

## ESTIMATING THE POWER GENERATION POTENTIAL OF MUNICIPAL SOLID WASTE, A CASE STUDY OF ILORIN METROPOLIS, KWARA STATE

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**Abstract:** *In this study, attempt was made to estimate the quantity of municipal solid waste (MSW) generated per annum, the generation rate in kg/capita/day as well as the quantity and the fractions of the waste streams available for energy production. The power generation potential of MSW in Ilorin metropolis, is presented in this paper. The analysis of the waste streams composition was conducted at Lasoju/Eyenkorin, the only functional dumpsite of the city during the study. The proximate and ultimate analyses of the waste fractions were performed using electric oven and furnace, and elemental analyzer. Energy content of the waste streams was determined experimentally using a bomb calorimeter (e 2k combustion calorimeter). Multiple regression analyses were performed to show the influence of the chemical elements (carbon, hydrogen, nitrogen and sulphur) of the waste streams on the net heating (calorific) value of the waste generated. The high heating value is 226 MJ/kg, and the low heating value is 20 MJ/kg. It was concluded that 1% increase in carbon and sulphur will increase heating value by 79.08% and 10.83% respectively while a 1% increase in hydrogen and nitrogen decrease heating value by 30.2% and 619.1% respectively. 1 % increase in fixed carbon and volatile matter will increase heating value by 8 % and 37 % respectively; while 1 % increase in moisture content will reduce heating value by 11 %. 1 % increase in Garbage, Cellulose and Polyethylene fractions, will cause heating value to increase by 2 %, 17 % and 3 % respectively. The energy potential ( $EP_{MSW}$ ) of the MSW based on the energy content of 584 tons/day MSW, is about 3244444 kWh or 3,244 MWh, Electrical Power ( $EPP_{MSW}$ ) of about 40555 kW or 41 MW and Power to Grid of 27 MW.*

**Keywords:** *Municipal solid waste, generation rate, heating value, energy and power potential.*

### 1. INTRODUCTION

Municipal solid waste (MSW) is the aggregate of the discarded unwanted materials which are generated from the daily activities of man as they interact with their environment. MSW are mostly wastes from residences, commercial centres and institutions. In most developing and developed nations of the world, increase in population, prosperity and urbanization has posed more challenges for municipalities to collect, recycle, treat and dispose of increasing quantities of MSW, especially in a changing climate (Ahmed, 2012). The rates at which MSW are generated, is alarming and constitutes a great problem for the government to manage particularly in Ilorin; because, residues of the used products are mostly discarded indiscriminately (Ajadi and Tunde, 2010). The illegal and indiscriminate disposal of these waste components contributes greatly to air, water, environmental pollution, even land degradation. Ilorin metropolis was selected for this study because of its demographic growth, urbanization, industrialization and influx of refugees from North Eastern part of Nigeria due to the activities of the armed insurgents (the bokoharams), over years now. Moreover the city functions as the capital city of Kwara state as well as the headquarters for three local government areas (Ilorin East, Ilorin west and Ilorin South) which has resulted to the generation of a very high quantity of MSW in the metropolis. Despite the rise in MSW generation rate in Ilorin metropolis, the city is still facing energy crisis that pose challenges to their economic and social development. Adopting an integrated MSW management method that encompasses thermal degradation and energy recovery, recycling and others will ensure adequate and efficient waste management system (Omari *et al.*, 2014). Utilizing MSW as a renewable energy source for power generation, would definitely complement the current inefficient grid power supply witnessed in the city. This will thereby boost the economy of the city and Kwara state at large. According to Tan *et al.*, (2005) and Ogunjuyigbe *et al.*, (2017); energy, clean and green environment are very essential to the growth and living standard of every nation; hence effective management,

recycling and energy recovery utilization of MSW (waste-to-energy) could provide a sustainable and environmental friendly solution to bridging the gap between energy and environmental development. Waste-to-energy (WTE) requires thermal and biological processes to extract useful energy that is stored in the combustible biogenic fractions of the MSW to produce heat (steam) or power (electricity) or both (combined heat and power). Ayodele *et al.*, (2017) reported that average electrical energy and power rate in Nigeria is in the range of 107 kWh, 12 W per capita per annum. This is quite inadequate compared to what is obtainable in some other developing countries that include Malaysia (3310 kWh and 337 W) and South Africa (4347 kWh and 496 W). If waste-to-energy project for power generation is encouraged in Nigeria, it will serve as an environmentally friendly and sustainable method to ameliorate waste management problem and issues of insufficient supply of electricity. There are more than 800 thermal waste-to-energy plants in about 40 countries around the globe lately; they utilize about 11 % of the MSW generated globally and produce about 429 TWh of power (Tan *et al.*, 2005). Waste-to-energy practice in Nigeria is limited to traditional biomass (wood fuel and charcoal) to complement grid heating and cooking in the rural areas. In this study, the quantity of MSW generated per year and the MSW generated per capita per day in Ilorin metropolis of Kwara State of Nigeria was determined. The available combustible waste fractions that could be used for power generation per day and their heating values were determined as well as the proximate and ultimate analyses of the waste fractions. The capacity of the required steam power plant to convert the available combustible waste fractions energy to electricity was designed.

### 1.1 Background of the Study

Chukwuemeka (2012) defines wastes as not useful materials that are thrown away, while Douglas (2004), describes wastes as discarded unwanted materials that are generated through human and animal activities, as they interact with their environment. The life of man is characterized with waste generation, the magnitude of which is limited by the size of population, level of formal education, level of technological development and the capacity and standard of waste management system put in place. The advancement in civilization, urbanization, modernization and industrialization has caused rapid migration of people from rural to urban centres (Martin *et al.*, 2014). Ilorin metropolis is known for its demographic growth over the years lately, because of the insurgency launched by a sect of Terrorists called 'Boko-Harm' in the Northern part of this country, which has caused a great migration of people to Ilorin; thereby increasing the population of the metropolis tremendously as well as the MSW generated. Moreover, Ilorin functions as a state capital as well as the headquarters for the three local government areas in the city. Eurostat (2012), reports that the main bulk of municipal solid waste is generated by households, public institutions, commercial centres and offices. The study reveals the major composition of MSW in Ilorin as food residue, wood, paper, packaging box, grass/garden-trimmings, textiles (rag), toiletries, faeces, nylon, cow-dung, polythene (bagco sac), plastic bottle, rubber, leather, glass/ceramics, bones, tins/metals, sand/ash.

The Egyptian Environmental Policy Program support unit (EEPP, 2000) defines Municipal Solid Waste Management (MSWM) as the systematic way of managing the activities involved in planning, funding, collecting, transporting and processing of municipal solid waste. The processes involved in the management operations are: storage, collection, separation, transportation, treatment, energy recovery from waste, recycling, composting and landfill of municipal solid waste (Trevor and Daniel, 2011). Municipal solid waste management (MSWM), is a major challenge in the urban centres of the developing countries (Zhen-Shan *et al.*, 2009 and Issam *et al.*, 2010) and Ilorin metropolis is not an exceptional; because of increase in population, urbanization, standard of living etc. The inability or unwillingness of most municipal authorities to make provision for efficient and functional waste collection and disposal services for the residents in their locality, has led to poor MSW management and disposal in developing countries (Issam *et al.*, 2010). Hence, the stakeholders concerned, particularly in the cities should try to improve on their level of participation in MSWM, in order to ensure a properly funded and equipped MSW systems. MSWM in Ilorin is divided into two sections namely, the social and the commercial. The social section is being handled by contractors that are paid

by the State Government, while the commercial section is handled by the Private Partner Contractors that are responsible for some selected areas of the metropolis, where people pay for the services rendered on the disposal of the wastes they generated. Because of the large amount of MSW collected from different locations of the city to the dump site, a representative number of loads of waste was selected on the dump site from which random samples were drawn for characterization after pooling (NT ENVIR 001, 2005 and Issam *et al.*, 2010). The process of taking some sub-sets of the parent population of the waste generated to get the required sample sizes for sorting, characterization and other analysis is called sampling (EC SWA-Tool, 2004 and Slavko *et al.*, 2012). This study describes the methodology approach for the representative sampling of the MSW composition. It also includes an approach for the manual sorting and analysis of the waste stream to determine the composition and quantification based on waste characterization. The heating value of the wastes fractions were determined for energy generation.

## 2. LITERATURE REVIEW

### 2.1 The Study Area

Ilorin the Capital City of Kwara State, Nigeria; is located on latitude 8°30'N and longitude 4°35'E with an area of about 100 km<sup>2</sup> (Ajadi and Tunde, 2010). The city is made up of three Local Government Areas viz: Ilorin East, Ilorin West, and Ilorin South. The demographic growth of the city over the years is responsible for the continuous rise in MSW generation rate as well as its consequential effects. The National Population Commission (NPC), gives the population census of Ilorin metropolis in 2006 to be 781934 people: Ilorin East 207462, Ilorin South 209251 and Ilorin West 365221. The population was projected for 2011 to be 908490: Ilorin East 241040, Ilorin South 243120 and Ilorin West 424330.

Like some other traditional cities in Nigeria, Ilorin is characterized of traditional town alongside a modern urban centre. The centre of the city encompasses the Emir's palace, the Central mosque and the Emir's market. The transitional zone contains deteriorating houses and the independent working man zone consists of second generative immigration into the city. The fourth zone is characterized of citizens that are in the categories of: middle class, businessmen and the professionals (Ajadi and Tunde, 2010). The commuter zone is the last; it consists of small towns villages and hamlets e.g. Tanke, Ganmo etc.

Ilorin has about 120 roro-bins placed by Kwara State Environmental Protection Agency (KWEPA) spatially at strategic locations of the city. The map showing the distribution of waste rolling containers (Roro – bins) is shown in Fig.1. The metropolis have some designated locations as dump sites which include: Airport road dump site (about 5 hectares), Lasoju (Eyenkorin) dump site along Ilorin-Ogbomosho express road (about 8 hectares), Oko- Olowo dumpsite along Alapa (20 hectares) and Asa – dam road dump site behind Dangote mill. During this study only Lasoju-(Eyenkorin) dump site was functional.

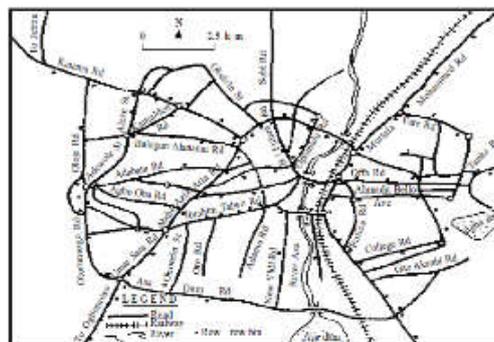


Fig. 1. Map of Ilorin Metropolis showing locations of Dumpsters (Row-row bins)  
Source: Ministry of Lands and Surveys, Ilorin (Ajadi and Tunde, 2010).

## 2.2 Significance of Waste Management

Waste management is of a universal concern that cannot be ignored because every community or settlement, whether in rural or urban centres generates wastes every day, due to human and animal activities. The drive for social, industrial and technological development is increasing on a daily basis, so is rapidly changing taste and fashion of men. Consequently, the evolution of more inventions and development of new materials becomes the order of the day while earlier products are considered old fashioned and obsolete, ready for disposal as waste and man's quest for development, has led to the invention and use of different materials and condemnation of some as wastes. Increase in standard of living also lead to increase in the rate of waste generation; because as the standard of living improves the demand for food and other materials also increases. There is the need to ameliorate the effect of pollution, proneness to breeding environment for disease causing rodents, bacteria, and the environmental degradation caused by improperly disposed wastes. The waste management sector can help to make less severe the effect of Green House Gas (GHG) (generated by waste) on people, by converting it to a source of energy that is of economic value. Global warming is experienced throughout the universe with varying degrees of adverse effect from region to region. Nevertheless, there is the need for a sustainable decent and safe environment that is conducive for healthy living (Reddy, 2011). It is therefore good if the municipalities could ensure a decent and healthy environment through appropriate and effective solid waste management programme. Municipal Solid Waste management (MSWM) activities include collection of waste generated, recovery, transfer, transportation, recycling, recovery and disposal. Reddy (2011) presented the reasons why an approval of a well-articulated plan, is required for the management/treatment of municipal solid waste. They are to: reduce drastically the consequential effect of waste, such as pollution and global warming; ensure clean and green habits for people whether in rural or urban settlements; recover resources that could be recycled to produce useful materials, and recover clean energy from the processed waste to generate heat or electric power. Waste-to-energy method of management is considered as the most appropriate method, because of it functions as an efficient method of waste management for clean and green environment and energy generation using municipal solid waste as a sustainable and renewable energy resource.

## 2.3. Characterization of Municipal Solid Waste

MSW Characterization simply means a descriptive way of identifying various constituents of the waste stream, considering the quantity and quality of waste generated. Nevertheless, the location as well as seasons in which the MSW are generated. It makes it possible to determine the percentage distribution of the waste fractions that are in the waste streams. Characterization of MSW is a fundamental component in the waste management system (MWMs) of any urban city; but reliable data of the waste characterization are not readily available in the cities of Africa continent (Benjamin *et al.*, 2014). Waste characterization data includes, information on the types and amount of waste materials (paper, food waste, glass, yard waste, etc.) in the waste stream. This depends on factors which include food cultural tradition, socioeconomic, climatic conditions and habits. It varies not from one city to another, community to community, nation to nation and even within different locations of the same city. The MSW characteristics and composition of municipal solid waste is influenced by factors which include, the area (residential, commercial, etc), the economic level (differences between high and low income areas), the season and weather (differences in the amount of population during the year, tourist places) and culture of people living or doing business in the area. Area where people with high income live, usually generate wastes that are more of inorganic materials like packaging box, plastics, cans and paper, while area with low-income residents, generate relatively more of organic wastes (Benjamin *et al.*, 2014). Characterization of MSW helps in the determination of the quantity of waste generated in a particular location at a particular time of the year. It helps in identifying the trend of generation as well as the influencing factors. In the proper planning of solid waste management systems, characterization of wastes is useful in determining the size, percentage distribution of waste fractions, the number of functional units and equipment required for waste management. It is also an appropriate procedure towards determining the energy potentials of MSW fractions.

### 3. MATERIALS AND METHOD

#### 3.1 Prediction of the population responsible for waste generation in Ilorin Metropolis as at the period of the study

The population data collected from National Population Commission (NPC), shows the population census of Ilorin metropolis in 2006 to be 781934. The projection for 2011 is 908490. In order to determine the population responsible for waste generation in 2016, a modified Malthusian model equation, for predicting population of a city (Mehmet, 2013), in Eq. 1 was adopted.

$$P_t = P_{(t-1)} * e^{K_p t} \quad (1)$$

Where, t is the time of interest in year,  $P_t$  is the estimated population at year t,  $P_{(t-1)}$  is the population at the previous year of concern, and  $K_p$  is the annual population growth rate constant.

$$\text{The annual population growth rate, } K_p = \left[ \frac{P_{pr}}{P_p} \right]^{1/n} - 1 \quad (2)$$

Where  $p_{pr}$  is the present population,  $p_p$  is the past population and 'n' is the number of years involved.

#### 3.2 Prediction of the quantity of MSW generated in Ilorin Metropolis per day.

The amount of MSW generated annually in any metropolis, is of fundamental importance in MSWM decisions and should be reliable because of the budgets prepared per annum by the municipalities for waste management based on annual MSW generation (Kawai *et al.*, 2012). The use of weighbridges, increases the reliability of data on waste generation; but Ilorin metropolis like many other cities in developing nations do not have weighbridges, as a result of budget constraints. Kosuke and Tomohiro (2016), suggested that the MSW generated annually in a city can be estimated, based on the available information on collection and transportation of waste using Equation. 3.

$$MSW_{gen.} = \sum_{j=1}^{365} \sum_{i=1}^m (C_i \times V_i \times d_i \times t_{ij}) \quad (3)$$

Where m is total number of trucks,  $C_i$  is the capacity of truck i ( $m^3$  /truck),  $V_i$  is the loading volume ratio of truck i,  $d_i$  is the density of MSW loaded on truck i (tons / $m^3$ ), and  $t_{ij}$  is the number of trips by truck i on day j (frequency of trips/day).

#### 3.3. Characteristics of municipal solid waste data

The samples characterized in this study were taken from Lasoju/Eyenkorin dumpsite. European commission for solid waste analysis tool (EC SWA-Tool, 2012); recommended 30 samples as being appropriate for this kind of study. Nevertheless, samples were taken twice per week (Tuesday and Saturday) for eight months; making 62 samples altogether, in order to avoid eventual error that may occur due to insufficient samples. A specific bin volume of 240 litres is considered in each sample as suggested by EC SWA-Tool (2012); and each is weighed and hand sorted into different components in a screening equipment, 1.5m x 3 m with 10 mm x 10mm mesh surface size designed for heterogeneous solid waste according to WHO, (1988) and Issam, *et al.*, (2010). In the entire period of characterization, nineteen waste fractions were obtained and the waste stream distribution in the city is represented in Table 4. There are nine waste fractions considered for energy content analyses out of the nineteen waste fractions during characterization; because of their availability and combustibility. They include food residue, paper, plastic bottles, textiles (rag), wood, grass/garden trimmings, nylon, packaging box (carton) and polythene-sac shown in Table 5.

### 3.4. Determination of the heating value of the waste components

The determination of high heating value (HHV) or Calorific value (CV) of MSW is important for the efficient design and operation of waste-to-energy conversion-based technologies. The HV was determined by using a bomb calorimeter (*e 2k* combustion Calorimeter), based on standard ASTM D5468-02 (Shi *et al.*, 2016). 0.5g weighed component sample was burnt in a high- pressure oxygen atmosphere in the cylindrical vessel called a bomb. The vessel was then placed at the filling station and filled with oxygen to the pressure of about 2000 M Pa; then the mass of the test sample (0.5g) was inputted to the system through the computer connected to it. The equipment prompted that the bomb be put into the calorimeter. After placing the vessel in the Calorimeter, the door was closed for the analysis to begin. The result was later displayed on the screen after completion to give the HHV of each component.

According to Islam (2016), the low heating value for each component can be obtained using Equation 4.

$$LHV = \sum_{j=1}^9 W_j \times HV_j \quad (4)$$

Where  $LHV$  is the lower heating value,  $HV_j$  typical heating values of MSW component-  $j$  and  $W_j$  is the weight fraction (%) of component-  $j$  (Islam, 2016).

### 3.5. Proximate analysis

The proximate analysis was carried out using ASTM D7582 – 12 Standard methods. It involved the determination of moisture content, volatile matter, fixed carbon content and the ash content of each of the nine selected waste fractions for energy generation. The moisture content was determined using an electric oven (DHG 9053, 200 °C capacity), 1g of grinded air dried sample, was weighed into a crucible is dried in the oven maintained at about 110 °C for about 1 h; it was later removed and cooled in a desiccator and weighed. The loss in weight is reported as moisture material according Vairam and Ramesh, (2013); Shi *et al.*, (2016) to by using Equation 5.

$$M_w = \frac{(w-d)}{w} \times 100 \quad (5)$$

Where  $M_w$  is the wet moisture content %,  $w$  is the initial mass of sample as delivered (kg), and  $d$  is the mass of sample after oven drying (kg).

After the determination of their moisture contents, the dried sample left in the crucible during moisture analysis, was covered with a lid and placed inside an electric furnace (TDW, 1200 °C capacity) maintained at 950°C. After 7 min of heating, it was removed from the furnace and cooled in a desiccator; then it was weighed again. The loss in weight is reported as volatile matter in percentage terms according to Adekunle *et al.*, (2015), and Shi *et al.*, (2016) using Equation 6.

$$V_d = \frac{A}{B} \times 100 \quad (6)$$

Where  $V_d$  is the percentage volatile matter,  $A$  is the mass loss of the sample, and  $B$  is the mass of the sample taken.

The residue left after determination of volatile matter was heated without the lid inside a furnace at 700 °c for 0.5 h. The crucible was taken out, cooled in the desiccator and later weighed; heating cooling and weighing was repeated until a constant weight is obtained. Ash content is the amount of residue obtained after ignition of solid waste which was obtained according to Vairam and Ramesh, (2013) and Kuleape *et al* (2014), using Equation 7.

$$\text{Ash (\%)} = \frac{w}{W} \times 100 \quad (7)$$

Where  $w$ , is the mass of ash and  $W$  is the mass of the sample taken.

The fixed amount of carbon left behind was calculated according to ASTM D3172-73 by deducting the percentage amount of ash, moisture, and volatile matter from 100, using Equation 8.

$$\text{Fixed carbon (\%)} = 100 - (\text{Moisture} + \text{Volatile matter} + \text{Ash}). \quad (8)$$

### 3.6. Ultimate Analysis

Ultimate analysis is the quantitative evaluation of the total carbon (C), hydrogen (H), nitrogen (N), sulphur (S), oxygen (O) percentages after removal of volatile matters, the moisture and ash contents (Benjamin *et al.*, 2014). This analysis was performed by using Flash EA 1112 Elemental analyzer; based on the standard ASTM D5291. Dried and powdered sample of about 0.5g was weighed into a crucible and combusted. The flue was passed into a chromatography column. The oxides of nitrogen, sulfur, hydrogen and carbon produced were detected by the thermal conductivity detector (TCD), and the electrical signal produced was processed by 'Eager 300 software' to give percentages of nitrogen, carbon, hydrogen, and sulfur contained in the sample. The samples were replicated three times in the experiment, and the average values of the results considered as the typical values.

### 3.7. Multiple regression analysis

Multiple regression analysis was used for the modelling of the energy content of the municipal solid waste (MSW). The multiple regression on high heating value of the MSW was estimated based on ultimate analysis of MSW. Diagnostic check was performed by using Jarque-Bera test to determine the error distribution. The correlation of the regressors were examined by using variance inflation factor (VIF) for a diagnostic check of a problem of multicollinearity. The regression model for the ultimate analysis is expressed in Equation 9:

$$HV = 1.3849 + 85.0807C - 28.9675H - 666.125N + 11.6296S \quad (9)$$

where: HV is the heating value, C is the carbon percentage content of the municipal solid waste, H is the hydrogen content percentage, N is the nitrogen percentage content and S is the Sulphur percentage content.

### 3.8. Estimation of the Electrical Power Generation from Municipal Solid Waste

#### 3.8.1. Estimation of Energy potentials of the MSW ( $EP_{msw}$ )

From the MSW generation prediction, in Table 3, about 827 tons of MSW is predicted per day and about 70 % of the predicted waste is considered for energy generation i.e. 584 tons/day. The net low heating value from Table... is 20 MJ/kg.

According to Kumar *et al.*, (2010); Gupta and Mishra (2015); and Daura (2016) energy potential recovery from MSW ( $EP_{msw}$ ) is calculated in Equation 10:

$$EP_{msw} = NCV_{msw} \times w_{msw} \times \frac{1000}{860} \quad (10)$$

Where  $EP_{msw}$  is the energy potential from MSW;  $W_{msw}$  (tons) is the weight of MSW;  $NCV_{msw}$  is the net calorific value of the MSW (kcal/kg). Converting ratio (1kWh = 860 kcal).

Therefore,  $EP_{msw}$  can also be calculated as in Equation 11:

$$EP_{msw} = LHV_{msw} \times w_{msw} \times \frac{1000}{3.6} \quad (11)$$

Where  $EP_{msw}$  is the energy potential from MSW  $W_{msw}$  (tons) is the weight of MSW,  $NCV_{msw}$  is the net low heating value of the MSW (MJ/kg). Converting ratio (1kWh = 3.6 MJ).

### 3.8.2. Estimation of Electrical Power Potential of the MSW ( $EPP_{msw}$ )

Electrical Power Potential ( $EPP_{msw}$ ) is calculated in Equation 12 as suggested by Kumar *et al.*, (2010); Gupta and Mishra (2015); and Daura (2016):

$$EPP_{msw} = 277.8 \times LHV_{msw} \times \frac{W_{msw}}{24} \times \eta \quad (12)$$

Where  $EPP_{msw}$  is the electrical power potential (kW),  $w_{msw}$  (tons) is the weight of MSW,  $LHV_{msw}$  is the net low heating value of the MSW (MJ/kg) and  $\eta$  is the converting efficiency in a power plant. Klein *et al.*, (2003) and Muhammad *et al.*, (2014) gives the conversion efficiency ( $\eta$ ) range to be 20-40%. The conversion efficiency of 30 % is adopted.

Power to grid is obtained using Equation 13.

$$\text{Power to grid (GP)} = EPP_{msw} \times \eta_g \times \eta_p \times \frac{1}{1000} \quad (\text{MW}). \quad (13)$$

Where  $\eta_g$  is the generator efficiency (assumed to be 90 %),  $\eta_p$  is the transmission efficiency (assumed to be 75 % of turbine work ( $W_T$ )) Generator efficiency range is 85- 90 % and turbine efficiency is 75- 80 % (BHE, 2016).

## 4. RESULTS AND DISCUSSION

In this section, the summary of the quantity of MSW generated, the generation rate (kg/capita/day), the quantity available for power generation in a day, the physical, chemical and thermochemical characteristics of the MSW generated are given. Regression model was developed on the ultimate analysis to show how the constituent elements of the MSW affect the intensity of the net heating value of the wastes streams..

### 4.1 The Predicted Population

Based on the demographic data of 2006 census and the projected population for 2011 collected from National Population Commission (NPC), the population distributin for waste generation in the city for 2016, was predicted to be 1,055515 as shown in Table 1.

**Table 1. Demographic Data of Ilorin metropolis**

Year	Demographic centres of Ilorin metropolis	Population	Total	Source
2006	Ilorin East Ilorin West Ilorin South	207,462 365,221 209,251	781,934	NPC (2006)
2011 Projection	Ilorin East Ilorin West Ilorin South	241040 424330 243120	908,490	NPC (2006)
2016 Prediction	Ilorin East Ilorin West Ilorin South	280049 493001 282465	1,055515	Mehmet (2013) equation 1 & .2
2017 Prediction	Ilorin East Ilorin West Ilorin South	288578 508015 291067	1,087,660	Mehmet (2013) equation 1 & .2

#### 4.2. Estimation of MSW Generation

The collection Trucks/Equipment made available for the MSW management system in Ilorin metropolis is given in Table 2. About 43 % of the collection vehicles available for MSW collection, are functional: 5 Dino Tipper Trucks, 3 Hino Tipper Trucks, 2 Scania compactors and 3 Arm roller plant. This is an evidence that the waste collection system in Ilorin metropolis lack enough equipment thereby encouraging insufficient collection.

**Table 2. The MSW collection vehicles in Ilorin metropolis**

S/N	Types of Vehicle	Quantity Provided	Number functional	Capacity/ vehicle (kg)	Volume / vehicle, Vv (m <sup>3</sup> )	Number of/trips/vehicle/day, Tn
1	Dino Tipper Truck	10	5	20,000	16	3
2	Hino Tipper Truck	5	3	25,000	22	3
3	Scania Compactor	10	2	30,000	22	2
4	Arm Roller	5	3	15,000	8	5
Total		30	13	90,000	68	13

The MSW generated in the year 2016, is predicted to be 301672.5 tons/year and about 827 tons/day with density of 5.625 tons/m<sup>3</sup> shown in Table 3, and the generating rate of 0.78 kg/cap/day given in Table 4.

**Table 3. Estimation of MSW generated in Ilorin metropolis/year based on transportation facts.**

S/N	Types of Vehicle	Number of trucks/day	Capacity/ vehicle (tons)	Volume / vehicle, C (m <sup>3</sup> )	Avg. volume ratio of a truck	Density of MSW loaded on truck	Number of Trips	MSW generated (tons/yr)	MSW generated (tons/day)
1	Dino Tipper Truck	5	20	16	0.95	1.25	3	104025	285
2	Hino Tipper Truck	3	25	22	0.95	1.136	3	78018.75	213.75
3	Scania Compactor	2	30	22	0.95	1.364	2	41610	114
4	Arm Roller	3	15	8	0.95	1.875	5	78018.75	213.75
Total		13	90	68	3.8	5.625	13	301672.5	826.5

### 4.3. Physical Characterization of MSW for Ilorin Metropolis

The MSW characterization for the months of November to February represents the MSW streams for the dry season. The MSW characterized during dry season was 1,308 kg with specific volume of 6.54 m<sup>3</sup>. The fractions distribution for dry season in Fig. 2 shows Nylon fraction (water sachet) of 19.42% as the largest waste component for the season followed by others 11.98% and the least is Leather 0.06% Nylon 22.6 %, followed by Organic fraction (Grass/garden trimmings) the least is rubber 0.15 %. The reason for having nylon as the highest waste fraction during the dry season, could be that people consume more of water packed in nylon sachets because they are readily available and affordable. Leather is a valuable material in Ilorin, used for making bags, hand fans and other ornamental materials for interior decoration in rooms; therefore it is scarcely discarded as unwanted materials.

The MSW characterization conducted during the months of May to August represents the wet season. The MSW characterized for the wet season was 1764.2 kg with specific volume of 8.83 m<sup>3</sup>. The components distribution in Fig.3 gives Food residue to be 14.14%, Packaging box 12.32% and the least is Leather 0.08%. Food residue as the highest percentage waste fraction during wet season, could be because of influx of newly harvested food crops from the farm. These food crops are cheaper during harvest and many people can afford them; thereby increasing the rate of food waste generation.

In the combined characterization of the MSW for eight months shown in Table 4, the total weight of MSW components analyzed was 3072.21.kg with specific volume of 15.37 m<sup>3</sup> and generation rate of 0.784 kg/cap/day. The components distribution in Fig. 4 shows Nylon waste as the highest waste fraction of 15.23%, Food residue 10.37%, followed by plastic bottle 9.79% and the least is Leather 0.07%. The first three waste components on the high side, are from food and drinks that common men can afford. This is an indication that majority of the populace of the city are low income earners. The generation rate of 0.784 kg/capita/day in Ilorin in 2016, shows that the waste generation in Nigeria has increased compared to 0.58 kg/capita/day generating rate of the entire nation (Nigeria), reported by Kawai and Tasaki (2016).

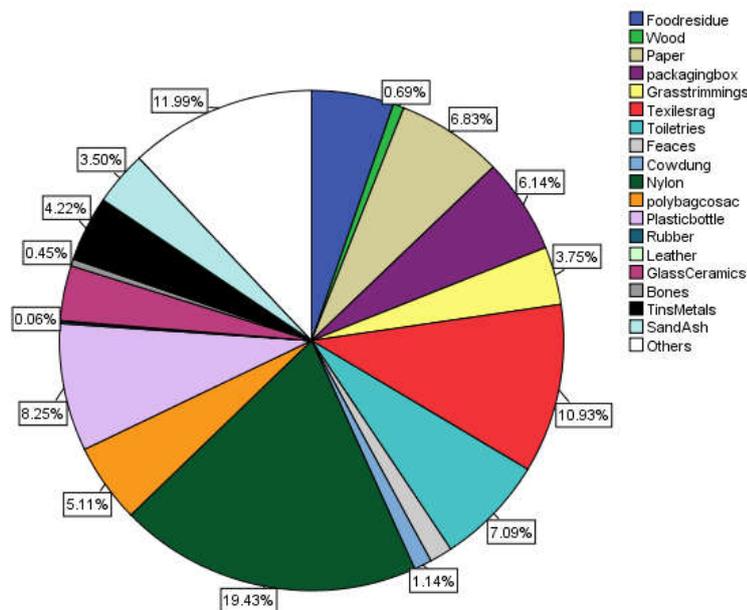


Fig. 2. MSW distribution in 2016 Dry Season

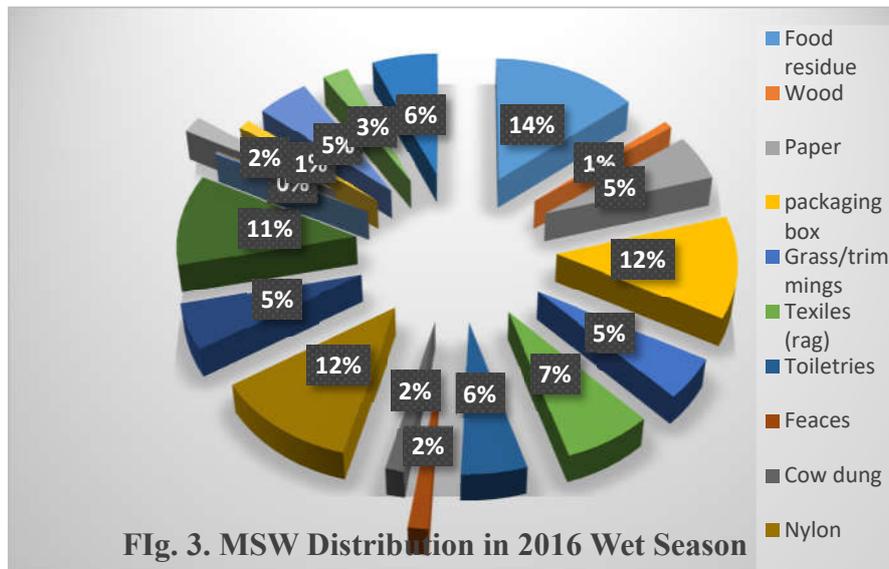
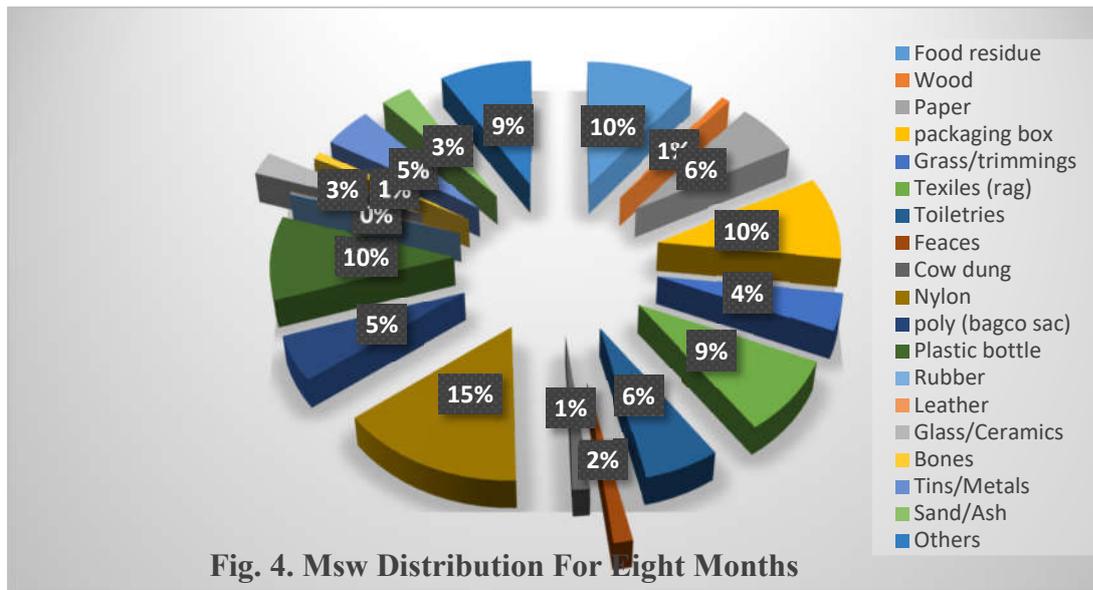


Table 4. The combined Physical Characterization of the MSW steams for Eight months

Types	Months								Mean	TOTAL Wt (kg)	Wt (%)	Volume m <sup>3</sup>	kg/cap/day
	1	2	3	4	5	6	7	8					
	NOV. Wt (kg)	DEC. Wt (kg)	JAN. Wt (kg)	FEB. Wt (kg)	MAY Wt (kg)	JUN. Wt (kg)	JUL. Wt (kg)	AUG. Wt (kg)					
Food residue	3.70	46.3	10.90	8.00	28.20	56.50	55.10	109.8	39.8±35.	318.50	10.37	1.43	0.081
Wood	1.60	3.4	4.00	0.00	4.70	2.40	8.00	0.60	3.1±2.56	24.70	0.80	0.11	0.006
Paper	14.8	31.5	30.50	12.60	21.50	15.50	32.50	26.80	23.2±8.1	185.70	6.04	0.93	0.047
Carton	10.4	49.6	12.50	7.80	56.80	47.50	50.00	63.00	37.2±28	297.60	9.69	1.38	0.076
Texiles (rag)	27.2	46.0	42.40	27.30	21.60	27.40	21.50	60.40	34.2±13.	273.80	8.91	1.42	0.070
Toiletries	18.4	14.1	29.10	31.10	33.70	22.80	25.60	15.60	23.8±7.3	190.40	6.20	1.06	0.049
Feaces	1.40	11.6	1.00	5.10	6.50	14.60	4.60	3.60	6.1±4.78	48.40	1.58	0.24	0.012
Cow dung	8.70	3.0	3.20	0.00	5.90	13.40	6.60	1.80	5.3±4.29	42.60	1.39	0.21	0.011
Nylon	59.0	70.4	72.20	52.50	58.40	66.80	41.10	47.40	58.5±11.	467.80	15.23	2.48	0.119
Polybag	23.2	11.3	24.20	8.20	19.80	17.50	25.92	33.40	20.4±8.1	163.52	5.32	0.84	0.042
Plastic bottle	7.00	64.2	18.40	18.30	80.50	48.40	26.50	37.40	37.6±25.	300.70	9.79	1.42	0.077
Rubber	0.40	0.1	1.20	0.00	0.80	1.00	0.80	1.00	0.6±0.44	5.30	0.17	0.01	0.001
Leather	0.60	0.2	0.00	0.00	0.00	1.00	0.00	0.40	0.2±0.36	2.20	0.07	0.00	0.001
Ceramics	10.4	9.8	20.40	6.00	7.90	9.60	9.60	8.60	10.3±4.3	82.30	2.68	0.44	0.021
Bones	2.60	0.0	0.80	2.50	7.60	8.60	3.20	2.20	3.4±3.06	27.50	0.90	0.14	0.007
Tins/Metals	8.00	35.0	8.00	4.20	45.20	15.20	22.10	6.80	18.1±14.	144.50	4.70	0.67	0.037
Sand/Ash	11.9	9.3	15.30	9.30	12.45	14.60	11.20	6.40	11.3±2.9	90.45	2.94	0.48	0.023
Others	20.00	50.6	59.40	26.80	29.30	37.50	25.00	20.40	33.6±14.	269.00	8.76	1.40	0.069
Grand Total	260.9	464.6	360.40	222.10	459.05	444.54	404.62	456.00		3072.21	100.00	15.37	0.784



The components of the waste stream considered for energy estimation, their corresponding percentage in the total waste generated and the fraction predicted per day is given in Table 5

Table 5. The waste components considered for Energy Generation

MSW Fractions	Months								TOTAL Wt.(kg)	WT. %	Waste fractions predicted/ day (tons)
	1	2	3	4	5	6	7	8			
	NOV. Wt (kg)	DEC. Wt (kg)	JAN. Wt (kg)	FEB. Wt (kg)	MAY Wt (kg)	JUN. Wt (kg)	JUL. Wt (kg)	AUG. Wt (kg)			
Food residue	3.70	46.30	10.90	8.00	28.20	56.50	55.10	109.80	318.50	10.37	85.7599
Wood	1.60	3.40	4.00	0.00	4.70	2.40	8.00	0.60	24.70	0.8	6.616
Paper	14.80	31.50	30.50	12.60	21.50	15.50	32.50	26.80	185.70	6.04	49.9508
packaging box	10.40	49.60	12.50	7.80	56.80	47.50	50.00	63.00	297.60	9.69	80.1363
Grass/trimmings	31.60	8.20	6.90	2.40	18.20	24.24	35.30	10.40	137.24	4.47	36.9669
Texiles (rag)	27.20	46.00	42.40	27.30	21.60	27.40	21.50	60.40	273.80	8.91	73.6857
Nylon	59.00	70.40	72.20	52.50	58.40	66.80	41.10	47.40	467.80	15.23	125.9521
poly (bagco sac)	23.20	11.30	24.20	8.20	19.80	17.50	25.92	33.40	163.52	5.32	43.9964
Plastic bottle	7.00	64.20	18.40	18.30	80.50	48.40	26.50	37.40	300.70	9.79	80.9633
Grand Total	178.50	330.90	222.00	137.10	309.70	306.24	295.92	389.20	2169.56	70.62	584.0274

#### 4.4. Proximate Analysis

Proximate analysis given in Table 6 shows that the range of moisture content of the components analyzed is 6%-13% and the dispersion is 0.58%-1.16 %; the highest is wood 13 %, followed by grass/trimmings 10 % and the least is packaging box (carton) 6 %. Volatile matter's range is 2 %-67 % and the dispersion is 0.58 %-15.18 %; the highest is paper 68 %, wood 67 % and the least is plastic bottle 2 %. Ash content's range is 1 %-36 % with dispersion of 0.00 % -4.04 %; the highest is grass 36 %, followed by Textile (rag) 23 % and the least is plastic 1.00 %.

Table 6. The result of proximate analysis of the waste sample

S/N	MSW Fractions	% FC	% VM	% Ash	% Moisture	HV (%)
1.	Packaging Box	65.32.22	16.0 ± 2.7	14.01.3	4.67±0.9	7.02
2.	Nylon	80.06.67	18.3±7.11	1.67±0.89	0.0 ± 0.0	20.4
3.	Textiles (rag)	43.09.33	30.7±10.9	20.02.0	6.33±0.4	6.96
4.	Wood	27.7±9.56	59.0 ±10.0	1.67±0.44	11.67±1.1	8.14
5.	Grass/Trimmings	15.3±0.89	51.7±8.44	23.33±8.4	9.67±0.4	7.88
6.	Plastic Bottle	97.7±0.44	1.33±0.44	1.00 ±0.0	0.0 ± 0.0	16.50
7.	Paper Waste	24.3±4.89	58.7±5.56	10.33±0.4	5.67±0.9	7.53
8.	Food Waste	88.7±3.11	2.67±2.22	2.33±0.44	6.33±0.44	18.03
9.	Bagco-Bag	90.0±2.67	4.33±0.44	5.67±3.11	0.00±0.00	38.69

#### 4.5. Ultimate analysis results.

The ultimate analysis in Table 7, shows that the carbon range of the components analyzed is 21 %-38 % with dispersion of 0.04 %-0.85 %; the highest is food residue 38.08 %, followed by wood 37.45 % and polythene 21.07 %. Hydrogen range is 0.09 %-0.17 % with standard deviation of 0.001 %-0.031 %; the highest is food residue 0.17 %, Polythene bagco-sac is 0.15 % and the least is Textile (rag) 0.09 %. Nitrogen range is 2.12 %-5.10% with dispersion of 0.01 %-0.71 %; the highest is paper 5.10 % followed by food residue 5.01 % and the least is Polythene bagco-sac 2.12 %. Oxygen range is 0.065 %-0.085 with dispersion of 0.0006%-0.001%; the highest is nylon 0.085 %, followed by packaging box (carton) 0.083 % and grass/trimmings 0.065 %. Sulphur range is 0.05 % - 3.13 %. With dispersion of 0.002 %-0.039 %; the highest is food residue 3.13 %, followed by wood 0.13 % and the least is nylon 0.52 %.

Table 7. The result of Ultimate analysis of the waste sample

MSW Fractions	C %	H %	N %	S %	O %	HV %
Food residue	38.020 ± 0.44	0.165±0.00	4.938±0.05	3.100 ± 0.02	0.081 ± 0.00	18.624
Wood	36.523 ± 0.62	0.105±0.02	4.501 ± 0.04	0.101 ± 0.02	0.067±0.00	18.418
Paper	35.327±0.08	0.107±0.02	4.748±0.24	0.081 ± 0.00	0.069±0.00	17.038
Packaging box	20.987±0.06	0.111 ± 0.00	2.765±0.10	0.078 ± 0.03	0.082 ± 0.00	15.883
Grass/Trimmings	30.860 ± 0.11	0.098 ± 0.02	3.862 ± 0.06	0.071 ± 0.00	0.064 ± 0.00	17.838
Textiles (rag)	34.047±0.14	0.098 ± 0.00	4.373 ± 0.00	0.084 ± 0.00	0.075 ± 0.00	15.747
Nylon	22.057±0.08	0.110 ± 0.00	2.823±0.02	0.052 ± 0.00	0.076±0.00	46.160
Poly sac	20.950±0.11	0.111 ± 0.02	2.669±0.01	0.052 ± 0.00	0.078±0.00	39.352
Plastic bottle	23.050±0.03	0.105±0.00	2.925±0.00	0.078±0.02	0.078±0.02	37.282

#### 4.6. The results of Heating value analysis

In Table 8, the net heating value of the waste components is determined to be about 20 MJ/kg. Nylon is the waste component that has the highest heating value of 20.4 %, Polythene bagco-sac 17.4 %, Plastic 16.5 % and the least is Textile (rag) 6.9 %.

Table 8. The results of the thermo-chemical analysis of the waste components.

Thermochemical characterization of the Waste fractions considered for energy generation									
		Replicates							
		1	2	3					
S/N	Types	MJ /kg	MJ /kg	MJ /kg	Mean	HV (MJ/kg)	HV%	Wt %	HV*Wt %
1	Food residue	18.031	19.102	18.740	18.624±0.545	18.624	8.23	10.37	1.9313
2	Wood	18.424	18.440	18.390	18.418±0.026	18.418	8.14	0.8	0.1473
3	Paper	16.093	17.930	17.090	17.038±0.920	17.038	7.53	6.04	1.0291
4	packaging box	15.440	17.250	14.960	15.883±1.208	15.883	7.02	9.69	1.5391
5	Grass/trimmings	17.753	17.640	18.120	17.838±0.251	17.838	7.88	4.47	0.7974
6	Texiles (rag)	13.900	19.010	14.330	15.747±2.834	15.747	6.96	8.91	1.4031
7	Nylon	46.340	45.880	46.260	46.160±0.246	46.160	20.4	15.23	7.0302
8	Polythene sac	38.694	40.012	39.351	39.352±0.659	39.352	17.4	5.32	2.0935
9	Plastic bottle	37.013	36.721	38.113	37.282±0.734	37.282	16.5	9.79	3.6499
Total						226.324	100	70.62	19.6209

The chart showing the relationship between the heating value and the values obtained from proximate analysis is presented in Fig. 5.

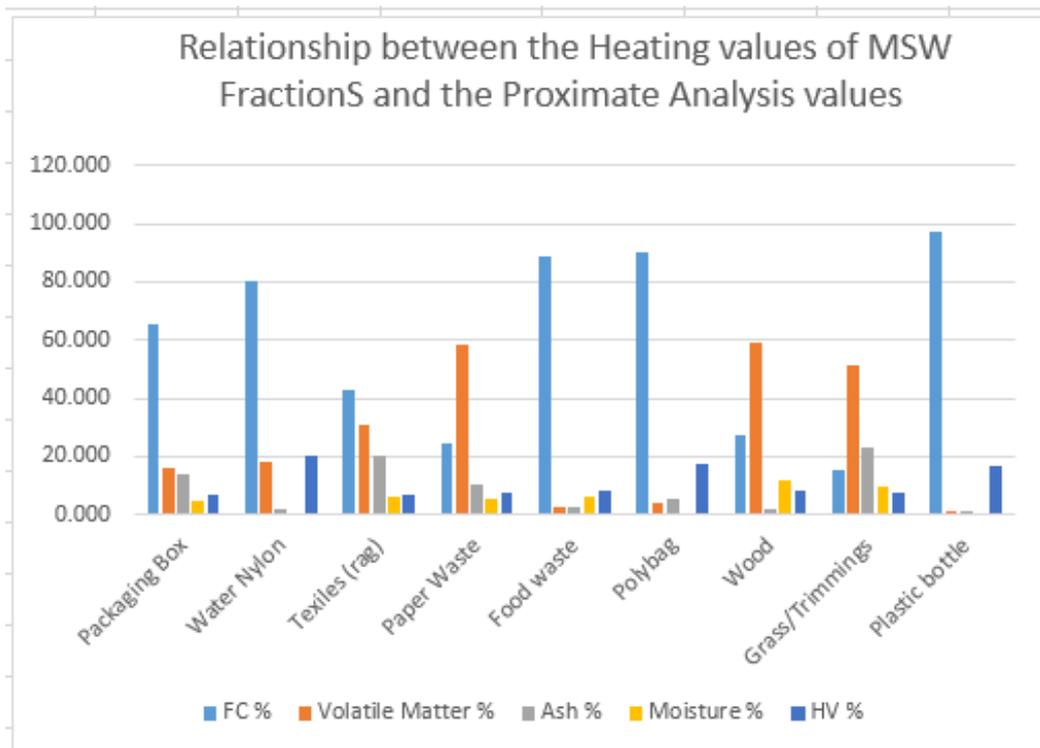


Fig. 5. The heating values versus the proximate analysis of MSW.

The chart showing the relationship between the heating values of the municipal solid waste and the values from the ultimate analysis is presented in Fig.6.

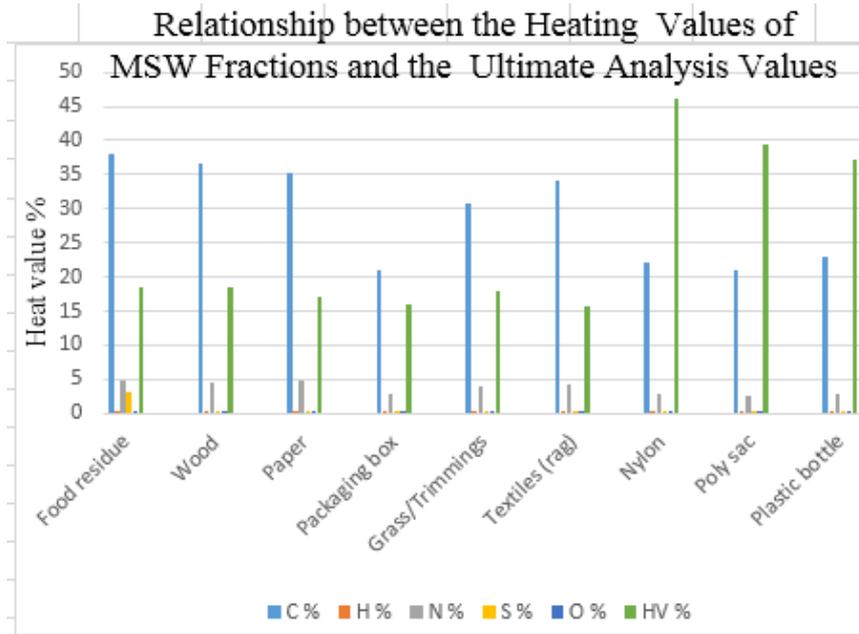


Fig. 6. The heating values versus the ultimate analysis of the MSW

#### 4.7. Multiple Regression Analysis result.

##### 4.7.1. Ultimate analysis model

The result of multiple regression analysis performed using ultimate analysis parameters (i.e. C, H, N, and S) is given in Table 9.

Table 9. Ultimate analysis using OLS

Ordinary Least Square Estimator and its Diagnostic check					Ridge Regression	
Regressors	coefficient	standard error	t-ratio	p-value	Regressors	coefficient
constant	1.3849	9.46871	0.1463	0.89079	constant	1.53324
C	85.0807	23.2496	3.6594	0.02159	C	79.08237
H	-28.9675	71.9485	-0.4026	0.70782	H	-30.16026
N	-666.125	182.261	-3.6548	0.02168	N	-619.09869
S	11.6296	3.60443	3.2265	0.03208	S	10.83630
R-squared	0.837249	Ftest	5.144354**			
Adjusted R-squared	0.674498	Jarque-Bera test	0.471254			
			(0.790075)			

MAX(VIF) 161359.816

\*\*\* \*\* and \* denote significant levels at 1%, 5% and 10% respectively. Value in parenthesis is the p-value

The multiple regression analysis results presented in Table 6 on Ultimate analysis parameters, was possible by using OLS estimator and ridge regression estimator. The regression model for the ultimate analysis is:

$$HV = 1.3849 + 85.0807\hat{C} - 28.9675\hat{H} - 666.125\hat{N} + 11.6296\hat{S} \quad (14)$$

Where: HV is the heating value, C is the carbon percentage content of the municipal solid waste, H is the hydrogen content percentage, N is the nitrogen percentage content and S is the sulphur percentage content. The diagnostic check using Jarque-Bera test shows that the error term is normally distributed since the p-value, 0.79 is greater than 5% level of significance. The variance inflation factor (VIF) is another diagnostic check conducted to examine if the regressors are correlated which is referred to as problem of multicollinearity. The rule of thumb says if the VIF is greater than 10 then there is multicollinearity which implies that the regressors are correlated. There is a need to correct this problem,

this necessitate the adoption of Ridge regression as an alternative method to OLS to correctly estimate the regression model. From the ridge regression estimate in Table 9, carbon and Sulphur both have a positive effect on heating value while hydrogen and nitrogen have a negative effect. A 1% increase in carbon and sulphur will increase heating value by 79.08% and 10.83% respectively while a 1% increase in hydrogen and nitrogen decrease heating value by 30.2% and 619.1% respectively. The R-squared shows about 84% of the variation in the response is explained by the regressors. The F test shows that the overall model fitted to the data is significant at 5%.

#### 4.8 Estimated Electrical Power Generation from MSW

The estimated Energy Potential ( $EP_{MSW}$ ) and Electrical Power ( $EPP_{MSW}$ ) when MSW of about 584 tons is utilized for energy generation in a day is given in Table 10.

Table 10. The estimated Energy and Electrical Potentials of the MSW

1	$W_{MSW}$ (tons/day)	LHV (MJ/kg)	$EP_{MSW}$ (MWh)	$EPP_{MSW}$ (MW)	GP (MW)
	584	20	3244	41	27
2		Conversion ratio			
	1000 kg = 1 ton	$10^6\text{J} = 1\text{MJ}$	1kWh = 3.6 MJ	$\eta = 30\%$	$\eta_g = 90\%$ , and $\eta_p = 75\%$

## 5. CONCLUSION AND RECOMMENDATIONS

### 5.1. Conclusion

The quantity of MSW predicted is about 320,000 tons/year, about 827 tons/day. The quantity useful for energy generation was about 584 tons/day and the generating rate was 0.78 kg/capita/day. The methodology and the number of samples taken at the dump site for the characterization in this study, enables sufficient size of samples, thereby preventing errors due to insufficient samples. The hand sorting of MSW components provides necessary information about material recovery and physical characterization of waste components. The physicochemical and the thermal characteristics of the MSW in Ilorin metropolis shows that the wastes streams produced is made of about 46 % combustibles, 34 % recyclables, but 29 % of the total recyclables are also combustible thereby making the total combustibles to be 75 %, about 6 % are compostable and 14 % belong to the group of others. The proximate analysis of the study shows that the waste contains more than 64% fixed carbon, 33 % volatile matter and 5 % of moisture content, while the ultimate analysis shows more than 29 % of carbon which can contribute to the calorific value of the MSW. Nitrogen is about 2.8 % and Sulphur about 0.2 %; the small amount of Nitrogen and sulphur present will cause reduction of emissions during combustion. It was inferred that the MSW generated in Ilorin would be appropriate as a renewable energy resource, because the model developed using multiple regression analysis reveals that 1% increase in carbon and sulphur will increase heating value of the MSW by 79.08% and 10.83% respectively and 1 % increase in fixed carbon and volatile matter will increase heating value by 8 % and 37 % respectively. The energy content of the MSW determined by using bomb calorimeter was 20 MJ/kg, which is about 50 % of energy contained in coal and about 100 % of the energy contained in biomass. The MSW of Ilorin metropolis has, the energy potential ( $EP_{MSW}$ ) of about 324 GWh, the electrical power potential ( $EPP_{MSW}$ ) of about 41 MW and can produce power to grid (GP) of about 27.4 MW.

### 5.1. Recommendations

In order to ensure a sufficient and efficient MSW management system, the municipalities and stakeholders that are involved in waste management should be more committed even financially to ensuring clean and green habit for people and environment.

WTE method of waste management system is recommended as the better option for every locality because of its dual purpose viz: efficient and sufficient waste management, and electrical power production using MSW as an energy resource.

In the future research it is recommended that scientific pretreatment of MSW to reduce its moisture content, hydrogen and nitrogen constituents before they are used for energy production, must be looked into; because it is inferred that 1% increase in moisture content, hydrogen and nitrogen will reduce the heating value of MSW by 11%, 30% and 619% respectively.

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