen content, nitrogen content and calorific value properties.

The proximate and ultimate analysis of the paper, wood, textile and kitchen wastes showed in Table 8 indicated that kitchen waste has the highest calorific value (cv), moisture (mc) and carbon content (cc), while textile contains more of

volatile matter (vm), least cc, hydrogen and nitrogen contents. Paper analysis gave the highest nitrogen and ash content and the least calorific value.

Table 8 Results of Proximate and Ultimate Analysis

Property	Paper	Wood	Textile	Kitchen Waste
Moisture content (%)	10.15	14.02	16.03	21.14
Volatile matter (%)	77.43	75.46	86.08	64.57
Ash content (%)	10.15	6.475	1.20	3.384
Carbon content (%)	22.57	25.54	15.92	25.54
Sulphur content (%)	1.97	0.14	2.73	0.62
Hydrogen content (%)	4.26	4.78	2.93	3.76
Nitrogen content (%)	11.7	0.17	0.06	0.15
Calorific value (MJ/kg.K)	12.91	18.93	28.82	18.07

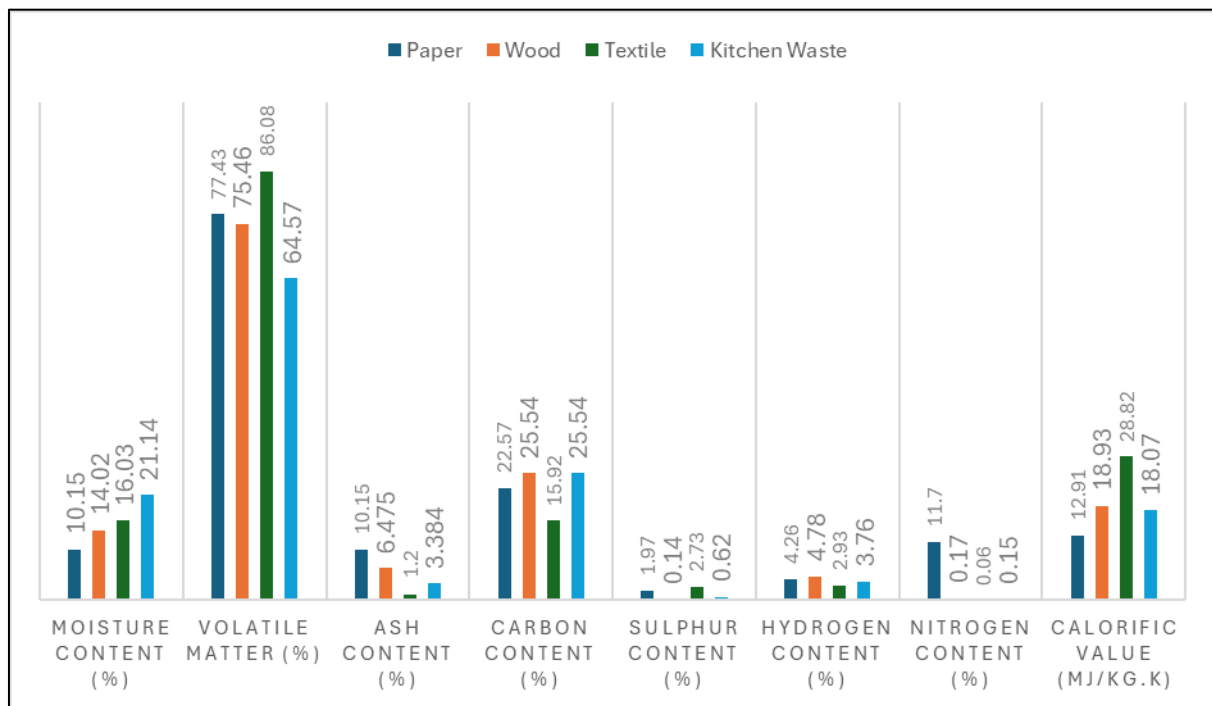


Figure 13 Proximate and Ultimate Analysis of the Solid Wastes Types

This laboratory analysis helps us to determine the physical and chemical properties of the waste stream (fuel) in consideration i.e. paper, wood, textile or kitchen waste materials. It also indicates the usefulness of the material concern in the process of combustion.

3.4. %Moisture Content

The comparative analysis of the moisture content for the selected four (4) waste streams indicates that the Kitchen waste has the highest content of Moisture i.e. 21.14% moisture content. It is experimentally proven that Moisture content in a fuel significantly impacts its combustion process by reducing the Combustion Efficiency of the combustion process because more moisture means less energy available for useful work, as part of the energy is diverted to vaporize the water. More moisture can also lower the Flame Temperature of the combustion process, the evaporation of water absorbs heat and hence reduces the flame temperature of the combustion process. Also, a lower flame temperature can affect the rate of chemical reactions in combustion, slowing the process and potentially leading to incomplete combustion. High moisture content can lead to Increased Emissions via incomplete combustion that is, producing higher

levels of unburned hydrocarbons, carbon monoxide, and particulate matter. Fuels with high moisture content are harder to ignite (Ignition Challenges) because the energy required to evaporate the water delays ignition. This can be particularly problematic in systems that rely on fast or consistent ignition. Excessive moisture has significant Impact on Equipment i.e. it can lead to corrosion in combustion equipment and exhaust systems. It may also increase the build-up of residues and soot, requiring more frequent maintenance. High Moisture content reduces the net calorific value (energy per unit weight or volume) of the fuel, as water does not contribute to the energy released during combustion. Therefore, for an effective utilization of Kitchen Waste as a combustion fuel, it will require that the Kitchen waste is properly dried before usage in order to improve its combustion efficiency and performance as a combustion fuel.

3.5. %Volatile Matter

The volatile matter in a fuel plays a significant role in the combustion process. Volatile matter refers to the components of the fuel that vaporize when the fuel is heated, excluding moisture. It primarily consists of hydrocarbons, carbon dioxide, and other gases.

A fuel with a high percentage of volatile matter has a better advantage when selected and used as fuel for combustion process.

Referencing the comparative analysis of the Volatile matter for the selected four (4) waste streams (Table 8 and Figure 13), it does indicate that Textile waste has the highest % of Volatile matter i.e. 86.08. Fuels with high volatile matter ignite more easily (Ease of Ignition) because the volatiles vaporize at relatively low temperatures and burn quickly. This property is advantageous in starting combustion processes, especially in solid fuels. A high volatile matter fuel typically leads to faster combustion because the volatiles burn rapidly in the gaseous phase. However, this can also make the combustion process harder to control in some systems. Volatiles contribute to the release of gaseous emissions such as CO, CH₄, and other hydrocarbons if combustion is incomplete. High volatile fuels may require careful control of air supply to ensure complete combustion and minimize pollutants.

3.6. %Ash Content

Higher Ash Content in a fuel reduces combustion efficiency in a combustion process.

Ash occupies space in the combustion system without contributing energy, effectively lowering the fuel's calorific value. High ash content reduces the thermal efficiency of combustion systems by increasing the burden of handling non-combustible material. Fouling occurs when ash deposits accumulate in the internals of the equipment e.g., ducts, or exhaust systems, this will eventually cause Fouling, which requires frequent cleaning and maintenance. Ash from combustion must be disposed of or utilized (e.g., in construction or agriculture). Higher ash content increases disposal volumes, raising costs and environmental impact. Referencing the comparative analysis of the Ash content for the selected four (4) waste streams (Table 8 and Figure 13), it does indicate that Paper waste has the highest % of Ash content i.e. 10.15%.

3.7. %Carbon Content

The carbon content in a fuel is a critical determinant of its energy potential and combustion characteristics. Carbon is the primary combustible element in most fuels, and its properties significantly influence the efficiency, emissions, and overall performance of the combustion process. Fuels with higher carbon content generally have a higher calorific value, meaning they release more energy per unit mass when burned. High carbon content ensures a sustained and stable combustion process if sufficient oxygen is provided and if on the other hand, insufficient oxygen is supplied, it can lead to incomplete combustion, producing carbon monoxide (CO) instead of carbon dioxide (CO₂). Combustion of carbon produces CO₂, a Greenhouse gas. Fuels with higher carbon content contribute more to CO₂ emissions per unit of energy generated.

Fuels with high carbon content produce higher flame temperatures because carbon combustion is highly exothermic. Also, higher temperatures can improve thermal efficiency but may increase the formation of nitrogen oxides (NO_x), which are harmful pollutants. Referencing the comparative analysis of the Carbon content for the selected four (4) waste streams (Table 8 and Figure 9), it does indicate that Wood and Kitchen waste has the highest % of Carbon content i.e. 25.54% each.

3.8. % Sulphur Content

The sulphur content in a fuel significantly impacts combustion, primarily affecting emissions, equipment longevity, and environmental compliance. During combustion, sulphur in the fuel oxidizes to form sulphur dioxide (SO₂) and, under

certain conditions, sulphur trioxide (SO_3). These gases are harmful pollutants, contributing to acid rain and air quality degradation. Combustion of sulphur can also indirectly increase particulate matter in the exhaust due to the formation of fine sulphate particles. High-Temperature Corrosion can occur in the equipment's when SO_3 combine with water vapor in the flue gas to form sulfuric acid (H_2SO_4), which causes severe corrosion in heat exchangers, boilers, and other high-temperature components. Also, Low-Temperature Corrosion can occur when acid condensation in exhaust systems or chimneys happens, which can lead to damage over time, especially in systems without adequate temperature control. Health wise, SO_2 and SO_2 are major air pollutants that contribute to respiratory and cardiovascular problems.

Referencing the comparative analysis of sulphur content for the selected four (4) waste streams (Table 8 and Figure 13), it does indicate that Textile waste has the highest % of Sulphur content i.e. 2.73%. Also, the injection of Dry Sorbent e.g. Calcium- or sodium-based compounds to neutralize sulphur compounds in the flue gas. Maintaining combustion and exhaust temperatures above acid dew points to prevent sulfuric acid condensation.

3.9. %Hydrogen Content

Combustion of hydrogen-rich fuels significantly reduces CO_2 emissions but may increase nitrogen oxide (NO_x) formation due to higher flame temperatures. Referencing the comparative analysis of Hydrogen content for the selected four (4) waste streams (Table 8 and Figure 13), it does indicate that Wood waste has the highest % of Hydrogen content i.e. 4.78%.

3.10. %Nitrogen Content

The nitrogen content in a fuel has important implications for combustion, primarily influencing emissions and environmental impact. While nitrogen does not directly contribute to energy release, its presence affects the combustion process in several ways. Nitrogen does not contribute to the calorific value of the fuel, thereby reducing the overall energy efficiency of the fuel. Referencing the comparative analysis of Nitrogen content for the selected four (4) waste streams (See Figure 13 and Table 8), it does indicate that Paper waste has the highest % of Nitrogen content i.e. 11.70%.

3.11. Calorific Value

The calorific value (or heating value) of a fuel is a critical parameter that directly influences the combustion process. It measures the amount of energy released when a fuel is completely burned, typically expressed in units like MJ/kg or BTU/lb. Fuels with high calorific values release more energy per unit mass or volume, making them more efficient for energy production while Low calorific value fuels require larger quantities to produce the same amount of energy, leading to increased fuel consumption and associated handling costs. High-calorific-value fuels often burn more efficiently, producing higher temperatures and better thermal performance in combustion systems. Referencing the comparative analysis of the Calorific value for the selected four (4) waste streams (see Table 8 and Figure 13), it does indicate that Textile waste has the highest % of Caloric Value i.e. 28.82%.

3.12. Compositional Analysis of Incinerated Gas Emissions

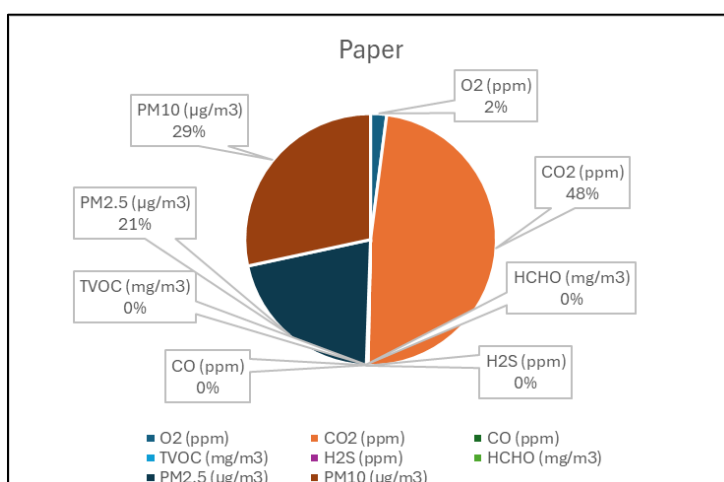
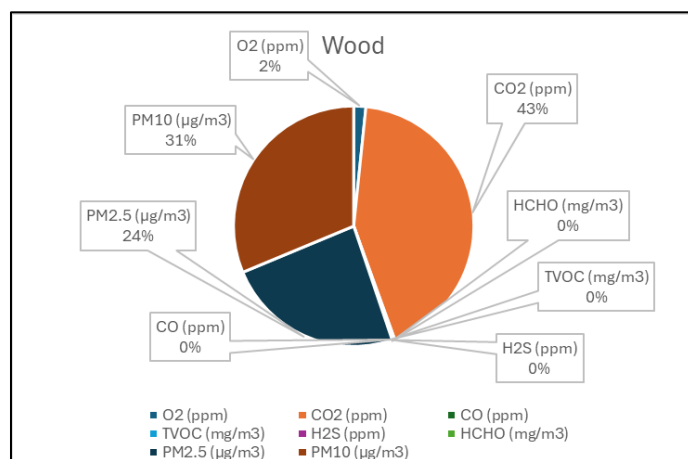
The Laboratory Incinerator Gas Emissions experiment analysed the different components of gas emission from the combustion process of the four (4) selected solid waste materials (paper, wood, textiles and kitchen waste) analyzed during the Incineration Gas Emissions experiment to ascertain the ppm of O_2 , CO_2 , CO , H_2S , and mg/m^3 of the Total Volatile Organic Compounds TVOC, Formaldehyde HCHO , and $\mu\text{g/m}^3$ of Particulate Matter $\text{PM}_{2.5}$ and Particulate Matter PM_{10} .

The analysis was based on analysing the individual waste components as graphically represented in percentages (%) are shown in Table 9 and Figures 14 to 16. Table 9 indicate the incineration result of the gas emissions for the analysis of the solid wastes conducted and results showed that textile wastes produce more of CO_2 , CO and total volatile organic compound (TVOC) of values 0.005, 0.00034, and 4.932mg/m^3 respectively, while wood gave more of H_2S , HCHO , and $\text{PM}_{2.5}$ of values 0.06ppm, 1.185mg/m^3 and $227\mu\text{g/m}^3$ respectively. Also, the analysis showed that kitchen wastes produce more of oxygen of value 19.57ppm compared to other types.

Table 9 Results of Incineration Gas Emissions

Gas	Paper	Wood	Textile	Kitchen Waste
O ₂ (ppm)	18.93	15.42	16.05	19.57
CO ₂ (ppm)	444	407	5000	328
CO (ppm)	1.01	2.01	340	0.42
TVOC (mg/m ³)	0.01	0.013	4.932	0.01
H ₂ S (ppm)	0.03	0.06	0.02	0.00
HCHO (mg/m ³)	0.973	1.185	0.758	0.824
PM _{2.5} (µg/m ³)	194	227	75	117
PM ₁₀ (µg/m ³)	261	297	95	153

The pie-charts in Figures 14 to 16 display the compositions of the various compounds produced when the solid wastes (paper, wood, textile and kitchen) are incinerated.

**Figure 14** Compositional Analysis of Gas Emissions from Paper Wastes Incineration**Figure 15** Compositional Analysis of Gas Emissions from Wood Wastes Incineration

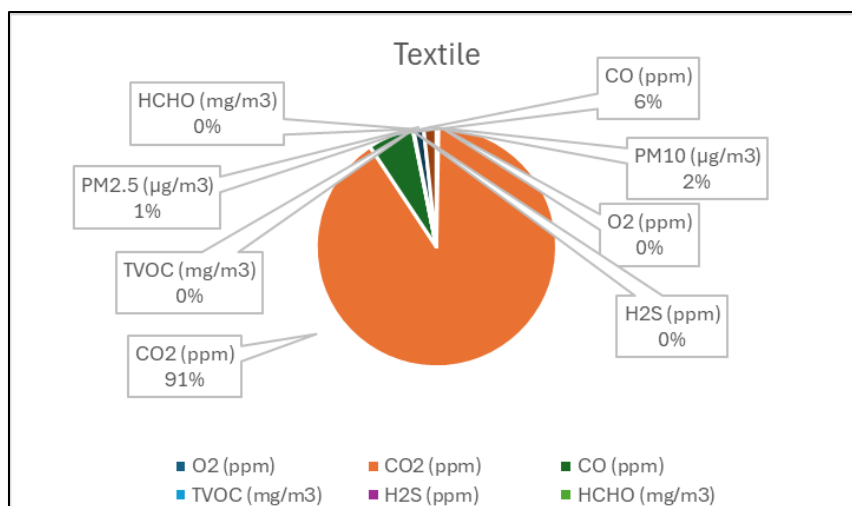


Figure 16 Compositional Analysis of Gas Emissions from Textile Wastes Incineration

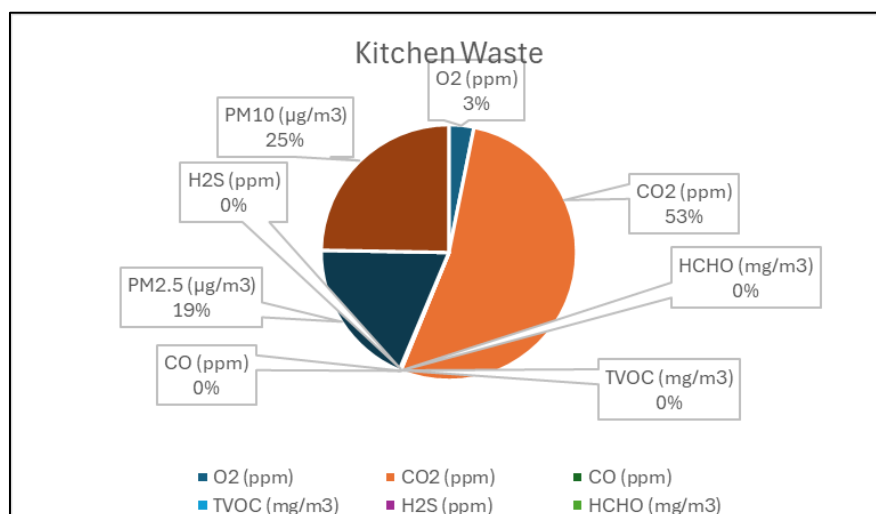


Figure 17 Compositional Analysis of Gas Emissions from Kitchen Wastes Incineration

3.12.1 Oxygen O₂

Oxygen O₂ in the flue gas emissions of an incinerator is not inherently harmful to health or the environment. However, its presence and concentration are significant in assessing combustion efficiency and the environmental impact of the incineration process. Adequate oxygen is essential for the complete combustion of waste. Insufficient oxygen leads to incomplete combustion, producing harmful pollutants like carbon monoxide (CO), soot, and unburned hydrocarbons. High levels of oxygen in the flue gas indicate that excess air is being supplied. While this reduces incomplete combustion, it can lower thermal efficiency, as excess air absorbs heat. Oxygen itself is non-toxic and does not directly harm health or the environment when released as part of flue gas. Referencing the gas emissions analysis of the ppm of O₂ for the selected four (4) waste streams (Table 9), it does indicate that the Kitchen waste has the highest ppm of O₂ released i.e. 19.57 ppm.

3.12.2 Carbon dioxide CO₂

Carbon dioxide (CO₂) is a significant component of flue gas emissions from incinerators due to the combustion of organic materials. While CO₂ is not directly harmful to human health at typical atmospheric concentrations, its release has profound long-term environmental and indirect health implications. Referencing the gas emissions analysis of the ppm of CO₂ for the selected four (4) waste streams (Table 9), it does indicate that the Textile waste has the highest ppm of

CO₂ released i.e. 5,000 ppm. This is indeed on a very high side, which have significant impact and contributes to GHG. The primary health impacts of CO₂ arise indirectly through its role as a greenhouse gas (GHG).

3.12.3 Carbon monoxide CO

Referencing the gas emissions analysis of the ppm of CO for the selected four (4) waste streams (Table 9), it does indicate that the Textile waste has the highest ppm of CO released i.e. 340 ppm. This is indeed on a very high side, which will have a significant impact to health and environment.

Reducing CO emissions from incinerators is crucial to minimize its health and environmental impacts. Strategies include

3.12.4 Total Volatile Organic Compounds (TVOC)

Total Volatile Organic Compounds (TVOCs) can have significant health effects depending on their concentration, exposure duration, and the specific compounds involved. Common TVOCs include benzene, toluene, xylene, and formaldehyde. High Exposure to TVOCs can lead to more severe symptoms, such as difficulty in breathing, neurological effects (e.g., confusion, memory impairment), and even organ damage. There is also the potential risk of Carcinogenic exposure with certain TVOCs, such as benzene and formaldehyde, which are known to be carcinogens. Prolonged exposure can increase the risk of cancer. TVOCs have significant environmental consequences, especially in terms of air quality and ecological health. Referencing the gas emissions analysis of the mg/m³ of TVOCs for the selected four (4) waste streams (Table 9), it does indicate that the Textile waste has the highest mg/m³ of TVOCs released i.e. 4.932 mg/m³.

3.12.5 Hydrogen Sulphide (H₂S)

Hydrogen sulphide can have significant environmental consequences, particularly in terms of air, water, and soil quality. Referencing the gas emissions analysis of the ppm of H₂S for the selected four (4) waste streams (table above), it does indicate that all the solid waste stream has a low ppm of H₂S content. Wood has the highest of them all i.e. 0.06 ppm while Kitchen waste has zero H₂S content. H₂S is highly corrosive and can damage equipment and infrastructure, leading to increased maintenance costs and environmental risks from leaks.

H₂S in flue gas emissions typically originates from Sulphur-Containing Wastes. Combustion of materials like rubber, gypsum, sulphur-containing chemicals, or organic waste with high sulphur content will result to flue gas with H₂S content. Decomposition of Organic Matter like Anaerobic decomposition of organic waste prior to combustion can also results to H₂S release. Reducing H₂S emissions from incinerators is essential to protect public health and minimize environmental harm. Effective strategies include; waste management, combustion optimization, emission control technologies, activated carbon filters and catalytic oxidation.

3.12.6 Formaldehyde (HCHO)

Formaldehyde is a highly reactive compound with acute and chronic health effects, depending on exposure levels and duration. Higher Exposure (>0.1 ppm) causes severe respiratory irritation and exacerbation of asthma symptoms, skin irritation and allergic reactions on direct contact and Headaches, nausea, and dizziness. It also has Carcinogenic Potential as Formaldehyde is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC). Long-term exposure has been linked to cancers of the nasopharynx, throat, and blood (e.g., leukemia). Referencing the gas emissions analysis of the mg/m³ of HCHO for the selected four (4) waste streams (Table 9), it does indicate that the Wood waste has the highest mg/m³ of HCHO released i.e. 1.2 mg/m³. This is indeed above the Higher Exposure rate of (>0.1 ppm) which will have a significant impact to health and environment. Formaldehyde contributes to environmental degradation, primarily through its role in air pollution and secondary pollutant formation. To reduce formaldehyde emissions from incinerators, a combination of improved combustion practices and advanced emission control technologies is necessary.

3.12.7 Particulate Matter (PM_{2.5}) and Particulate Matter (PM₁₀)

Particulate matter (PM) refers to a mixture of tiny solid particles and liquid droplets suspended in the air. PM_{2.5} (particles ≤2.5µm) and PM₁₀ (particles ≤10µm) are critical components of air pollution and are often emitted as part of flue gas from incinerators. These particles are generated during the combustion of various materials, especially when combustion is incomplete or poorly controlled. Particulate matter is a major public health concern due to its ability to penetrate deep into the respiratory system and, in the case of PM_{2.5}, even enter the bloodstream. PM 2.5 penetrates deep into the lungs, causing inflammation, reduced lung function, and exacerbation of asthma and chronic obstructive pulmonary disease (COPD). PM 10 affects the upper respiratory tract, causing coughing, throat irritation, and

exacerbation of respiratory diseases such as bronchitis and asthma. Particulate matter not only harms human health but also has severe environmental consequences.

4 Conclusion

The study aimed at evaluating the Municipal Solid Waste Management (MSW) of Kano Metropolis in Nigeria by studying the conversion, conducting characterization, and management strategies of the different types of solid wastes streams generated across Kano Metropolis (8 Local Governments Areas). The findings gave the following;

The proximate and ultimate analyses of the different types of solid wastes when compared to kitchen solid wastes after incineration process revealed that more of nitrogen (0.117) and ash content (0.102) is present in paper wastes, more calorific value (0.288), and volatile matter (0.861) is present in the textile wastes and more of hydrogen content (0.0478), and same amount of carbon content (0.254) is present for wood and kitchen wastes. Kitchen wastes gave more of moisture content (0.211) compared to other others. The gas emissions for the analysis of the solid wastes conducted and results showed that textile wastes produce more of CO₂, CO and total volatile organic compound (TVOC) of values 0.005, 0.00034, and 4.932mg/m³ respectively, while wood gave more of H₂S, HCHO, and PM2.5 of values 0.06ppm, 1.185mg/m³ and 227µg/m³ respectively. Also, the analysis showed that kitchen wastes produce more of oxygen of value 19.57ppm compared to other types.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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