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ORIGINAL RESEARCH ARTICLE

SOLID WASTE GENERATION AND CHARACTERIZATION IN ILORIN, NIGERIA

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ABSTRACT

Global per capita waste generation rates and characterization vary by regions, countries, and within cities. The generation, I and characterization of waste from selected areas in Ilorin, Nigeria, prone to indiscriminate disposal of solid waste without consequence were analyzed for proper management. Municipal solid wastes were sorted, analyzed by weight and percentage composition using the quantitative approach. The average generated waste per capita was estimated to be 0.66 kg/day, w/w distribution was 57.53% food waste, 9.07% nylon (flexible films), 5.98% plastic (rigid containers),4.95% textile, 10.51% paper and 11.96% others. The average moisture content was 46.16% food waste, 20.63% nylon, 18.65% plastic, 36.67% textile, 18.45% paper and 42.89% others. The results show an average bulk density of 10.36 Kg/m^3 of food waste, 2.14 of nylon, 0.5 of plastic; 0.93 of textile; 2.74 of paper and others 5.36. The chemical analysis showed that volatile matter ranged from 20.55 to 24.10%, ash content 3.10to 3.90%, fixed carbon 7.5to 9.8%, calorific value 14820to 18360 (kJ/kg), nitrogen 0.40to 0.50%, hydrogen 4.38to 5.80%, carbon 40.90 to 44.30%, oxygen 30.80 to 34.60%, Sulphur 0.19 to 0.24%, fusing point of ash 3.12to 4.38 °C, and heating value from 13.520to 13.64 KJ/Kg. The results generated could play a positive role in the management of solid waste in that area.

1.0 Introduction

Increase in the global population and rising demand for food and other essentials, has caused a rise in the amount of solid waste generated daily at household level. Solid wastes can be defined as non-liquid and nongaseous products of human activities, regarded as being useless (Mungure, 2008; Babayemi and Dauda 2009). Poor waste management poses several challenges to human healthespecially those living close to the dumpsites which could pollute the environment and affect water, food sources, land, air and vegetation (Njoroge and Busman 2007).

Solid waste management has emerged as one of the greatest challenges facing State and Local Government Environmental Protection Agencies in Nigeria (Olukanni and Mnenga 2015). However, the capacity to develop an efficient and sustainable waste management program in developing nations has been limited by insufficient documentation of the volume and characterization of solid waste generation (Olukanni *et al*. 2013) which has caused public health issues and environmental problems (Yoshida, 2018). According to Pervez and Kafeel (2013), improper waste disposal and management causes all types of pollution in the air, soil, and water, indiscriminate dumping of refuse contaminates surface and groundwater supplies. In urban areas, improper waste disposal clog drains, creating stagnant water for insect breeding and floods during rainy seasons. Uncontrolled burning of waste also contributes significantly to air pollution. Dumpsites are known for their smelly and unsightly conditions, these conditions are worse in the summer because of extreme temperatures, which speed up the rate of bacterial action on biodegradable organic material (Salam, 2010). Globally, about 37 percent of waste is disposed of in some type of landfill, 33 percent is openly dumped, 19 percent undergoes materials recovery through recycling and composting, and 11 percent is treated through modern incineration. Lower-income countries generally rely on open dumping with 93 percent of waste is dumped in low-income countries and only 2 percent in high-income countries. Upper-middle-income countries practice the highest percentage of landfilling, at 54 percent. This rate decreases in high-income countries to 39 percent, where 35 percent of waste is diverted to recycling and composting and 22 percent to incineration. By 2030, the world is expected to generate 2.59 billion tonnes of waste annually.

The world generates 0.74 kg of waste per capita per day, which is correlated with income levels and urbanization rates. In Nigeria, municipal waste densities generally range from 250-370 kg/m^3 (Olukanni and Mnenga 2015); waste generation rate is 25 million tons annually and at a daily rate of 0.44kg - 0.66 kg/capital/day (Ogwueleka, 2009) Africa regions is growing rapidly, whereby in 2050, the total waste generated is expected to triple, double, and double; respectively. Thus, addressing this disturbing issue that has assumed a frightening height with associated effects on the environment holistically is an unavoidable alternative for a safe, healthy and viable living (Ahmad *et al*., 2013; Adewumi and Ajibade 2015; Akinbile *et al*., 2016a, b).

Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. It was reported by Hoornweg and Bhada-Tata (2014) that urban residents produce about twice as much waste as their rural counterparts.

The characterization, generation and disposal of waste in a developing nation is an intrinsic part that should not be ignored (Adewumi *et al*., 2017) and waste characterization data specific to African cities are generally not available, though some regional evaluations could be made. This study thus characterized and quantified municipal solid waste generated in some selected areas of Ilorin metropolis for proper management.

2. Materials and Methods

2.1. Study Area

The study area is a densely populated community in Ilorin, Kwara State, Nigeria, located at Emirs road, Gambari, and Centre- Igboro on latitude of 8° 29' 33"N, 8° 30' 02"N and 8° 29' 52"N and longitude of 4° 33' 22"E, 4° 33' 37"E and 4° 33' 19"E respectively. Preliminary survey revealed that these areas were prone to indiscriminate disposal of solid waste. without consequence. Figure 1 shows the study area on the map of Kwara state Nigeria.

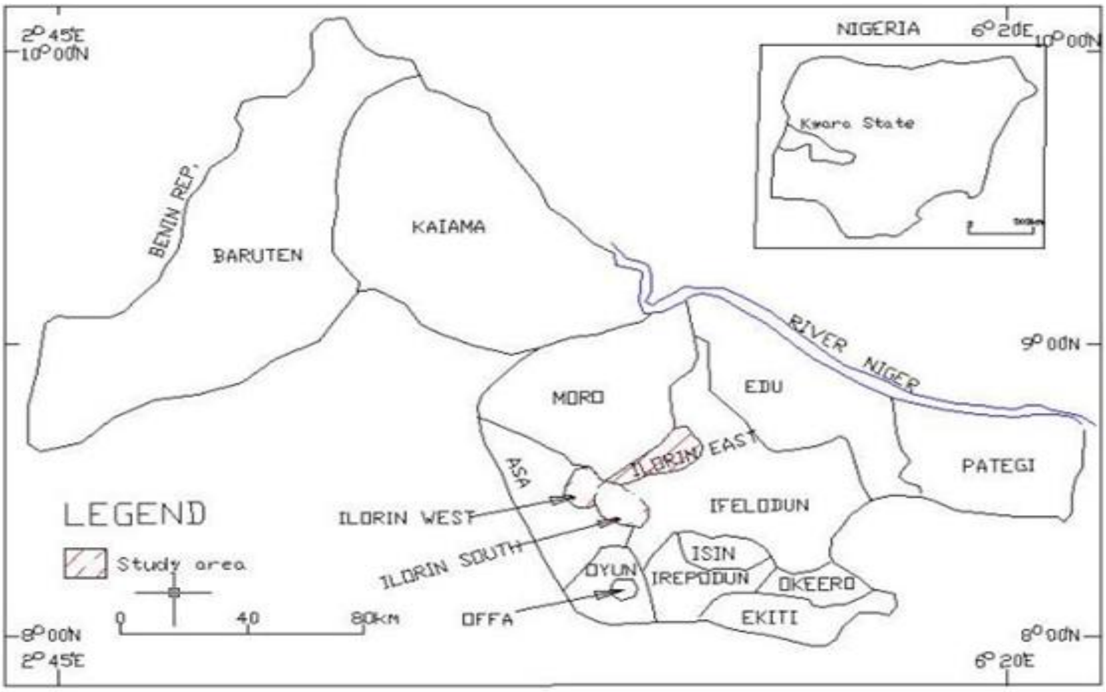

Figure 1: Map of Kwara State showing the study area
Source: Mokuolu (2014)

2.2. Waste Quantification

Primary data were collected randomly from selected households. The total waste generated and other data were determined according to Kodwo *et al.* (2015). Total waste generated in the study area was determined using Equation (1)

$$\text{Per capita waste generation} = \frac{\text{weight of municipal solid waste generated at the household}}{\text{total number of persons in the household} \times \text{total generation day}} \qquad (1)$$

2.3. Physical Composition of Municipal Solid Waste Analysis

Municipal solid waste from the study areas were sorted manually with the use of hand gloves, apron, boots and nose masks into the following compositions and analyzed by weight and as well as the percentage composition.

I. Food waste
II. Plastics
III. Metals
IV. Papers (cardboard, sheet, office print, tissue, and diapers)
V. Nylon
VI. Textiles
VII. Miscellaneous (other materials which could not fit in above)

2.4. Percentage Weight of Waste Components

After sorting, the waste was collected in an empty container (W_1) using the laboratory weighing scale. The weight of container along with individual component was measured as (W_2). The individual weight of the component ($W_C = W_2 - W_1$) was thus calculated.

2.5. Determination of Moisture Content

The moisture content was determined as the weight of moisture per unit weight of dry or wet material. In equation (2), the moisture content was expressed as follows:

$$moisture\ content\ \% = \frac{a-b}{a} \times 100 \qquad (2)$$

Where: a = initial weight of the sample (g)

b = weight of the sample after drying (g).

2.6. Determination of Bulk Density

The bulk density was determined by weighing a container of known volume as (V_1), the weight was recorded as (W_1). The waste sample was poured into the container until it overflowed, the sample was then compacted three times by dropping it from a height of 10 cm and the container was refilled after the compaction. The container and its content were weighed and recorded as W_2. The bulk density was determined from Equation 3.

$$bulk\ density\ = \frac{w2\ -w1}{v1}\ (\mathrm{kg/m^3}) \qquad (3)$$

2.7. Chemical Composition

The chemical composition such as carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Sulphur (S), and Ash were determined. The following procedures were used:

2.7.1. Carbon

In Equation 4, the percentage total carbon of the waste sample was determined directly by adding the volatile matter and the fixed carbon together.

$$\%\ Total\ carbon = Volatile\ matter\ + Fixed\ carbon \qquad (4)$$

2.7.2. *Hydrogen and oxygen*

The percentage of hydrogen and oxygen in the waste sample were obtained analytically by the difference between the sum of percentage total carbon, nitrogen, sulphur, and 100.

$$\%\ Hydrogen\ +\ \%\ Oxygen\ = 100 - (\ \%\ of\ C\ + N + S) \qquad (5)$$

2.7.3. *Nitrogen*

Nitrogen was determined using Kjeldahl's method. of the solid waste sample 1.00g was heated with concentrated H_2SO_4 (tetraoxosulphate (vi) acid) in the presence of K_2SO_4 (Potassium tetraoxosulphate (vi) salt) and $CuSO_4$ (Copper (ii) tetraoxosulphate (vi) salt) in a long-necked flask called Kjeldahal's flask thereby converting the nitrogen in the solid waste sample into ammonium sulphate. When a clear solution is obtained, the solution was treated with 50% NaOH (Sodium hydroxide) solution. The ammonia formed was distilled over and absorbed in a known quantity of standard H_2SO_4 solution. The volume of an un-used acid was then determined by titration against a standard solution of NaOH. The amount of acid neutralized by liberated NH_3 from the solid waste sample was evaluated. The percentage of nitrogen in the waste was then calculated.

2.7.4. *Sulphur*

Of the weighed samples, 25 ml were dissolved in water and pipetted into 50 ml standard flasks followed by 20 ml gelatin $BaCl_2$ solution and made up to 50 ml mark. The solution was allowed to stand for 30 minutes.

A known weight of the dried sample was taken into an open crucible and heated to open air at 700-750 °C in a muffle furnace until a constant weight was obtained. The weight of the residue was reported as ash.

$$\text{Percentage of ash} = \frac{weight\ of\ residue}{weight\ of\ dried\ waste} \times 100 \qquad (6)$$

2.7.6. *Fusing point of ash*

This is the temperature at which the ash resulting from the burning of waste will form a solid (clinkers) by fusion and agglomeration and the typical fusing temperatures 1100 - 1200°C.

2.7.7. *Proximate analysis*

This is the analysis of waste to determine moisture content, volatile matter, ash and fixed carbon.

The moisture content of the collected waste samples was determined using ASTM 3173 method in which 1 kg of the solid waste sample was placed in a pre-weighed dish and placed in an oven at 105 °C to a constant weight. The moisture content was calculated as a percentage.

$$\%\ \text{moisture content} = \frac{wet\ weight - dry\ weight}{wet\ weight} \times 100 \qquad (7)$$

2.7.8. *Volatile matter (additional loss on ignition at 950 °C)*

This was determined by weighing 5 kg of dried waste samples and placing in a furnace for 7 minutes at 950 °C (ASTM 3175). After combustion, the samples were weighted to determine the ash dry weight, with the volatile matter being the difference between the dried sample and the ash

$$\%\ \text{volatile matter} = \frac{dry\ sample\ weight - ash\ weight}{dry\ sample\ weight} \times 100\% \qquad (8)$$

2.7.9. *Fixed carbon*

The percentage of fixed carbon was determined by deducting the sum total of moisture volatile matter and ash percentage from 100 %

$$= 100\% - \%\ \text{moisture content} + \%\ \text{volatile matter} + \%\ \text{ash} \qquad (9)$$

2.7.10. *Data analysis*

The results were checked for errors and cleaned as appropriate before computation and data analysis. The data were analyzed using SPSS 17.0 software packages.

3. Results and Discussion

The results are presented in Tables 1 to 6., .

Table 1 shows that average waste generation per households is 0.54 kg/capita/day in Emirs Road, 0.48 kg/ capita/day in Centre- Igboro and 0.84 kg/ capita/day in Gambari. A higher standard of living, economic status of people and affluence results in more wastes and higher per capita generation (Mathur 2018; Irwan *et al*., 2012) Waste generated is higher in all households in Gambari compared to households in Emirs Road and Centre- Igboro revealing a higher standard of living in Gambari compared to the other two centers. According to Babayemi and Dauda (2009), this trend could have been influenced by the population, level of industrialization, socio-economic status of the citizens and the kinds of commercial activities that are predominant.

The ANOVA indicates that f- value (0.073) is less than the critical f value (3.885), which means per capita waste generated among the areas is significant as indicated in Table 2. This also shows that per capita waste generated among the areas is significantly different. This implies that waste generation at Gambari is significantly higher than those generated from Emirs Road and Centre- Igboro, whereas no significant different exist between the latter two areas.

Table 1: Average waste generation in the study areas

Location	Average waste generation (kg/c/d)
Emirs road	0.54
Centre-Igboro	0.48
Gambari	0.84

Table 2: ANOVA for waste generation in the study areas

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	5.32E+08	2	2.66E+08	0.073047	0.929967	3.885294
Within Groups	4.37E+10	12	3.64E+09			
Total	4.43E+10	14				

After physical characterization, the results showed different categories of wastes including food waste, textiles, plastic, nylon, paper were present in varying proportions. 60% of waste components from Ilorin is generated by women from homes (domestic refuse) since the industrial and commercial base of the metropolis is negligible. Table 3 reveals the constituents and proportion of solid waste generated by households in the study area. It was observed that food waste is the dominant type of waste generated in these households and it accounts for 57.53% of the weight composition in the waste. Nylon waste 9.07% is next to food waste. Paper waste is 10.51%, Textile waste is 4.95%, whereas plastic waste is 5.98% only. The remaining 11.96% accounts for other types of wastes. It is therefore evident that most wastes generated in the study area are biodegradable. This agrees with the findings of Wolf (2004), that most wastes generated in households in growing cities of developing countries are biodegradable wastes (food, paper, fabrics etc). However, major waste composition obtained in Ghana were organics and plastic (Kodwo *et al*., 2015). According to Yoshida (2018), Nigeria, Ghana, Zambia, Namibia and Congo (the Republic of Congo) are countries where the waste generation volume are relatively small compared with other African countries. At the global level, food and green waste comprise more than 50 percent of waste in low- and middle-income countries while in high-income countries the amount of organic waste is comparable. Recyclables make up a substantial fraction of waste streams, ranging from 16 percent paper, cardboard, plastic, metal, and glass in low-income countries to about 50 percent in high-income countries. As countries rise in income level, the quantity of recyclables in the waste stream increases, with paper making significant increase. At an international level, dry recyclables (plastic, paper and cardboard, metal, and glass) amount to another 38 percent of waste. Waste composition varies considerably by income, the percentage of organic matter in waste decreases as income levels rise. Consumed goods in higher-income countries include more materials such as paper and plastic than they do in lower-income countries. The granularity of data for waste composition, such as detailed accounts of rubber and wood waste, also increases by income level.

The ANOVA produces a test statistics of (0.17) and p-value (0.91) which is greater than a significant level (0.05) as indicated in Table 4.

Table 3: Average percentage weight composition, moisture content and bulk density of waste from the study areas

S/No	Waste Components	Weight Composition (%)	Dry Weight (%)	Volume (m^3)	Moisture Content (%)	Density (kg/ m^3)
1	Food waste	57.53	41.19	0.14	46.16	10.36
2	Textiles	4.95	3.69	0.14	36.67	0.93
3	Plastic	5.98	1.99	0.14	18.65	0.50
4	Nylon	9.07	24.15	0.14	20.63	2.14
5	Paper	10.51	7.67	0.14	18.45	2.74
6	Others	11.96	21.31	0.14	42.83	5.36

Table 4: ANOVA for waste composition

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	0.160679	3	0.05356	0.171826	0.913863	3.238872
Within Groups	4.987321	16	0.311708			
Total	5.148	19				

Table 5 shows the heating value, Hydrogen, Carbon, Oxygen, Nitrogen, Sulphur, Fusion point of ash, moisture content, volatile matter, ash content, fixed carbon and calorific value of the samples taken from the study areas.

Table 5: The average heating value (kJ/kg), ultimate analysis, proximate analysis, fusing point of ash and calorific value

S/No		Sample A (Emirs road)	Sample B (Gambari)	Sample C (Centre igboro)
1	Heating value (kJ/kg)	13.632	13.520	13.641
2	Hydrogen %	4.50	5.80	4.38
3	Carbon %	42.50	44.30	40.90
4	Oxygen %	30.80	34.60	33.10
5	Nitrogen %	0.40	0.50	0.40
6	Sulphur %	0.21	0.24	0.19
7	Fusion point of ash	3.12	4.38	3.64
8	Moisture Content	24.52	24.93	23.51
9	Volatile matter	49.79	47.86	48.68
10	Ash content	7.51	7.75	8.51
11	Fixed carbon	18.17	19.46	19.29
12	Calorific (kj/kg)	16343.00	18360.00	14820.00

Table 6: ANOVA for heating value

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	7.665233	2	3.832617	0.011055	0.989014	3.68232
Within Groups	5200.479	15	346.6986			
Total	5208.144	17				

The heating value of the waste samples in the study area ranged from 13.520 kj/kg to 13.641kj/kg with waste from location (Centre Igboro) having the highest heating value while waste from location (Gambari) has the lowest

4. Conclusion and Recommendations

The average per capita waste generated was in the range of 0.48- 0.84 kg/d. Wastes generated were mainly food waste, paper, plastic, textiles, nylon and metals. Food waste is generated more in all the study areas with percentage weight composition of 41.19%, moisture content of the waste stream for food waste is 46.16% and the bulk density is 10.36 kg/m^3. The carbon content and calorific value of 44.30% and 18360.0 (kJ/kg) respectively for Gambari is high consequently this will yield a quality fuel and energy potential of waste for the area. also hydrogen and oxygen were present in large quantities of 34.60% and 5.80% respectively in same area. The outcome of this research can be used to determine specific energy content for energy production which is a source of renewable energy and it will help in reducing the release of greenhouse gas emission from open burning.

It is recommended that sorting of recyclable be done by residents prior to waste disposal.

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