NIGERIAN JOURNAL OF ENGINEERING RESEARCH UNICROSS (NJERU)

Volume 1, Issue 2, 1st June, 2024

Generation Rate Estimation of Municipal Solid Waste (Msw) Using Model of Quantity and Composition Approach: A Case Study of Calabar Metropolis

Joseph Eventus Etim[a], Samuel Oliver Effiom[b*], David Olusola Fakorede[c]

[a,b,c] Department of Mechanical Engineering, University of Cross River State, Nigeria

[*]Correspondence Author: samueloliver@unicross.edu.ng

Received: 14th September, 2024 Reviewed: 20th September, 2024 Accepted: 20th October, 2024

Abstract:
This study aims to estimate the generation rate of municipal solid waste (MSW) in Calabar Metropolis using a model based on both waste quantity and composition. The primary objective is to evaluate the MSW generation rate in Calabar for the year 2024 and provide projections up to 2060 to inform effective waste management planning. To achieve this, the study employs the Load-Count Analysis method to compute the number of individual waste loads and their corresponding characteristics, alongside the Material Balance Analysis method to categorize waste into distinct components, including putrescible waste, plastics, paper, textiles, metal, glass, and others, using specific tonnage values. These methods collectively allow for an accurate evaluation of waste generation rates. The findings indicate that the per capita waste generation rate for 2024 is 2.19 kg per capital per day, based on an estimated population of 685,000 people, compared to 0.79 kg per capita per day in 2012, when the population was 449,057. This represents a 2.5% increase in waste generation over the period. The composition of the waste reflects factors such as consumption patterns, cultural habits, and waste management infrastructure. The study reveals the following waste composition: putrescibles (35%, 124,164.26 tons), plastics (14%), paper (12%), textiles (10%), metals (8%), glass (10%), and other materials (11%, 39,023.05 tons). Monthly waste generation is estimated at 123,300 tons, with an annual total of 1,500,150 tons. Projections for waste generation from January 2024 to December 2060 suggest a cumulative total of 55,505,550 tons over the next 37 years. The database generated as part of this study (Appendices) provides a crucial tool for strategic planning, resource allocation, and future research aimed at optimizing waste reduction efforts, enhancing public health, and promoting environmental sustainability in Calabar Metropolis.

Keywords—Waste, Calabar, Quantity and Composition Approach, waste generation.

INTRODUCTION

Municipal Solid Waste (MSW) management has become one of the most pressing challenges facing rapidly urbanizing cities globally. As urban populations grow, alongside industrialization and evolving consumption patterns, the volume and diversity of waste produced continue to increase (Noor *et al.*, 2020). This trend is particularly evident in developing countries, where the capacity for effective waste management is often outpaced by these changes (Ogwueleka, 2010). In Calabar Metropolis, located in the Southern Senatorial District of Cross River State, Nigeria, this challenge is especially acute. The city, with a population of approximately 371,022 as of the 2006 census (Ering, 2010, Bassey, 2023), has seen rapid urbanization and increased waste generation, resulting in significant waste management concerns. Calabar's administrative division into Calabar Municipality and Calabar South Local Government Areas adds to the complexity of addressing waste across various urban and suburban areas (Ahsan *et al.*, 2015).

To mitigate the environmental and public health risks associated with waste mismanagement, it is crucial to understand the rate of waste generation and its composition within the urban environment (Das *et al.*, 2019). However, one of the key obstacles to effective waste management is the lack of accurate and reliable data on waste generation rates and composition (Zohoori & Ghani, 2017). This data gap hinders the design of efficient waste management strategies, such as optimized collection routes, recycling programs, and sustainable disposal methods (Ogwueleka, 2010, Aziz *et al.,* 2021).

In response to this challenge, this study seeks to provide a comprehensive analysis of MSW generation rates and composition in Calabar Metropolis, using an innovative model that integrates both the quantity and composition of waste. This approach, which has not been extensively applied in the context of Calabar, will contribute significantly to the development of accurate, data-driven strategies for waste management. The research will estimate both the monthly and annual waste generation rates for Calabar and analyze the waste composition across residential, commercial, and institutional sectors. By using a combination of waste sampling, direct measurements, and a model-based approach, this study aims to create a reliable database for waste management planning.

Furthermore, the novelty of this research lies in its focus on the intersection of urbanization, population growth, and changing consumption patterns specific to Calabar. While numerous studies have examined MSW generation in other parts of the world, there is a lack of focused research on the detailed waste characteristics and generation rates in Nigerian cities, particularly in Calabar. The outcomes of this study will therefore not only fill a critical gap in waste management knowledge for Calabar but also provide a replicable framework for similar cities in Nigeria and other developing countries.

The study is framed within the context of Nigeria's regulatory environment, which includes the Federal Environmental Protection Act of 1988 and the Calabar Urban Development Authority (CUDA), responsible for waste management in the city (Ogwueleka, 2010; Factsheet CUDA, 2000). Despite the presence of these regulations, waste management remains a significant challenge due to inadequate data and infrastructure. This research, therefore, aims to contribute to the ongoing efforts to improve waste management systems in Calabar, providing a robust methodology for estimating future waste generation and supporting the development of sustainable waste management solutions.

Therefore, this study provides valuable insights into MSW generation patterns in Calabar Metropolis, highlight the composition of waste, and offer recommendations for optimizing waste management strategies. Addressing the gaps in data collection and analysis is critical for the efficient management of resources, reducing landfill dependency, and minimizing environmental impact. By doing so, this research will not only benefit Calabar but also contribute to the broader discourse on sustainable urban waste management in Nigeria.

methodology

Materials

The materials used in this study includes:

- Waste collection data showing the number of waste collection unit in Calabar metropolis from the department of solid waste management, ministry of Environment, Calabar.
- Field survey sheet showing the number of approved households in Calabar metropolis from the Ministry of Land and housing, Calabar.
- Categories of trucks for waste collection are depicted in Figure 1 to 3.

Figure 1. Category A – Compactor Trucks (Average weight of 10/15 Tons)

Figure 2. Category B – Flat Bed Trucks (Average weight of 5 Tons)

Figure 3. Category C – Tipper Trucks (Average weight of 10 Tons)

HH. Methods

There are about 1,973 collection units or centers in the entire Calabar metropolis with 963 units in Calabar municipality and 1011 units in Calabar South Local Government Area which are stationeries. Nevertheless, the workers involve in collections are not properly sensitized on the best ways of collection that are environmentally friendly as may be seen in the collection of hazardous waste in an open flatbed trucks and tippers, and the workers themselves do not properly protect themselves by using hand gloves and nose muffs which can cause unsafe-acts accident and unsafe condition accident (Sahrma & Jain, 2020).

Determination of Waste Quantities

Waste is usually estimated on the basics of data gathered by conducting a waste characterization study using previous waste generation data or some combination of the two approaches (Jaunich *et al.*, 2016).

According to Abdel-Shafy & Mansour (2018), methods commonly used are:

- Load – count analysis method: This is the number of individual loads and the corresponding wastes characteristics which has been taking into consideration.
- Weight – volume analysis method: This is the average volume per millimeter's square of the waste consideration.
- Material balance analysis method: This is the process of separating waste materials in their characterization using specific tonnage for consideration. (i.e. combination of the 2 analytical methods of load count and weight volume).
- Mass-Volume Analysis Method: this is another method that represent weight volume (which means if you do not use weight-volume you can use mass-volume)

However, for this particular study, we used the "Load – count analysis method" and in this method, the number of individual loads and the corresponding wastes characteristics as been taken into considerations for which the following assumptions were made;

- That compactor trucks were used in disposing waste at least once per day
- That each compactor trucks, weight about 10 tones
- That there are five flat-bed trucks and that these trucks disposed waste at least once per day.
- That the compactor trucks have an average volume of 10 cubic meters while the flatbed trucks have an average volume 5 cubic meters.
- That each household comprise of 3.5 average household size.

The total tonnage of municipal solid waste Calabar metropolis is equal to the total weight of MSW divided by number of approved household times number in household times duration as shown in Equation (1)

$$Total\ tonnage = \frac{Total\ weight\ of\ MSW}{(Number\ of\ approved\ household\ x\ No.in\ household)\ x\ Duration} \quad (1)$$

Determination of Waste Composition

Due to the heterogeneous nature of municipal solid waste, determination of the composition is not an easy task for statistical procedure. For this reason, more generalized field procedures based on common sense and random sample techniques has evolve for determining composition

In other word, to assess the total mix of waste components, the load-count and the mass-volume method of analysis were recommended estimating with the mass – volume method, the following were made;

Assumptions:

- That there was unloading a truck load of waste from a compactor truck (Aarts & Veld, 2012)
- That there was quartering of the waste load
- That one of the quarters was selected and quartered again

- That the selected quarter was separated into all of the individual components of the waste into preselected components
- That there was placing of the separated components on a scale to get the mass and volume.
- Determination of the percentage distribution of each component by mass was made.

The relationship between quantity and composition of municipal solid waste linear as presented in Eqn. (2) to (3).

$$MSW(q) = MSW(C)(quarters) \quad (2)$$

$$MSW(q) = MSW(C)(PL + T + M + G + P + O) \quad (3)$$

Where; PL = plastics, P = Paper, T = Textiles, M = Metals, G = Glass, O = Others

Then; MSW = Municipal solid waste

While;

(q) = quantity of waste

(c) = composition of waste

results and discussion

Result of the waste quantity estimation

Table 1 presents the data of the load count analysis. This shows the result of the waste rate estimation of items, number of loads, average volume, specific weight and total weight that were used for unit rate calculation.

TABLE 1
LOAD COUNT RESULT

Items	No. of loads	Average volume	Specific weight (tons)	Total weight (tons)
Compactor trucks	300	10	500	1,500,000
Flatbed truck	150	5	225	168,750
				1,668,750

It equally shows that waste evacuation was limited to the use of compactor trucks and flatbed trucks only with 1,500,000 tons and 168,750 tons per day respectively.

Table 2 shows the data of the load count analysis obtained in 2024. This shows the types of trucks used, the result of the waste rate estimation of items, number of loads, average volume, specific weight and total weight that were used for unit rate calculation. It shows that the use of tippers was incorporated in the evacuation of waste in addition to the use of compactor trucks and flatbed trucks, this measure is seen to meet the increased waste generation rate in Calabar metropolis which is seen to increase from 1,668,750 Tons total weight per day in 2012 to 7,080,000 Tons total weight per day in 2024.

TABLE 2 - DATA FROM LEMNA WASTE DUMP SITE

S/N	Types Of Trucks/No. Of Trucks		No. Of Load Per Day	Average Volume Per M^3	Specific Tons (Weight)	Total Weight (Tons)
1.	Compactor trucks	4	18	16	15 (15,000kg)	4,320,000
2.	Flatbed trucks	15	44	8	5 (5000kg)	1,760,000
3.	Tipper trucks	5	10	10	10 (10,000kg)	1,000,000
						7,080,000tons

Note

- Total number of useful compactor trucks = 4
- Total number of useful flatbed trucks with 6 tyres = 15
- Total number of tippers = 5
- Average weight of compactor truck = 15 tones
- Average weight of flatbed truck = 5 tones
- Average weight of tipper truck = 10 tones
- Each compactor truck has a total volume of 6000 litres
- Each of tipper truck has a total volume of 6000 litres
- Each of tipper truck has a total volume of 4000 litres
- Total dumping times per day = 72 times

II. *Result of the composition of waste quantity estimation*

The values in Table 3 were obtained from Figure 4, (composition of waste stream and characteristics) by using material balance analysis methods which separated all the items and weighed them by their percentage composition and tonnage

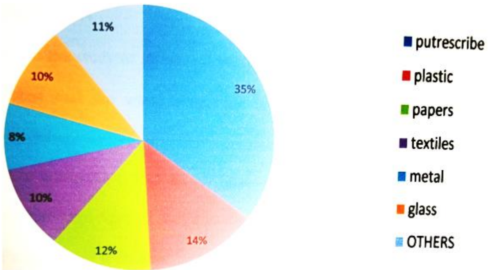

Figure 4. Composition of waste stream and characteristics

TABLE 3

THE PERCENTAGE COMPOSITION AND THE CORRESPONDING TONNAGE

S/N	Items	% Composition	Tonnage
1	Putrescribe	35	124,164.26
2	Plastics	14	49,665.70
3	Papers	12	42,570.60
4	Textiles	10	35,475.50
5	Metals	8	28,380.40
6	Glass	10	35,475.50
7	Others	11	39,023.05

JJ. Result of the household composition and waste collection rate

The composition of waste in Calabar Metropolis reflects several interrelated factors including lifestyle, consumption patterns, waste management systems, and cultural habits. Putrescible Waste (35%) is the highest as it involves dietary Habits as seen in Table 3. The high percentage of organic waste stems from a diet heavily reliant on fresh fruits, vegetables, and other perishables. Calabar, known for its rich culinary culture, likely generates significant food waste from households, markets, and restaurants. Market Structures: Open-air markets are common in Calabar metropolis, contributing to large amounts of organic waste from spoiled or discarded produce. Nevertheless, inadequate Composting Systems means organic waste often ends up in landfills or streets.

It could also be seen that Plastics formed 14% of the waste composition as Increasing Use of Packaged Goods as the rise in urbanization and consumption of processed foods packaged in plastics has contributed to this percentage. Inadequate Recycling Facilities for plastics exacerbates resulted in the accumulation of plastic waste. Improper Disposal Practices as a result Poor public awareness and inadequate disposal systems lead to improper handling of plastics. However, the percentage composition in Table 4.3 also show that papers composition is 12% with a corresponding tonnage of 42,570.60 tons, this is evident in the educational and commercial activities in Calabar metropolis as the presence of tertiary institutions like the University of Calabar, Cross River State University, School of Nursing Science, College Of Health Technology, Calabar and a litany of so many public and private nursery, primary and secondary schools, offices and businesses in the metropolis contributes to the generation of paper waste, such as old newspapers, books, and office documents. Limited recycling options for paper may be minimal, leading to increased waste accumulation.

Textiles is seen to have 10% composition with a corresponding 35,475 tonnage, this is due to cultural practices and fashion trends prevalent in Calabar metropolis; high textile waste may have arisen from the prominence of traditional attire, fashion turnover, and disposal of old or damaged clothing. Secondhand clothing markets around the beach area known as beach market play host to 90% of secondhanded clothing known as “OK” these worn-out items eventually add to textile waste because of the short life span of the product owing to their previous uses, leading to their inclusion in general waste streams.

The percentage of metals in waste is 8% with a corresponding 28,380.40 tonnage, these may originate from construction debris, used cans, and other discarded metal products. however, Scrap Metal Recycling may be informal as some are separated and taken to EPZ by Scrap metals scavengers for recycling into various sizes of mild steel, not all metal waste is captured, resulting in its presence in waste streams (Mohammad, 2016).

It also shows Glass with 10% composition and a corresponding 35,475 tons, this is evident in the prevalent beverage consumption because Glass waste likely comes from beverage bottles, jars, and household products. However, some glass bottles may be reused by producers, but broken or non-reusable glass contributes to waste. Low Recycling Rates, Glass recycling infrastructure may be underdeveloped, limiting reuse options (Adriaanse, 2018).

From Table 3 it is also evident that others waste such as E-waste and hazardous materials which could be electronics, batteries, and other less common waste types fall into this category formed 14% of the waste composition (Akram *et. al.,* 2019). As Calabar grows, urban lifestyles promote higher consumption and more waste.

Nevertheless, Lack of Proper Waste Management Systems, Limited waste segregation, collection, and recycling infrastructure result in a mixed waste stream, consumer Behaviour add to the waste burden. The waste composition in Calabar Metropolis reflects a mix of cultural, economic, and infrastructural factors (Bassey, 2023).

The unit waste collection rate based on the assumption that each house hold is comprise of 3.5 average household is 2.19kg/capita/day

The total tonnage of waste generation of the entire Calabar metropolis was evaluated to be 1,500,150 tons This is due to increased population as orchestrated by rural urban migration (Onu, 2014). Nevertheless, the generation rate per day was also evaluated to be 4,110 tons/day and generation rate per week was equally evaluated to be 28,770 tons/week while the generation rate per month is 123,300 tons/month and the generation rate per year is evaluated to be 1,500,150/year

Then the Generation rate projection from January 2024 to December 2060 is evaluated to be 55505550 tons/37 years.

TABLE 4
CALABAR METROPOLIS SOLID WASTE GENERATION RATE ESTIMATION OF 2024 AND 2012

City	Population as at 2024	Agencies	kg/capital/day	Per/day	Per/week	Per/month	Per/year
Calabar metropolis	685,000	Calabar Urban Development Authority	2.19kg	4110 tons/day	28770 tons/week	123,300 tons/month	7,080,000 tons/years
	Population as at 2012						
Calabar metropolis	449057	Calabar Urban Development Authority	0.79kg	971.93 tons/day	6803.51 tons/week	29,157.9 tons/month	354754.45 tons/years

Table 4 shows the current estimated population of Calabar metropolis in 2024 as 685,000 with that 2012 as 449,057 (national population data). It is evaluated that 2.19kg per capital per day waste is generated for the year 2024 as opposed to 0.79kg/capital/day evaluated in 2012.

It is evident that the tonnages were evaluated to be 4,110 tons/day, 28,770 tons/week, 123,300 tons/month and 1,500,150 tons/year as at 2024, as opposed to 971.93 tons/day, 6,803.51 tons/week, 29,157.9 tons/month and 354,754.45 tons/year in 2012. This shows the waste generation increment of 2.5 percent in Calabar metropolis like the case of Ado-Ekiti (Ogunleye and Uzoma, 2018).

conclusion

Conclusion

The study sought to:

- Develop an efficient data-base for waste generated in Calabar metropolis.
- Estimate the monthly/annual waste generation rate in Calabar metropolis.
- Analyze the waste composition in Calabar metropolis

The development of an efficient database for waste generation, coupled with the estimation of monthly and annual waste generation rates and the analysis of waste composition in Calabar Metropolis, has proven to be a significant step toward sustainable waste management. This study has successfully established a reliable framework for recording, organizing, and analyzing waste-related data, providing stakeholders with accurate and actionable insights. The following conclusions were drawn:

- By using material balance analysis methods which separated all the items and weighed them by their percentage composition and tonnage, it is evident that Putrescible Waste is the highest with percentage composition of 35% as it involves dietary Habits. The high percentage of organic waste stems from a diet heavily reliant on fresh fruits, vegetables, and other perishables and this is prevalent in the raining season, Plastics formed 14%, Papers composition is 12% with a corresponding tonnage of 42,570.60 tons, this is evident in the Educational and Commercial Activities in Calabar metropolis, Textiles is seen to have 10% composition with a corresponding 35,475 tonnage, the percentage of metals in waste is 8% and Glass with 10% composition.
- The waste generation rate per day is evaluated to be 4,110 tons/day and 28,770 tons per week

- while the Generation rate per month is 123,300 tons/month and that of the year is evaluated to be 1,500,150/year, interestingly the Generation rate projection from January 2024 to December 2060 is evaluated to be 55505550 tons/37 years.
- The database generated in the Appendices serves not only as a tool for effective planning and resource allocation but also as a foundation for future research aimed at optimizing waste reduction, improving public health, and fostering environmental sustainability in Calabar Metropolis.

Recommendation

The data from the Lemna Dumpsite in the study generally provides valuable insights into the waste generation patterns and management operations in Calabar Metropolis. While the current system effectively handles significant volumes of MSW, it also highlights pressing challenges related to landfill capacity, environmental sustainability, and resource recovery. To address these challenges, Calabar must adopt integrated waste management strategies, combining technology, policy innovation, and community engagement to enhance sustainability and reduce the ecological footprint of its MSW system.

References

[1] Aarts, L., & Veld, T. (2012). Increasing number of truck breakdowns: simply bad luck? In *HVTT12: 12th International Symposium on Heavy Vehicle Transport Technology*.

[2] Abdel-Shafy, H. I., & Mansour, M. S. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian journal of petroleum*, *27*(4), 1275-1290.

[3] Adriaanse, F. G. (2018). *The design and testing of a decision support tool for the evaluation of the reusability of glass wine bottles: A South African case study* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

[4] Ahsan, A., Alamgir, M., Imteaz, M., Shams, S., Rowshon, M. K., Aziz, M. G., & Idrus, S. (2015). Municipal solid waste generation, composition and management: Issues and challenges. A case study. *Environment Protection Engineering*, *41*(3).

[5] Akram, R., Natasha, Fahad, S., Hashmi, M. Z., Wahid, A., Adnan, M., ... & Nasim, W. (2019). Trends of electronic waste pollution and its impact on the global environment and ecosystem. *Environmental Science and Pollution Research*, *26*, 16923-16938.

[6] Al-Tamimi, W. M., Khatib, I., & Kontogianni, S. (2018). Household Hazardous Waste Quantification,

[7] Aziz, H. A., Abu Amr, S. S., Vesilind, P. A., Wang, L. K., & Hung, Y. T. (2021). Introduction to solid waste management. *Solid Waste Engineering and Management: Volume 1*, 1-84.

[8] Bassey, B. J. (2023). Urban Landuse And Generation Of Solid Waste In Calabar Metropolis, Cross River State, Nigeria. *Global Journal of Social Sciences*, *22*(1), 167-178.

[9] Das, S., Lee, S. H., Kumar, P., Kim, K. H., Lee, S. S., & Bhattacharya, S. S. (2019). Solid waste management: Scope and the challenge of sustainability. *Journal of cleaner production*, *228*, 658-678.

[10] Jaunich, M. K., Levis, J. W., DeCarolis, J. F., Gaston, E. V., Barlaz, M. A., Bartelt-Hunt, S. L., ... & Jaikumar, R. (2016). Characterization of municipal solid waste collection operations. *Resources, Conservation and Recycling*, *114*, 92-102.

[11] Mohammad, R. (2016). Concentration of trace metals in water, sediments, some commercial fish and crustacean species in the coastal area, Bangladesh and health risk assessment.

[12] Noor, T., Javid, A., Hussain, A., Bukhari, S. M., Ali, W., Akmal, M., & Hussain, S. M. (2020). Types, sources and management of urban wastes. In *Urban ecology* (pp. 239-263). Elsevier.

[13] Ogwueleka, T. (2009). Municipal solid waste characteristics and management in Nigeria. *Journal of Environmental Health Science & Engineering*, *6*(3), 173-180.

[14] Onu, B., Surendran, S. S., & Price, T. (2014). Impact of inadequate urban planning on municipal solid waste management in the Niger Delta Region of Nigeria. *Journal of sustainable Development*, *7*(6), 27.

[15] Sharma, K. D., & Jain, S. (2020). Municipal solid waste generation, composition, and management: the global scenario. *Social responsibility journal*, *16*(6), 917-948.

[16] Zohoori, M., & Ghani, A. (2017). Municipal solid waste management challenges and problems for cities in low-income and developing countries. *Int. J. Sci. Eng. Appl*, *6*(2), 39-48.