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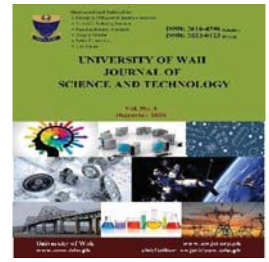

Simulation of Greenhouse Gases Emission from Different Solid Waste Management Practices in Gombe, Gombe State, Nigeria

Richard Balthi Mshelia and Michael Chima Onuigbo

Abstract—Solid waste management (SWM) is a major challenge for most municipalities. Research has shown that some municipalities spend up to 50% of their budget on SWM. Asides from the economic burden, SWM practices have varying degrees of impacts on the environment. This research strived to determine the eco-friendliest SWM practice among five (05) of the most common practices. This is done by first determining the annual generation rate and characteristic of the unsegregated MSW generated in Gombe. Using these information, a Greenhouse Gases (GHGs) emission tool authored by Institute for Global Environmental Strategies (IGES) is used to simulate the GHGs emission from these 5 SWM practices. It is found that Gombe generates an average of 139,875 tonnes of MSW annually and that of the 5 SWM processes simulated, landfilling generates the most amount of GHGs into the atmosphere (36%), the other four processes in descending order are open burning (33%), composting (27%), incineration with electricity recovery (3%) and anaerobic digestion (1%). It is deduced from the observation made that in spite of anaerobic digestion being the least emitter of GHGs, incineration with electricity recovery is the most suitable SWM technique for the city because a reduction of 29,687.07 tCO_2eq can be achieved if it replaces the current practice of landfilling while also supplementing the electricity needs of the city.

***Index Terms*–Solid waste management, Greenhouse gas emissions, Anaerobic digestion, Composting, Incineration, landfilling, Waste to energy.**

I. INTRODUCTION

SOLID waste management (SWM) is becoming one of the major problems of the 21st century, particularly in urban areas. In some places, it has been found that about 50% of the municipal budget is spent on SWM [1]. The cost of SWM keeps increasing largely because of the increase in waste generation levels which has been found to be because of an increase in number of factors like population, Gross Domestic Product (GDP), family or per capita disposable income, consumption expenditure [2], [3]. Other socioeconomic factors that are responsible for the increase in solid waste generation and consequently the increase in costs associated SWM as pointed out by researchers are economic development, improvement in the standard of living, levels of education, the degree of industrialization, public habits, local climate, age of population and environmental laws/policies [4–6].

Increased municipal solid waste (MSW) generation rates do not only put a strain on the economy, the environment also suffers. The SWM technique in practice in any location has a bearing on the environment. Researchers have found that the impact MSW generation rates have on the environment depends on the SWM technique being implored [7–10].

Key among the impacts of SWM on the environment is the emission of greenhouse gases (GHGs) into the atmosphere, others are defacing of lands, pollution of surface and groundwater [11].

In developing economies like Nigeria, SWM is largely the responsibility of state governments, Gombe the capital of Gombe state in the northeast region of the country is not an exception. A walk through the city will reveal the humongous quantity of MSW piled up at designated collection points. The case is not different when one drives by the city's only landfill site, which is a few kilometres away from the city centre. The stench from accumulated MSW decomposing at the unmanaged landfill site is not a welcoming experience. The city's SWM process of open dumping is the cause of MSW decomposing at the unmanaged landfill site. Organic components of MSW at dumpsites naturally decompose

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and lead to the emission of methane (CH_4) gas, it has been estimated that a fifth of all global methane emissions are from the decomposition of MSW from sanitary landfills [12].

Anthropogenic emission of GHGs has been identified as the main reason for the change in the earth's climate and warming of the globe [13-14]. In the race to taming rising average global temperature and capping it to an increase of not more than 2°C in line with the 2015 Paris Climate Agreement, the SWM industry needs to contribute its quota by reducing its carbon footprint. One of the ways to achieve this reduction is by determining and adopting the most climate friendly SWM process. Objective of this research work is aimed at determining the SWM practice with the least carbon footprint. Objective of research will be achieved by comparing the GHGs emission from five (5) most commonly practiced SWM processes. Gombe, the state capital of Gombe state in northeast Nigeria is the place selected for case study.

II. MATERIALS AND METHODS

A. Data Collection

This research made use of primary and secondary data. The secondary data for this research work included the average daily, monthly and annual quantity of MSW generated in the city. The number of collection vehicles; collection schedules and size of sanitary landfill are obtained from Gombe State Environmental Protection Agency (GOSEPA) which is the agency saddled with the responsibility of SWM in Gombe. GOSEPA reported to the researchers that there are 49 identical open waste collection points spread around the city, these collection points are officially designated places where residents dump their solid waste. GOSEPA officials also reported that the organisation has eleven (11) waste collection vans which they use to haul the unsorted MSW from collection points to the city's only sanitary landfill on a daily basis (except Sundays). The 40,000 m^2 sanitary landfill is located about 4km from the city centre.

Primary data for the research i.e SWM process being practiced in the city and the composition of the waste being generated in the city are obtained by observation and collection of samples at the city's landfill. Rake and shovel are used to collect the samples which are packaged in large polythene bags and labelled with the date of collection. The weight of each batch of MSW collected is recorded. The collected samples are sorted and characterised in accordance with ASTM D 5231-92 standard [2]. This is done on three different occasions in the year that is in the months of January, April and August 2019. Collection of samples from the unsegregated MSW disposed at the dumpsite is done at these three different times so as to account for seasonal variation which influences vegetation, consumption pattern and waste profile [15]. These three months represent the three seasons experienced in the region. Table I clearly shows data used and their sources.

B. Data Analysis

Institute for Global Environmental Strategies (IGES) GHGs emission tool is used to analyse the data obtained from the sanitary landfill. Institute for Global Environmental Strategies (IGES) GHGs emission tool utilises the composition and quantity of MSW generated to estimate the amount of GHGs emissions into the atmosphere from a certain SWM practice. Five (5) SWM practices are considered and their corresponding GHGs emission are obtained. The five (5) SWM techniques are Anaerobic Digestion; Composting; Incineration; Landfilling and Open Burning. A 'tailpipe' carbon footprint analysis for SWM is adopted, which means only direct GHGs emissions are accounted for in the studies. Emissions from other related activities like transportation and sorting of MSW is not considered.

For anaerobic digestion, it is assumed that the only GHGs emission from the SWM process comes from the leakages that occur in the digestion facility or during collection of the methane gas produced in the process. The formula for estimation of GHG emissions from anaerobic digestion embedded in the estimation tool is expressed in equation (1) [16].

$$E_T = E_{CH_4} \times DM \times 1000 \times GWP_{CH_4} \ , \qquad (1)$$

Where:

E_T	=	Emissions from anaerobic digestion,
E_{CH4}	=	Emissions of CH_4 due to leakages (kg of CH4/kg of dry matter),
DM	=	Dry matter percentage in the influent (%),
1000	=	per tonne of organic waste,
GWP_{CH4}	=	Global warming potential of CH_4 (21kg CO_2/kg of CH_4).

When composting is used as the preferred SWM technique, GHGs are emitted in the process in two major ways. The first being from utilization of fossil energy (e.g. electricity and diesel) for composting operations and the second being GHGs emissions from organic waste degradation. The latter being the source considered in this research work is a tailpipe approach. The formula embedded into the tool for estimating emissions from composting is expressed in equation (2) [16].

$$E_D = E_{CH_4} \times GWP_{CH_4} + E_{N_2O} \times GWP_{N_2O} \ , \qquad (2)$$

Where:

E_D	=	Emissions from organic waste degradation (kg CO_2/tonne of organic waste),
E_{CH4}	=	Emissions of CH_4 during organic waste degradation (kg of CH_4/tonne of waste) 0.4, [17]

GWP_{CH4} = Global warming potential of CH_4 (21 kg CO_2/kg of CH_4),
E_{N2O} = Emissions of N_2O during waste degradation (kg of N_2O/tonne of waste 0.3 [17],
GWP_{N2O} = Global warming potential of N_2O (310 kg CO_2/kg of N_2O).

Incineration of MSW with electricity recovery is pretty popular and becoming a one of the most preferred SWM techniques [18–20]. This is so because the electricity recovered offsets GHG emissions from fossil fuel sources that would have been used to generate electricity and also reduces the costs involved in the process [21-22]. The formula embedded in the IGES software, which estimates the amount of GHGs emitted into the atmosphere from the incineration of MSW is presented in equation (3) [17].

$$CE = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12}, \quad (3)$$

Where

CE = Combustion Emissions ($kgCO_2$/tonne of MSW),
SW_i = Total amount of solid waste,
dm_i = Dry matter content in the solid waste,
CF_i = Fraction of carbon in the dry matter,
FCF_i = Fraction of fossil carbon in the tot alcarbon,
OF_i = Oxidation factor,
$\frac{44}{12}$ = Conversion factor from C to CO_2.

When mixed waste landfilling is considered as the preferred SWM process, it is assumed that the solid waste is not sorted before landfilling. Emissions from mixed waste landfilling emanate from the anaerobic decomposition of the organic component of the waste.

The formula embedded in the estimation tool is presented in equations (4-7) [17].

$$ECH_4 = MSW_x \times L_o \times (1 - f_{rec}) \times (1 - OX), \quad (4)$$

Where:

ECH_4 = Total CH_4 emission (tonnes of methane),
MSW_X = Mass of solid waste sent to landfill in inventory year (tonnes),
L_o = Methane generation potential (m^3/tonne),
f_{rec} = Fraction of methane recovered at the landfill (flared or energy recovery),
OX = Oxidation factor (0.1 for managed sites, 0 for unmanaged sites),

$$L_o = MCF \times DOC \times DOC_F \times F \times \frac{16}{12}, \quad (5)$$

Where,

MCF = Methane correction factor which is based on type of landfill (0.4),
DOC = Degradable organic carbon, fraction (tonnes C/tonnes waste),
DOC_F = Fraction of DOC that ultimately degrades (0.6),
F = Fraction of methane in landfill gas (0.5),
$\frac{16}{12}$ = Stoichiometric ratio between methane and carbon,

$$DOC = (0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) + (0.15 \times F) \quad (6)$$

A = % of solid waste that is food,
B = % that is garden waste and other plant debris,
C = % of solid waste that is paper,
D = % of solid waste that is wood,
E = % of solid waste that is textiles,
F = % of solid waste that is industrial waste.

Solid waste emission (SWE) in tonnes of carbon dioxide equivalent (tCO_2eq) is estimated thus:

$$SWE = CH_4 \text{ Emissions} \times GWP \text{ of } CH_4, \quad (7)$$

TABLE I
DATA USED AND THEIR SOURCES

Parameter	Type of Data	Source
Quantity of MSW	Secondary Data	GOSEPA
Number of MSW Collection Points	Secondary Data	GOSEPA
Number of collection vehicles	Secondary Data	GOSEPA
MSW Collection schedule	Secondary Data	GOSEPA
Size of sanitary landfill	Secondary Data	GOSEPA
Composition of MSW	Primary Data	
SWM Technique in Practice	Primary Data	

Where,
SWE = Global Warming Potential (GWP) of CH_4
= 28 [23].

For open burning, the estimation tool is designed in compliance with IPCC's 2006 guidelines for estimation of GHGs. The formula embedded in the software for open burning is the same as that of incineration as seen in Eq. (3), the only difference is that the oxidation factor is lower in open burning (58%) because it experiences higher incomplete combustion in open burning [16].

III. Simulation And Results

It is found from the data obtained from GOSEPA that in the inventory year – 2019, 139,875 tonnes of MSW is disposed off at the city's dumpsite, that mathematically amounts to 383.22 tonnes on a daily basis and 11,496.6 tonnes monthly, which is higher than what is obtainable in other state capitals in the same north eastern region of Nigeria. Abba found out that the estimated quantity of MSW reaching dumpsites in Yola, the capital of neighbouring Adamawa state, is about a third (3rd) of Gombe's despite Yola being a larger city [24]. Jones and Alkali whose research is also undertaken in neighbouring Borno state in the same north eastern region, found that Maiduguri, the state capital, which is about twice in land size and population when compared to Gombe has just about 61,317 tonnes of MSW reaching its dumpsites annually, that is less than half of Gombe's [25]. Further probe showed that the reason for this high quantity of MSW reaching the dumpsite in Gombe (compared to other states in the region) is the high MSW collection efficiency in the state capital instead of higher per capita MSW generation rate in the state capital. Table II shows the annual quantity of MSW disposed at the dumpsite for the 10-years period that it has been in existence.

For composition of the MSW generated in Gombe, inert materials are found to be the common type of waste (22.2%), followed by garden/yard waste (13.9%). Papers are found to be the least type of waste being generated in the state capital. Table III shows the composition by weight for the MSW generated in Gombe.

For the five (5) SWM techniques being considered, it is simulated and found that 1,141.13 tonnes of carbon dioxide equivalent (tCO_2eq) will be emitted into the atmosphere annually if Anaerobic Digestion is used as the most preferred method of SWM, given the composition and quantity of MSW generated in Gombe. On the other hand, if composting is used as the preferred SWM method, 24,418.78 tCO_2eq of carbon dioxide will be emitted annually. If either incineration, landfilling or open burning is used as the preferred SWM processes in the city, 2,578.47tCO_2eq, 32,265.54tCO_2eq and 30,126.34 tCO_2eq will be emitted into the atmosphere on an annual basis respectively. *Fig. 1* shows graphically the quantity of GHGs that can be emitted into the atmosphere if either of the five (5) SWM techniques is used.

Table II
Annual Quantity of MSW Disposed of at Dumpsite

Year	Quantity (Tonnes)
2009	29,022
2010	110,376
2011	115,920
2012	126,168
2013	71,568
2014	206,052
2015	184,548
2016	139,404
2017	126,221
2018	135,601
2019	139,875
Total	1,384,755

Table III
Average Composition MSW in Gombe

Material Category	% Weight
Paper	8.2
Plastic	11.4
Yard waste	13.9
Food Waste	9.0
Wood	8.3
Metals	8.3
Glass	8.9
Textiles	9.8
Inert Materials	22.2
Total	100

It can be seen in *Fig. 1* that the current SWM technique being practiced in Gombe - open dumping of unsorted waste (landfilling) has the highest carbon footprint. It can be seen that an estimated 32,265.54 tCO_2eq is currently being emitted into the atmosphere on an annual basis from this practice. From an interview carried out with GOSEPA leadership, it is gathered that whenever the sanitary landfill is getting filled up, the accumulated waste is burnt without the aid of any form of incineration equipment. This practice of open burning will be responsible for the second highest carbon footprint (30,126.34tCO_2eq) if it is adopted as the preferred SWM technique in the city as shown *Fig. 1*. On the other hand, an estimated 24,418.78tCO_2eq will be emitted into the atmosphere on an annual basis making it rank as the 3rd worse GHG emitter among the five (5) SWM techniques simulated from the simulation if composting is to be used as the preferred SWM technique in Gombe. As seen from

Fig. 1 above, incineration ranks 4th among the five (05) SWM practices simulated, it is found that the carbon footprint from incineration will be just about 2,578.47tCO_2eq on an annual basis given the current MSW generation rates and composition. Anaerobic digestion is simulated to have the least impact on the environment, which is about 2,578.47 tCO_2eq annually. Despite this being the least among the five (5) SWM practices simulated, there is a catch with anaerobic digestion. It is assumed that the MSW is sorted and only the emission from the decomposition of its organic component is captured. What happens with the inorganic component which in the case of Gombe constitute about 50% of the waste is not taken into consideration by the IGES simulation tool, this therefore leaves a grey area for the estimation of GHGs emission from anaerobic digestion, the carbon footprint reported does not give a full picture of the carbon footprint from this SWM process.

Since it has been established that of the five (5) SWM techniques simulated, numerically, anaerobic digestion has the least carbon footprint, the next being incineration with electricity recovery. It however is important to state that a critical look at the two SWM processes reveals incineration with electricity recovery will be the best for the city given that it has the following inherent advantages over anaerobic digestion and the remaining SWM processes: it has the best waste volume reduction ratio (≈ 80%) [26-27],electricity generated from it, offsets the GHG emissions from conventional fossil fuel sources, electricity generated from the process can be sold thereby reducing the cost involved in the process.

Since landfilling is the current SWM technique being practiced in the city and it produces an annual GHGs emission of 32,265.54tCO_2eq, adopting incineration with

electricity recovery will cut down the existing annual GHGs emission by 29,687.07tCO_2eq, that is a reduction of about 92%. In a relatable term, given that an average sized tree sequesters 25kgCO_2eq/yr [28], the 32,265.54tCO_2eq/yr avoided by this process is equivalent to the amount of GHG emissions that can be sequestered by 1,290,622 average sized trees. If implemented, this will be a good contribution in the race against the increase in average global temperature rise and reduction in the quantity of anthropogenic GHGs

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IV. CONCLUSION

Emission from the solid waste sector is responsible for about a fifth (5th) of the total global GHGs emission. Given that GHGs emission from this sector has been intricately linked to economic and population growth, Gombe being a city with a burgeoning population and a growing economy, it became pertinent to profile the MSW generated in city and simulate which of the five (5) most common SWM techniques will have the least carbon footprint and be most suitable for the city.

After a dutiful analysis and comparison using the data obtained from primary and secondary sources, it was found that anaerobic digestion emits the least amount of GHGs. However, incineration with electricity generation is the recommended SWM practice for Gombe because in addition to having the 2nd least carbon footprint, electricity generated from the process can be used to compliment the insufficient electricity being supplied to the city from the national grid.

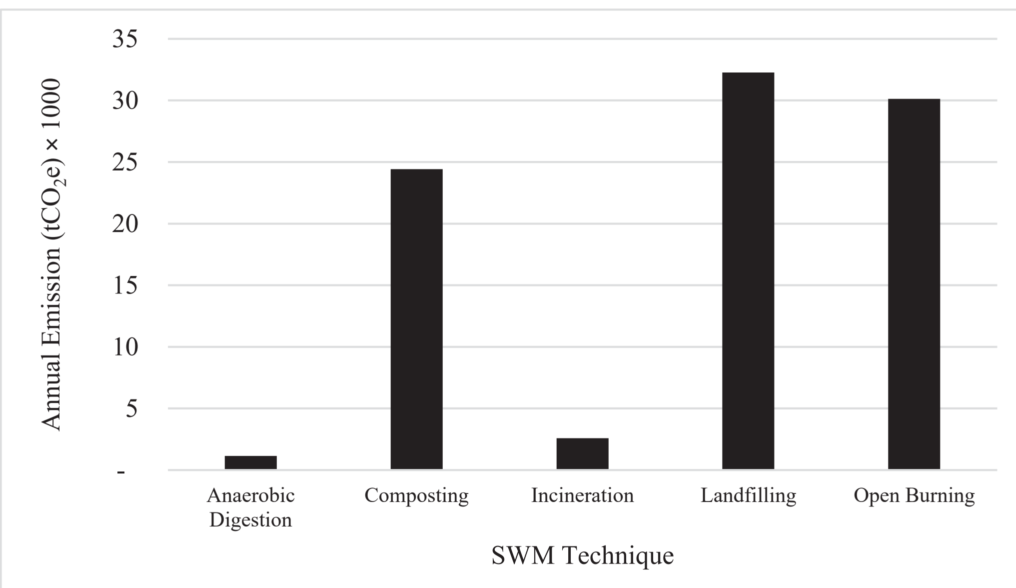

Fig. 1. Annual GHGs emission for the different SWM techniques in Gombe.

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