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Affordable and Sustainable Clean Energy Generation Potentials from Municipal Dumpsites: A Case Study of Oke Saje Dumpsite, Abeokuta, Ogun State Nigeria

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ABSTRACT

This study assessed waste management practices at Oke Saje dumpsite in Abeokuta. Ogun State, Southwest, Nigeria), where open dumping and burning are the primary disposal methods. For six months in 2023, solid waste samples were collected from seven 1 sq.m plots, analyzed, and categorized. The total waste generated was 3,718,832.03 kg (3718.83 tonnes), with an estimated energy content of 46,370.47 MJ, potentially generating 12.881 MWh of electricity daily. The proposed integrated waste management strategy includes recycling 46% of waste (composting, biofuel production, recyclables) and recovering 56% of energy (electricity generation, incineration and ash for landfilling). This approach could yield 5.923 kWh from recycling and 6.956 kWh from energy recovery. The study recommends that Ogun State Waste Management Authority adopt sustainable practices like waste minimization, sorting, reuse, recycling, and incineration to improve waste management in the state.

INTRODUCTION

Population growth, urbanization, and economic development are key drivers of increased waste generation in African urban cities, straining waste management systems (Scarlat *et al.,* 2015). The rapid advancements in science and technology, coupled with rising resource consumption, have led to the accumulation of significant amounts of solid waste from domestic, agricultural, and industrial activities. This waste often carries heightened toxicity and hazards, posing serious threats to public health (Sangodoyin and Ipadeola, 2000; Oladejo, 2011).

Uncontrolled population growth, community density, consumption habits, standard of living, monthly wages, dwelling population, urbanization rate, age, sex, ethnicity, housing unit size, geographical location, land use patterns, productive activities, and cost of living are all factors that influence waste generation, with population being the primary determinant of unit waste generation rate (Cheng and Hu, 2010). Estimating the quantity of solid waste generated in a city is crucial for effective waste management. While many developed countries treat waste as a resource, poor waste management in developing countries poses significant challenges for governments, particularly in collection and disposal, making solid waste hazardous. This issue has become a serious concern for experts in developing cities (Rahaman et al., 2013; Noor et al., 2013; Chung and Lo, 2008; Imam et al., 2008).

In most developing countries, waste management services, including waste collection and transportation to final disposal sites, are typically managed by local authorities. However, these services are often hindered by inadequate financial resources and limited human resource capacity, leading to ineffective waste management (Barton et al., 2008). This inefficiency contributes to significant problems, including threats to human and animal health, and results in economic, environmental, and biological losses (Sharholy et al., 2008).

In Nigeria, effective municipal waste management is challenged by poor funding, uncontrolled population growth, lack of trained waste management professionals (Okeniyi and Anwan, 2012), ineffective monitoring and control, insufficient maintenance culture, and the absence of modern technology or reluctance to implement efficient waste management methods. Recovering energy from waste offers a promising solution to mitigate environmental pollution caused by municipal waste disposal.

Urbanization in African countries is rapidly increasing, leading to the generation of large volumes of waste. Municipal Solid Waste (MSW) is a significant renewable energy resource in these urban areas, where poor waste management practices are prevalent (Adeniran *et al*., 2017; Mwangomo, 2018). Converting waste into useful energy is a viable waste management strategy. Technologies such as pyrolysis, gasification, plasma arc gasification, incineration, landfilling, anaerobic digestion, and refuse-derived fuel can be utilized for this purpose (Campos et al., 2015; Kumar, 2016; Jehangir, 2018).

Waste can be converted directly into energy in the form of biogas, syngas, and heat through physical, thermal, and biological methods. Jain *et al.* (2014) identified environmental impacts, technical aspects, and socio-economic factors as key influences on waste-to-energy technology. In Oke Saje community, waste management typically involves direct disposal at nearby dumpsites, which contributes to environmental pollution and degradation. Improving solid waste management by enhancing collection rates and adopting waste-to-energy technologies could mitigate these issues. Jehangir (2018) emphasized that in many developing countries, a significant portion of municipal solid waste remains uncollected, and achieving a 100% collection rate should be of priority before implementing other waste-to-energy options. Furthermore, waste management facilities are often inaccessible to large segments of the population in less developed countries.

This research focused on characterizing the solid waste at the Oke Saje dumpsite in Abeokuta, with the goal of exploring the potential for converting the generated waste into valuable energy resources. The study aimed to recommend suitable waste collection and disposal methods that align with an integrated waste management approach.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Oke Saje dumpsite (coordinates: 7.1816^{o} N and 3.3653^{o} E) in Abeokuta with the field work comprising of reconnaissance survey to the general overview of major dump sites in the study area, temporary collection and sorting points to observe the physical conditions regarding quantity and quality of the municipal solid waste of Abeokuta.

After obtaining the necessary permissions, an exploratory study was conducted over six months, from May to November 2023. Seven randomly selected 1-square-meter plots were identified at the Oke Saje dumpsite in Abeokuta. Solid waste was collected from each plot, from the surface down to a depth of 300 mm, following the methodology of Oladejo et al. (2020a). The collected waste was sorted and weighed to obtain weight-based characterizations of the waste components. Sorting was done according to the College and University Recycling Council (CURC, 2001) system, with modifications to reflect the specific waste streams found at the Oke Saje dumpsite. Selected waste samples were then taken to the laboratory for detailed physical, chemical, and proximate analyses. The primary data collected was analyzed using descriptive statistics.

RESULTS AND DISCUSSION

The composition of municipal solid waste (MSW) components at Oke-Saje, dumpsite, Abeokuta is presented in Table 1, while Table 2 shows the combustible components of solid waste generated, energy content (MJ) and electricity generation potential (MWh). Table 3 presents the zero waste concept and analysis of value addition to waste generated in Oke-Saje, dumpsite, Abeokuta.

Estimated total solid waste generated from Oke-Saje, dumpsite, Abeokuta

The estimated total solid waste generated at the Oke Saje dumpsite in Abeokuta was 3,718,832.03 kg (3,718.83 tonnes), with individual waste categories ranging from 65,177 kg (1.75%) to 637,933.85 kg (17.15%). The waste characterization by percentage is illustrated in Figure 1. Metal wastes, primarily from scrap businesses, canned drinks, milk cans, and other food cans, constituted the largest portion at 17.15%. This high percentage is likely due to the significant metal scrap industry in the area, a trend also observed by Oladejo et al. (2020a). Sanitary wastes (16.52%) and textiles/rags (12.29%) were the second and third most common waste types, likely due to local textile industries producing tie and dye materials. Leather waste accounted for 4.91%, attributable to the indigenous leather goods industry. Jikmika and Mirunalini (2017) highlighted the use of leather waste in concrete as a way to reduce pollution and landfill pressures.

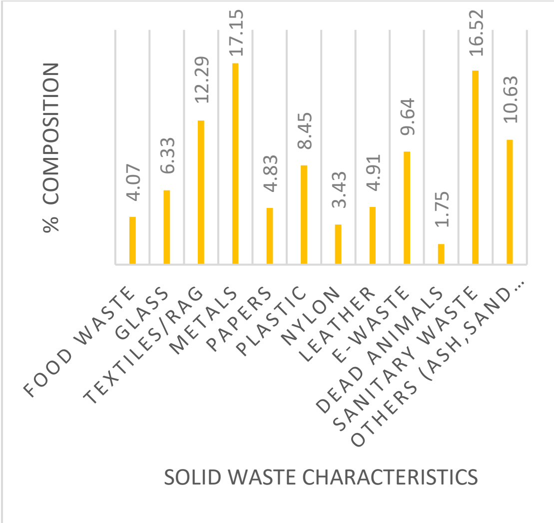

Figure 1: Total solid waste characterization by percentage (%) from in Oke-Saje, dumpsite, Abeokuta

Plastic bottles (8.45%) and polythene nylon (3.43%) were also present, though their quantities were likely reduced due to scavenging for reuse. Babatunde (2013) noted that polythene bags are typically the second largest waste category after organics in Nigerian municipalities. The prevalence of sachet water, driven by the need for affordable potable water, contributes to plastic waste, as noted by Dada (2009). Policies to reduce plastic waste generation, such as promoting water dispensers and strategic placement of plastic collection bins, may be beneficial. Food wastes (4.07%) and dead animals (1.75%) were among the least generated wastes but pose significant environmental and health risks, such as greenhouse gas emissions and attraction of disease vectors if not properly managed. Westerman and Bicudo (2005) suggested using organic wastes for composite production, energy generation, and composting to enhance soil nutrients. Smyth et al. (2010) reported a food waste composting program in British Columbia, and Oladejo et al. (2020b) noted that anaerobic digestion of food waste produces three times the methane of municipal wastewater solids. Other waste categories included paper and paper products (4.83%), e-waste (9.64%), and ashes (10.63%).

Physical combinations of solid wastes for energy recovery and recyclability potential

Table 2 details the combustible components of solid waste at the Oke Saje dumpsite, including their energy content (MJ) and potential for electricity generation (MW). Figures 2 and 3 illustrate the electricity generation potential (MWh) and the percentage of waste with value addition.

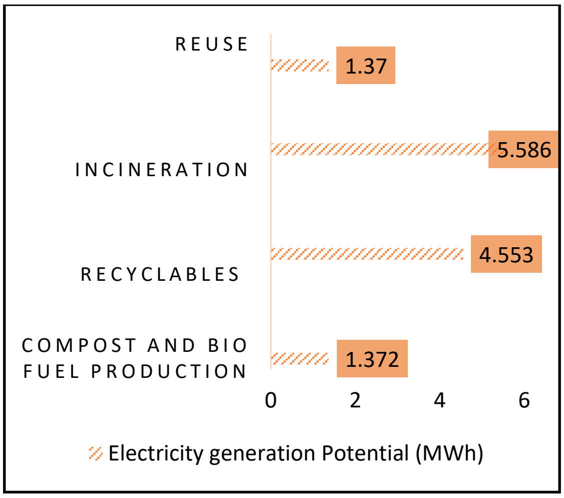

Figure 2: Value addition and Electricity generation Potential (MWh) from Oke-Saje, dumpsite, Abeokuta

Currently, complete incineration of the solid waste at Oke Saje can generate up to 12.881 MWh of electricity. Given the calorific value of the waste, utilizing it as a renewable energy source is both economical and environmentally beneficial. According to Arise News (2022), the total installed electricity capacity in Nigeria is 18,000 MW, with an actual generation of 8,000 MW due to low hydro dam levels. The Nigerian Electricity Regulatory Commission (NERC) reported an average residential energy consumption of 50-60 kWh per month in 2019 (Energy Independence Newsletter, June 6, 2023). Thus, the electricity potential from waste incineration (12.881 MWh) could supply over 6,000 households (2 kWh/day) in Nigeria.

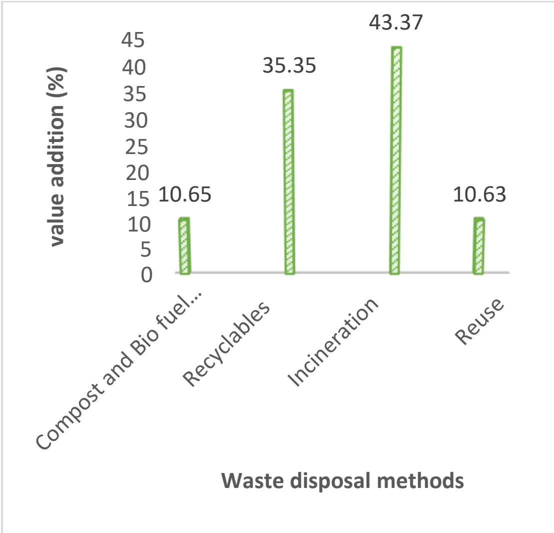

Figure 3: Percentage waste generated with value addition from Oke- saje, dumpsite, Abeokuta

Table 3 and Figure 3 show the zero-waste concept and the value addition of waste from Oke Saje. Approximately 10.65% (396,127.19 kg) of the waste consists of food waste, paper, and dead animals, which can be processed into compost or bio-fuel, yielding an electricity potential of 1.372 kWh. Recyclables such as polythene bags, plastic bottles, metal cans, and glass make up 35.35% (1,314,713.2 kg) of the waste, aligning with previous studies and demonstrating a recycling potential of 4.553 kWh.

Around 43.37% (1,612,665.2 kg) of the waste, including leathers, e-wastes, and textiles, is suitable for incineration, producing an electricity potential of 5.586 kWh. Incineration ash can be combined with residual ash for landfilling or soil enhancement. This differs from findings in Dhaka, where non-recyclable waste is 70-80% (Anon, 2004; Aubert, 2004, Salam *et al.*, 2011). Bottom ash can be repurposed for construction or concrete production (Aneeta et al., 2018).

Table 1: Composition of MSW components at Oke- saje, dumpsite, Abeokuta- 18.622 hectares

S/N	Waste categories	Plot A (g)	Plot B (g)	Plot C (g)	Plot D (g)	Plot E (g)	Plot F (g)	Plot G (g)	Total (g)	Average (g/sqm)	Total (Kg)	% Composition
1	Food Waste	-	-	2900	-	2,340	450	-	5,690	812.9	151,378.24	4.07
2	Glass	6,100	-	-	2740	-	-	-	8,840	1262.9	235,177.24	6.33
3	Textiles/Rag	350	6,480	-	3700	-	-	6,650	17,180	2454.3	457,039.75	12.29
4	Metals	1100	3700	5700	-	4630	2430	6400	23,980	3425.7	637,933.85	17.15
5	Papers	540	1200	450	1430	750	1400	980	6,750	964.3	179,571.95	4.83
6	Plastic	2200	1050	1560	1800	2700	1750	750	11,810	1687.1	314,171.76	8.45
7	Nylon	780	400	240	650	850	1870	-	4790	684.3	127,430.35	3.43
8	Leather	-	-	4300	1050	1510	-	-	6860	980.0	182,495.60	4.91
9	E-waste	4920	2670	-	-	4490	-	1400	13,480	1925.7	358,603.85	9.64
10	Dead Animals	-	-	-	-	-	2450		2,450	350.0	65,177.00	1.75
11	Sanitary waste	600	2400	3600	6,680	-	7850	2180	23,310	3330.0	614,526.00	16.52
12	Others (Ash,sand e.t.c)	3410	2100	1250	1950	2710	1800	1640	14,860	2122.9	395,326.44	10.63
	Total Waste generated at Oke-Saje dumpsite, Abeokuta										**3,718,832.03** (3718.83203 tonnes)	100%

Table 2: The combustible components of solid waste generated in Oke-Saje, dumpsite, Abeokuta (kg/day), energy content (kJ/day) and electricity generation potential (MWh)

S/N	Combustible Components	Moisture content	% Composition	Quantity of MSW generated (kg)	Specific Energy Content (kJ/kg)	Total Energy Content (MJ)	Electricity generation Potential (MWh)
1.	Food Waste	35.9	4.07	151,378.24	14360.49	2173.87	0.604
2.	Textiles/Rag	-	12.29	457,039.75	17445	7973.06	2.215
3.	Metals	-	17.15	637,933.85	558.56	356.32	0.616
4.	Papers	5.57	4.83	179,571.95	12975.42	2330.02	0.647
5.	Plastic	1.80	8.45	314,171.76	31246.63	9816.81	2.727
6.	Nylon	1.82	3.43	127,430.35	29084.24	3706.21	1.030
7.	Leather	-	4.91	182,495.60	19771	3608.12	1.002
8.	Dead Animals	-	1.75	65,177.00	4575.10	298.20	0.083
9.	Sanitary waste		16.52	614,526.00	15119	9291.02	2.581
10.	Ashes	-	10.63	395,326.44	17243.56	6816.84	1.894
Total						**46370.47**	**12.881**

The integrated waste management approach for Oke Saje includes a zero-waste concept with 46% of waste recyclable or usable for composting and bio-fuel, generating 5.923 kWh of electricity, and a 56% energy recovery rate from incineration and ash, equating to 6.956 kWh.

CONCLUSIONS

This study highlights the urgent need for improved waste management strategies driven by rapid urbanization and economic development. The research reveals a significant volume of waste, with metals and textiles being the most prevalent, and lower quantities of plastics due to scavenging and reuse. Despite the environmental and health risks associated with improper waste disposal, the study shows substantial potential for converting waste into renewable energy. The total waste generation of 3,718.83 tonnes could produce up to 12.881 MWh of electricity through incineration. Additionally, 10.65% of the waste could be processed into compost or biofuel, and 35.35% is recyclable, presenting further opportunities for energy recovery and material reuse. Implementing an integrated waste management approach, including recycling, composting, and efficient energy recovery, could significantly mitigate environmental impacts and support sustainable development in the community.

RECOMMENDATIONS

To enhance waste management in Oke-Saje, Abeokuta, the following measures are recommended:

1. Develop comprehensive strategies for waste reduction, recycling, and long-term management, involving the private sector and ensuring the participation of all stakeholders in a formal waste management system.
2. Launch public awareness campaigns, particularly in schools and communities, and utilize social media to educate people about effective waste management practices.

3. The government should offer subsidies for waste-to-energy plants to attract foreign investment. Evaluate various waste-to-energy technologies and implement the most suitable option based on the waste composition at Oke-Saje dumpsite.
4. Install weight bridges at landfill sites to accurately measure waste volumes and conduct further studies on waste characterization in other cities. Establish a dedicated statistical unit to gather and analyze reliable data for future development projects.
5. Implement rigorous monitoring to ensure proper waste collection, storage, and transportation, while preventing landfill leaching and ensuring emissions from waste-to-energy projects are safe.
6. Appoint highly qualified officials to local solid waste management departments who understand local issues and can address them effectively.

Table 3: Zero waste concept and analysis of value addition to waste generated in Oke-Saje, dumpsite, Abeokuta

Value Addition	**Waste components**	**Ave Waste (kg) generated**	**% waste generated**	**Electricity generation Potential (MWh)**	**Zero Waste Concept**
Compost and Biofuel Production	Paper	179,571.95			
	Food wastes	151,378.24			
	Dead Animals	65,177.00			
	Sub total	**396,127.19**	**10.65**	**1.372**	
Recyclables	Plastics (water bottles)	314,171.76			Material Recyclable **46%**
	Polythene (water sachet, nylons)	127,430.35			**(5.925 MWh)**
	Metals (tins, cans bottles)	637,933.85			
	Glass	235,177.24	**35.35**	**4.553**	
	Sub total	**1,314,713.2**			
Incineration	Textiles/ Rags	457,039.75			
	E- wastes	358,603.85			
	Sanitary (diapers, pads, rags)	614,526.00			Energy Recovery Material
	Leathers	182,495.60			**54%**
	Sub total	**1,612,665.2**			
			43.37	**5.586**	**(6.956 MWh)**
Reuse	Residuals (ashes, sand, etc)	395,326.44	**10.63**	**1.370**	
	Total	**3,718,832.03**	**100.00**		**100%**

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