Global Scientific JOURNALS

GSJ: Volume 8, Issue 12, December 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

INTEGRATED SOLID WASTE MANAGEMENT: KEY TO REDUCTION OF SOLID WASTE MANAGEMENT CARBON FOOTPRINT IN EMERGING ECONOMIES, A LOOK AT YOLA, ADAMAWA STATE, NIGERIA

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ABSTRACT

The current solid waste management (SWM) practice of open dumping prevalent in developing countries is not sustainable. It is responsible for an unusually high amount of greenhouse gases (GHGs) emission from the sector, this is in addition to other environmental woes it poses. Integrated Solid Waste Management (ISWM) is an effective SWM technique. Life cycle approach was used to develop an ISWM model suitable for Yola, the capital of Adamawa State in Nigeria based on its municipal solid waste (MSW) profile. The potential for reduction of GHGs emission from the SWM sector in Yola was ascertained using the model. Data used for the analysis was obtained from literature. It was determined that if this model is implemented in the city, a reduction of 188% in the carbon footprint of the city's SWM sector could be achieved. It was also found that the composting is the ISWM element with the highest carbon sink potential, this is because the city's MSW has high organic matter content. The study suggested synergy between government and the organised private sector so as to be able to make the SWM sector in the city sustainable. It also suggested creating awareness on the need for responsible usage and disposal of materials by the city's inhabitants.

Keywords: Carbon footprint; Composting; Greenhouse Gases; Integrated Solid Waste Management; Municipal Solid Waste; Solid Waste Management; Recycling; Waste to energy.

INTRODUCTION

Global rise in population and general economic growth experienced since the end of the last global recession has enhanced the purchasing power of people and consequently brought about an increase in the generation of municipal solid waste (MSW). The solid waste management (SWM) sector has been identified to be responsible for the emission of 5% of all greenhouse gas emissions globally [1]. The fact that the SWM sector is not among the industries with very high carbon footprints does not exonerate it from utilising available opportunities to curtail its carbon footprint and become more sustainable.

Researchers have pointed out that in developing countries, the emission of GHGs from the SWM sector is higher than that of developed countries, therefore, the opportunities for curtailing the carbon footprint of the sector in developing countries are much [1]–[3]. Organised formal SWM systems in most developing countries are non-existent in rural areas, in urban areas where such formal service exists, the services do not cover all areas and their modus operandi is essentially the same – residents dump MSW in designated collection points, the agency responsible collects and transports it to dumpsites and unsanitary landfills [4]. This SWM method of disposal of MSW in unmanaged dumpsites and unsanitary landfills has been found to be responsible for higher GHGs emission in comparison to better coordinated SWM techniques [5].

In view of the aforementioned, it has become important to seek eco-friendlier and cost effective SWM techniques to replace the existing one. This will position the waste management sector as a responsive and responsible sector which is playing its part in curbing the global emission of GHGs to the barest minimum so as to stem the tide of global warming and its attendant consequences. Yola, the capital city of Adamawa State in the north-eastern region of Nigeria being a city that still disposes of its MSW in unmanaged dumpsites has a huge potential for reducing the GHGs emissions from its SWM sector. This research considers the role an integrated solid waste management (ISWM) system can play in reducing the GHG emissions from the solid waste sector in a developing country using Yola as a case study.

SOLID WASTE MANAGEMENT IN YOLA

Yola the capital of Adamawa state situated within latitudes 9°11’59’’N and longitudes 12°28’59’’E and at an altitude of about 192m [6], like most other cities in Nigeria and the developing world still manages its solid waste the traditional way – collection of unsegregated waste and disposing them in unmanaged dumpsites [7]. Municipal solid waste in the state capital is managed by the state’s environmental protection agency (ASEPA). ASEPA has designated collection points in residential and commercial areas, these points are usually built dumpsters or the conventional large metal dumpsters. Residents dispose of their waste in these dumpsters and ASEPA routinely collects and transports it to the city’s dumpsite. In between disposing of waste in the dumpsters and transporting them to the dumpsite, scavengers collect metal scraps and bottles which they sell for reuse or recycling. That is the only form of recycling that exists in the SWM system in Yola even though there exist transfer depots where MSW is meant to be segregated for recycling purposes, however, those depots are not in use because equipment needed for segregation and further processing of the waste were never bought nor installed [7]. Since the city disposes of its unprocessed waste, it is expected that there exists a sanitary landfill, however, only an open dumpsite exists which is largely unmanaged.

It was found from literature that on average, 49,447 tonnes of MSW is disposed of at the city’s dumpsite annually [8]. Given that the city has a waste collection efficiency of 40% [9], it is therefore estimated that the city generates 123,618 tonnes of MSW annually. A composition analysis of the MSW disposed of at the city’s dumpsite showed that about half of it was food waste, papers and plastics make up almost 40%. Table 1 shows the composition of MSW disposed of at the city’s dumpsite.

Table 1: Composition of MSW at Dumpsite in Yola

Component	Composition Weight (%)
Food wastes	42.45
Paper	14.37
Plastic	25.66
Rubber	1.93
Textile	2.69
Yard Waste	7.71
Wood	0.90
Metal	0.81
Glass	1.83
Diaper	0.09
Battery	1.56

[6]

INTEGRATED SOLID WASTE MANAGEMENT

Lately, the concept of ISWM has been gaining more acceptance in the SWM industry, researchers have alluded to it as the silver bullet to making the SWM industry more sustainable [10]–[12].

ISWM as the name implies, is a multidimensional approach to SWM, it is the use of a range of different waste management options rather than using a single option [13]. The concept of ISWM emerged from the realisation that technical solutions alone do not adequately address the complex issue of SWM and that a single choice of approach/method for waste management is frequently unsatisfactory, inadequate, and not economical [13]. ISWM approach to waste management is not a strict technical approach to handling waste, it is an approach that relies on a wide range of complementary techniques – technical and behavioural to achieve sustainability in waste management. ISWM is a holistic approach to SWM which encapsulates all aspects of the SWM process in an integrated manner, these aspects start from generation, segregation, transfer, sorting, treatment, recovery and disposal. The ultimate goal of ISWM is maximization of resource use and boosting efficiency.

Fundamental elements that constitute ISWM in order of importance are waste prevention, waste reduction/minimization, re-use of materials and products, material recovery from waste streams, recycling of materials, composting to produce manures, incineration with energy recovery, incineration without energy recovery and disposal in landfills [14]. The ISWM approach to handling MSW as postulated by Girling places the constituting elements in a hierarchical order[15], this order is based on the 3Rs of SWM. Figure 1 shows this hierarchy which has waste prevention and reduction at the top, meaning the best way to deal with waste is to prevent its production, and where this is not possible, reduction in the quantity of waste produced is the next best option. At the bottom of the pyramid lies waste disposal, meaning it is the least sustainable method for managing waste. Ironically, this is the most commonly practiced SWM process.

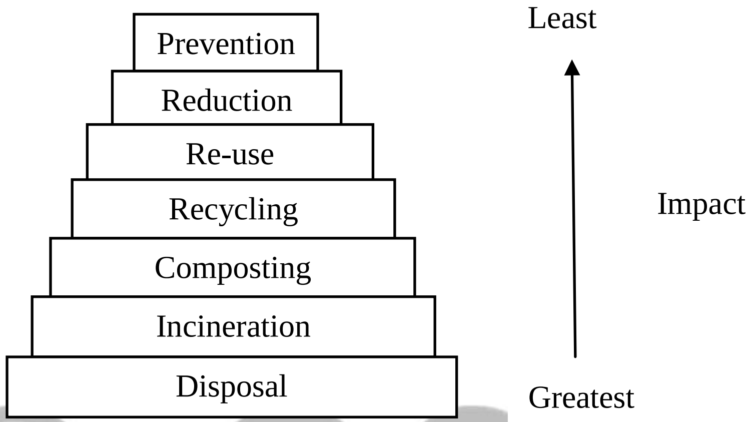

Figure 1: Waste Management Hierarchy

MATERIALS AND METHODS

In developing an ISWM model suitable for Yola, an extensive study of literature was undertaken to obtain the necessary data. Data obtained from literature include the quantity of waste disposed of at the city's dumpsite, the existing SWM technique in practice in the city, the city's waste composition.

Since the rate at which materials are being reused cannot be ascertained, reuse of materials was excluded from the elements that form the ISWM model developed for Yola. The ISWM elements considered for the formulation of the ISWM model are recycling, composting, and landfilling of inert materials. These elements were selected based on the composition of the city's MSW, organic materials get composted; glass and metals get recycled garbage gets incinerated with energy in form of electricity recovered from, and inert materials get landfilled. The conceptual framework for the ISWM model showing the material flow and system boundary is shown in figure 2.

Following precedence in literature, the following assumptions were made:

1. All glass materials in the city's MSW are recyclable.
2. All papers in the city's MSW are high grade deinked paper.
3. All metals in the city's MSW are aluminium.
4. The humus obtained from composting is used as substituted for chemical fertilizer.
5. MSW incineration is with electricity recovery.

Life cycle assessment (LCA) approach for estimation of the carbon footprint of an ISWM scheme was adopted [16], [17]. This approach makes use of the individual lifecycle carbon footprint for each element of the ISWM model. Data for this was obtained in literature, Table 2 shows this data.

Table 2: ISWM Elements and their Corresponding LCA Carbon Footprints

ISWM Element	Carbon Footprint
Recycling of Glass	1.25tCO_2eq/tonne of glass [18]
Recycling of Paper	212kgCO_2eq/tonne of waste [19]
Recycling of Aluminium	3.05tCO2eq/tonne of Aluminium [20]
Composting of Organic Waste	-690kgC/tonne of Composted Waste [21]
Incineration with electricity recovery	-0.179tCO2eq/tonne of incinerated waste [22]

Assumptions 1-3 were made so as to be able to use a harmonised LCA carbon footprint data for the different types of glasses, papers and metals in the waste.

To determine the potential contribution of this ISWM model in the reduction of Yola's SWM carbon footprint, the emission from the current practice of open dumping was first estimated. This was done using IPCC's waste model shown in equations 1-3 [23].

$$CH_4\ Emissions = MSW_X \times L_o \times (1 - f_{rec}) \times (1 - OX) \qquad \dots (1)$$

Where:

MSW_X = Mass of solid waste sent to landfill in inventory year (metric 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)

$$L_o = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \qquad \ldots (2)$$

Where,

MCF = 0.6 for dumpsites and unmanaged landfills

DOC = Fraction of Degradable organic carbon (tonnes C/tonnes waste)

DOC_F = Fraction of DOC that ultimately degrades (0.6).

F = Fraction of methane in landfill gas (0.5)

$\frac{6}{12}$ = Stoichiometric ratio between methane and carbon

$$DOC = (0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) \qquad \ldots (3)$$

A = Fraction of solid waste that is food

B = Fraction of solid waste that is garden waste and other plant debris

C = Fraction of solid waste that is paper

D = Fraction of solid waste that is wood

E = Fraction of solid waste that is textiles

Global warming Factor of CH_4 = 28 [24]

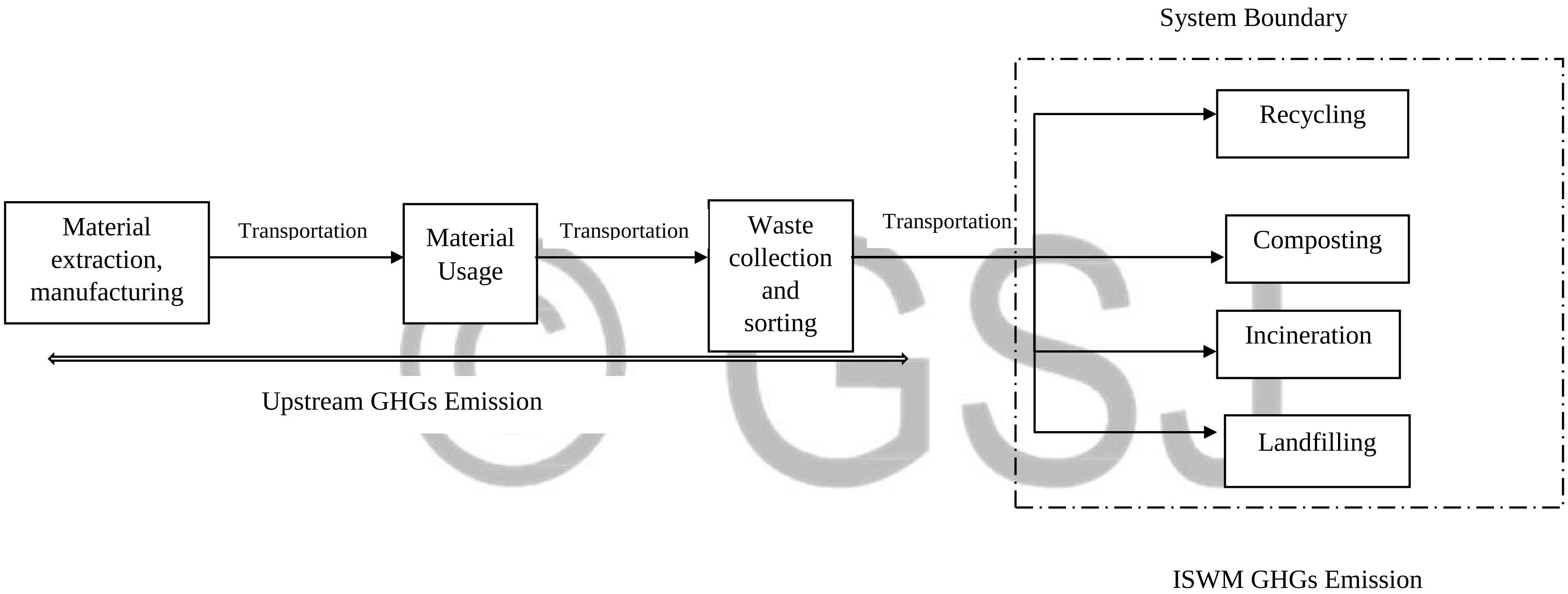

Figure 2: ISWM Model

RESULTS AND DISCUSSIONS

It was estimated that with the city's current SWM practice of open dumping in an unmanaged dumpsite, when the 49,447 tonnes of MSW disposed of in the dumpsite annually anaerobically digests, 18,304.69tCO_2eq is emitted into the atmosphere. This means that each tonne of MSW disposed of in the city's dumpsite has a carbon footprint of 370.18kgCO_2eq. This is somewhat similar to the 375kgCO2eq/tonne of MSW obtained in the neighbouring Gombe State as seen in literature [4]. Since it has been established that waste generation in any location is influenced by socioeconomic/demographic factors like per capita disposable income, levels of education, the degree of industrialization, public habits, local climate, age of population and environmental laws/policies influence [25]–[27], it can therefore be speculated that the reason the two cities have somewhat similar MSW profile and carbon footprint from its management (open dumping) is because of their socioeconomic and demographic similarities.

It was found that the MSW disposed of in the dumpsite in Yola has 1.83% composition by weight of glass, this translates to 904.88 tonnes of glass annually. Using the LCA carbon footprint of glass obtained from literature (presented in Table 2), the carbon footprint for recycling 904.88 tonnes of glass on an annual basis amounts to 1,131.1tCO_2eq. It was found that the city's MSW contained 14.37% paper (as presented in Table 1), this translates to 7,105.53 tonnes of papers annually. The carbon footprint for recycling that amount of paper was estimated to be 1,506.37tCO_2eq. For metals, it was estimated that recycling 400.52 tonnes will result in the emission of 1,221.59tCO_2eq into the atmosphere. Food and yard wastes form 50.2% of the MSW generated in the city, composting this waste and using the humus as organic fertilizer in place of chemical fertilizers serves as a carbon sink, it was estimated that when this is done, a savings of 17,113.81tCO_2eq will be achieved.

The last element for the ISWM in Yola is the incineration and recovery of electricity from the remaining components of the MSW – plastics, rubbers, textiles, wood and diapers. It was found that these items constitute 31.3% of the MSW disposed of in Yola's dumpsite. Substituting grid electricity with that generated from these items will offset the grid's carbon footprint therefore resulting in a negative carbon footprint (carbon sink). It was estimated that this element of the ISWM will sink 2,767.71tCO_2eq. Cumulatively, the ISWM model presented here will lead in a carbon sink of 16,022.45tCO_2eq annually. When juxtaposed with the 18,304.69 tCO_2eq/yr that the current SWM practice of open dumping is responsible for, this is a reduction of about 188%. Table 3 shows the estimated GHG emission from the handling of each MSW component in the proposed ISWM model for Yola.

Table 3: Carbon Footprint for Each Component of Yola's MSW

MSW Component	Carbon Footprint (tCO_2eq/yr)
Recycling of Glass	1,131.10
Recycling of Paper	1,506.37
Recycling of Metals	1,221.59
Composting of Food Waste	-14,483.27
Composting of Yard Waste	-2,630.53
Incineration of *PRTWD	-2,767.71
Total	**-16,022.45**

*PRTWD = Papers, rubber, textile, wood and diapers.

When the elements of the ISWM model are looked at individually, it can be seen from Figure 3 that composting is the biggest carbon sink, this is unsurprising given that more than half of the city's waste is food and yard wastes. It can also be seen that incineration with electricity recovery is a carbon sink. Even though recycling as an element of the proposed ISWM model has the highest carbon footprint, it is still a better option than the current SWM process of open dumping.

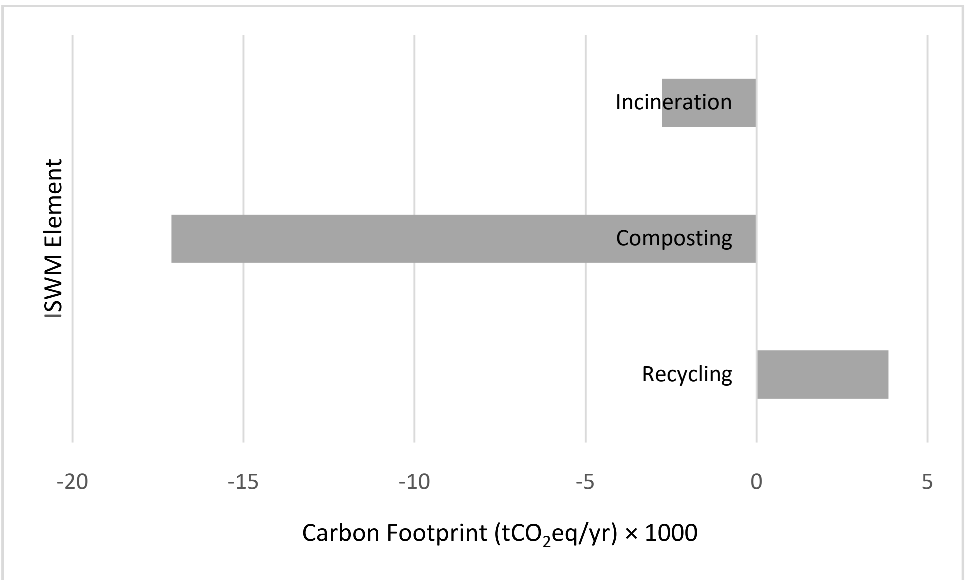

Figure 3: ISWM Model Elements and their Carbon Footprint

When this study is compared to similar research done in other places, the potential reduction in the emission of GHGs is significant, a study done in Bucharest, Romania showed that implementing an ISWM model in the city would bring about a reduction in the emission of GHGs from the SWM sector by 5% [28]. A comparative study of Japan and China found that implementing an ISWM model has a potential for reducing the emission of GHGs of up to 181.37 million tCO_2eq and 96.76 million tonnes respectively [29]. In another study, an ISWM model developed was tested on a number of cities in different countries, it was found that the potential for GHGs emission reduction ranged between 24 and 95%, with the developing economies having a higher emission reduction potential [30]. It has been observed that the potential for reduction in GHGs emission due to the implementation of an ISWM model is higher in developing countries than in developed countries, this is because in developed economies the SWM sector is better coordinated and modern SWM processes are already in practice in some of these places, whereas, in developing countries, the conventional open dumping and open burning are still very much in practice.

CONCLUSIONS

An efficient waste management system plays an important role in reducing CO_2 emissions, conserving energy and ultimately promoting sustainability. Therefore, the LCA approach to ISWM was used to develop an ISWM model suitable for developing countries using Yola's waste profile. Its role in reducing the carbon footprint of the SWM sector was assessed. It was found that the city's current SWM process of open dumping is responsible for the emission of 18,304.69tCO_2eq/yr into the atmosphere. It was estimated that a potential reduction in the emission of GHGs of 188% can be attained when the ISWM model is implemented. Of the three elements of the model, composting was found to be the element with the highest potential for CO_2 reduction. Evidently, this is so because of the high content of organic matter in the city's MSW.

Incineration with electricity recovery is the element with the second highest potential for carbon sinking, it was found that this element of the ISWM model has the potential of sinking 179kgCO_2eq per tonne of garbage incinerated. Though recycling was found to be the element with the least ability to sink CO_2 emissions, its role in the ISWM model cannot be disparaged.

In achieving the implementation of the ISWM model or any other advanced SWM system in the city or any other city in the developing world, a number of steps need to be taken. The first being creating awareness about the need for waste reduction, the second is the need to reuse items that can be reused instead of discarding them. Thirdly, the segregation of waste from source should be encouraged, this will ease the cost and energy associated with sorting of MSW for further processing. Fourthly, adopting the proximity principle [31], this is a principle that advocates for the processing (sorting, recycling, composting, landfilling and/or incineration) of waste as close to its source as possible, this will help to reduce the time spent, cost and carbon footprint associated to its transportation.

Setting up an ISWM system is capital intensive, at the moment, the government is responsible for SWM in Yola, this is also so in most other parts of the country. In order to achieve sustainability in the sector, the government should consider partnering with private investors so that the necessary investments that will aid the transition to the use of more sustainable SWM processes can be made.

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