Indices of solid Wastes Environmental Impacts in Ilorin East Local Government Area using GaBi₆ modeling Tool

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Abstract

The problems of solid waste in Ilorin East Local Government Area (LGA) of Kwara State are uncontrolled dumping of wastes in the environment, lack of standard landfill and poorly located dumpsites. In this paper, the life-cycle of solid wastes in Ilorin East Local Government Area of Kwara State was examined using GaBi₆ modeling tool and the implications of their environmental impacts were identified.

Three major dumpsites viz: Apado, Agbeyangi, and Oke-Oyi were selected and the concentration levels of CH₄, CO₂, SO₂ and CO gases were measured using ToxiRae gas sampler. Two waste management scenarios were developed and compared using GaBi₆ software version. Scenario 1 involved collection, transportation and landfilling, while Scenario 2 involved collection, transportation, and incineration. The impact indices determined for both scenarios were Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Ozone layer Depletion Potential (ODP) using the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) of the United States Environmental Protection Agency and the Methodology of the Centre for Environmental Studies (CML) of the University of Leiden in the GaBi₆ software version.

The impact indices of landfilling scenario for GWP, AP, EP, and ODP were 2.63(kgCO₂ Equiv.), 1.50E-03 (kgSO₂ Equiv.), 3.22E-03(kg Phosphate Equiv.) and 9.98E-12(kg CFC 11-Equiv.), respectively. Those of the impacts of incineration scenario for GWP, AP, EP, and ODP were 3.32(kgCO₂ Equiv.), 9.20E-04(kgSO₂ Equiv.), 3.72E-04(kg Phosphate Equiv.) and 2.49E-08(kg CFC 11-Equiv.), respectively.

Landfilling of wastes poses a lesser burden on the environment, using ODP index, as compared to incineration and therefore recommended for use in the study area.

Keywords: Landfilling, Incineration, Global Warming Potential, Acidification Potential, Eutrophication Potential, Ozone Depletion Potential

Introduction

Waste has been a great challenge since the beginning of civilization when humans gathered in communities (Priestly, 1968). Wastes generated then were managed by natural means. However, as population increased and villages developed in to towns and cities, the amount of waste produced increased (Ogola *et al.*, 2010). Since no waste management scheme was available at that time, waterways, empty lands and access roads were used as waste dumping spots. The dreadful conditions gave rise to epidemics like the "Black plague" that destroyed large population of Europe in the 14th century (Priestly, 1968). Similar conditions were also experienced in other parts of the World. The 19th century European industrial revolution marked a turning point in the history of waste management (Ogola *et al.*, 2010). It resulted to migration from rural areas to urban areas in search for jobs and better standard of living. The resultant effect of rural-urban migration lead to congestion of towns and cities which eventually gave rise to alarming proportion of wastes being dumped in the streets and waterways.

In the early days, man was restricted to residential and agricultural land use. With technological advancement in industrialization came changes in needs, taste, consumption, perception, societal value among others, which in turn gave rise to different activities of man and therefore evolution of different land use types (Odita, 1987). In studying solid waste, its generation was found to increase directly with income level (Ojoawo, 2011). In other words, the bigger the size and density of the city, the higher the waste generated. This finding seems more realistic or logical since it can be assumed that the bigger the size and density of the city, the higher the population of waste generators and consequently the greater the quantity of solid waste generated (Odita, 1987).

As Ilorin city grew over time, social-economic activities and physical development doubled, and thus led to the increase in daily inflow of people (Ibrahim *et al.*, 2012). The growth in population resulted into day-day increase in waste generated by the state dwellers. The Kwara State Government hereby intervened by establishing government agencies to tackle the problems of waste management in the state. Agencies such as Kwara Waste and Environmental Protection Agency (KWEPA) were established in August 2003 under the Ministry of Environment

and Tourism. KWEPA collects solid waste by locating Roll on Roll off (RORO) waste bins at strategic locations in Ilorin, this solid waste bin is normally made of steel that is not galvanized (Ibrahim *et al.*, 2012). The frequency of collection depends on the population and land use of the area i.e. whether it is a residential, industrial or commercial area. KWEPA stopped operation in 2012 due to fund restriction and unstable government policies (Ibrahim *et al.*, 2012). This led to the removal of the waste bins from the area, making waste disposal a problem for the masses. To combat the menace of indiscriminate dumping of solid waste in the environment, the State Government decided to involve a number of Private Sector Partnership (PSP) solid waste contractors in solid waste collection and management but the economic situation of the country, among other factors has not allowed most residents to fully cooperate with the new arrangement, hence the challenges of waste disposal inherent in the study area.

The framework for Life Cycle Assessment (LCA) consists of the following interrelated components: Goal definition and scoping; Inventory analysis; Impact assessment; Classification Characterization; Valuation; Interpretation. Figure.1 depicts the Framework for LCA according to ISO 14040 (1997).

Figure 1: Framework for LCA according to ISO 14040

In describing goal definition and scope, the purpose and the scope of the study should be defined. This includes system boundaries, data requirements, assumptions and limitations. During the inventory analysis, the inputs and outputs of the system under study are analyzed. The inventory analysis results in tables of inputs and outputs of the system(s) under study. The impact assessment is a process used to characterize and measure the impacts of the inputs and outputs found in the inventory analysis. The impact assessment of an environmental LCA does consider the following major categories: resource depletion, impacts on human health, ecological impacts. The impact assessment is divided into three steps: classification, characterization, and valuation. In the classification the different inputs and outputs are assigned to different impact categories. An analysis and quantification of each impact category is made in the characterization. Valuation is the step in which the data of the different specific impact categories are weighted for comparison. A sensitivity analysis is then carried out, with the objective to identify the different aspects of the life-cycle that are responsible for major environmental impacts. The identified critical parts can then be further analyzed in a detailed LCA if needed. According to the framework, emissions from treatment of solid waste should be analyzed in the inventory analysis. The impacts caused by these emissions should then be analyzed and assessed in the impact assessment in parallel to other emissions caused by the product during its life-time (PE- International, 2011).

The Life Cycle Impact Assessment (LCIA) classifies and evaluates the amount and significant of the potential environmental impacts arising from the Life Cycle Inventory (LCI). The inputs and outputs are first assigned to impact categories and their potential impacts quantified according to characterization factors. For example: GWP $11.3\text{kg CO}_2 \times 1$; $3\text{kg CO} \times 3$; $6\text{kg CH}_4 \times 25$ gives 160.3 kg CO_2 equivalent. Also, AP $0.001\text{kg SO}_2 \times 1$; $0.08\text{kg NO}_x \times 0.7$; $0.9\text{kg HCL} \times 0.88$ gives 0.849 kg SO_2 equivalent. Mandatory elements include the selection of relevant impact categories, characterization and classification. The optional elements of the study are normalization, grouping and weighting (PE- International, 2011).

There are various methods that can be used to perform a Life Cycle Impact Assessment. These methods are constantly researched and developed by different scientific groups based on different methodologies. In life cycle impact assessment methods, TRACI or CML are the two main methodologies that are used to classify and characterize environmental impacts: With the service of the CML and TRACI methods, more than a thousand substances are classified and characterized in related to the extent to which they contribute to a list of environmental impact categories. CML is the methodology of the Centre for Environmental Studies of the University of Leiden and emphasizes on a series of environmental impact categories stated in terms of emissions to the environment. This method includes classification, characterization, and normalization. The impact categories for the global warming potential and ozone layer depletion are established on Intergovernmental Panel on

Climate Change (IPCC) factors. The Tool for the Reduction and Assessment of Chemical and other Environmental Impacts, called TRACI. It was developed by the U.S. Environmental Protection Agency (USEPA) and is primarily used in the US.

After the relevant impact categories are selected, the LCI outputs are assigned to one or more impact categories. If substances supply more than one impact category, they must be classified as contributors to all relevant categories. For example, CO₂ and CH₄ are both assigned to the impact category Global Warming Potential (GWP). NO_x emissions contribute to both Eutrophication and Acidification Potentials (E & AP) and so the total flow will be fully assigned to these two categories. Likewise, SO₂ is assigned between the impact categories of human health and acidification. Human health and acidification are parallel mechanisms; the flow is therefore allocated between the two impact categories.

Characterization quantifies and describes the environmental impact of the analyzed product system. After allocating the LCI outcomes to the impact categories, characterization factors have to be applied to the relevant numbers. The characterization factors are involved in the selected impact category methods like CML or TRACI. Results of the LCI are changed into reference units using characterization factors. For example, the reference substance for the impact category Global Warming Potential is CO₂ and the reference unit is defined as "kg CO₂-equivalent". All the emissions that contribute to global warming are converted to kg CO₂-equivalents according to the related characterization factor. Each emission has its own characterization factor. For example: GWP 11.3kg CO₂ * 1; 3kg CO * 3; 6kg CH₄ * 25 gives 170.3 kg CO₂equivalent. Also, AP 0.001kg SO₂ * 1; 0.08kg NO_x * 0.7; 0.9kg HCL * 0.88 gives 0.849 kg SO₂ equivalent.

The choice of impact category for this research include: Global Warming Potential (GWP); Acidification Potential (AP); Eutrophication Potential (EP); and Ozone Layer Depletion Potential (ODP). The first environmental impact category is the GWP. It is an index that measures the impact to global warming of a substance that is released into the atmosphere. These gases, mainly emitted through human activities, are summarized as greenhouse gases, GHGs and enhance the natural mechanism of the greenhouse effect (OSRAM, 2013). The effect occurs by short-waves radiation from the sun that encounters the earth's surface, which is either partly absorbed leading to direct warming or partly reflected as infrared radiation. The reference substance for the GWP is CO₂ meaning that the greenhouse potential of any emission in this impact category is given in relation to CO₂ and calculated in carbon dioxide equivalents (CO₂-equiv.).

Acidification Potential (AP) is an amount of emissions that cause acidifying effects to the environment. Acidification is in terms of the environmental media, understood as an increase in the concentration of H⁺ - ions in air, water and soil. Acidifying pollutants form acidifying H⁺ ions. It is a measure of the number of H⁺ ions produced per kg substance relative to SO₂. Major contributors to that acidification are gases such as sulphur dioxide and nitrogen oxide and their respective acids, (H₂SO₄ and HNO₃). Compounds of these gases react in the air with water vapour and form sulfuric and nitric acid, which fall subsequently down to the earth as "acid rain", snow or even as dry deposits and damage soil, water, living organisms and buildings. The reference substance of the impact category AP is sulphur dioxide and it is measured in sulphur equivalent (SO₂-equiv.) (OSRAM, 2013).

Eutrophication, specifically nutrient enrichment, refers to a deposit of nutrients in a particular location. Thereby, it is distinguished between the discharge of nutrients into the water (aquatic) and into the soil (terrestrial). Wastewater, fertilizers used in agriculture and air pollutants all contribute to eutrophication. An end result of aquatic eutrophication is an increased growth of algae, which prevents sunlight from reaching deeper depths of water, leading to a reduction in photosynthesis and a lower production of oxygen. The combination of all these effects can result in the obliteration of an ecosystem, (USEPA, 2012). Regarding terrestrial eutrophication, it is observed that plants growing in the effective soil have an increased susceptibility to diseases and pests. The reference substance in this impact category is phosphate and the EP is measured in phosphate equivalents (PO₄ eq).

Ozone Depletion Potential (ODP) is the measure of air emission that contributes to the depletion of the stratospheric ozone layer. Depletion of the ozone results to higher level of UV rays reaching the surface of the earth with detrimental effect on humans and plants (USEPA, 2012). It is measured in kg CFC-11 equivalent. This final phase involves identifying the most significant outputs of the LCI and LCIA phases. This is mostly accompanied by a discussion of the sensitivity and uncertainty of the study and a critical review of the approaches that have been employed.

GaBi software aids every stage of an LCA, from data collection and organization to presentation of results and

stakeholder engagement. GaBi automatically tracks all material, energy, and emissions flows, as well as defined monetary values, working time and social issues, giving instant performance accounting in dozens of environmental impact categories.

GaBi, is an holistic cycle analysis tool that permits rapid modeling even of complex processes and different production options. In order to conduct the LCA contained within this report, the computer program GaBi₆ was utilised. The GaBi software has been developed in accordance with the ISO 14040 and ISO 14044 standards and allows for storing and managing the necessary data, as well as performing the calculations and required sensitivity tests. The functional unit adopted for this research was the establishment of the amount of municipal solid wastes generated in each selected public and commercial areas over a period of one month and the determined green house gases emission from the selected dumpsites in Ilorin metropolis.

This paper focused on identifying the indices of the environmental impacts of solid wastes in Ilorin East Local Government area of Kwara State with the use of GaBi₆ modeling tool. The impacts were measured in terms of Global Warming Potential (kg CO₂ equiv.), Acidification Potential (kg SO₂ equiv.), Eutrophication Potential (kg phosphorus equiv.) and Ozone Layer Depletion Potential (R11 equiv.)

2. Methodology

(a) The study area:

Kwara State is strategically located, as it is a gateway between the Southern and Northern parts of the country and has the potential of attracting settlements. Its capital is Ilorin. The population according to the National Population Census Commission (2006) figure is 781,934. Its major land use is agriculture. Kwara State is surrounded in the North by Niger State, in the South by Ekiti, Osun, Ekiti and Oyo States, in the West by Benin Republic and in the East by Kogi State. The state witness influx of people from the rural area and neighbouring States the City experienced tremendous expansion and developed into a metropolis (KWSME, 2013).

(b) The reconnaissance survey

A reconnaissance survey was carried out to know the location of the dumpsites. Three major dumpsites: Apado, Agbeyangi and Oke-Oyi were studied. Plate I shows the Apado dumpsite as a representative of the rest. The two (2) main approaches to this study were field work and software application. The field work was carried out in order to determine the waste composition and per capita waste generation of Ilorin East Local Government Area, detection and measuring gas concentration on the selected dumpsites. GaBi₆ software was then employed to analyze the waste composition and predict the future pattern of their waste generation through projected population figure for twenty years.

Figure 2: Map of Kwara State showing Ilorin East Local Government Area

Source: Ministry of Lands and Housing, Ilorin

Plate I: Apado Dumpsite in Ilorin East Local Government Area of Kwara State

(c) Population of Ilorin and its projection over twenty years

The 2006 population census estimated the population of Ilorin to be 781,934 with Ilorin East, Ilorin South and Ilorin West estimated to be 207,462, 209,251 and 365,221 respectively. The focus is on Ilorin East with the estimated population of 207,462 (NPC, 2006).

The projected population figure for Ilorin East Local Government Area is obtained using Population Growth Formula in equation 1.

$$P = P_0 e^{rt} \quad (1)$$

where

P = Total Population after time "t"

P₀ = Starting Population

r = % Rate of Growth

e = Euler number = 2.71828

$$P_{2006} = 207,462$$

According to the report on the census 2006 final results, the annual exponential population growth rate is 3.18%.

t = 10 years

$$\begin{aligned} P_{2016} &= P_{2006} e^{rt} \\ &= 207462 \times 2.71828^{0.0318 \times 10} \\ &= 285,130.79 = 285,130 \end{aligned}$$

The volume of wastes generated in residential buildings in the city is proportional to the population density of the occupants; therefore waste future prediction can be projected using population projection figure say 20 years.

$$\begin{aligned} \text{Waste generated in 2016} &= 285,130 \times 0.46 \text{ kg/day} \\ &= 131,159.8 \text{ kg/day} \\ &= 131.16 \text{ ton/day} \end{aligned}$$

Per capital waste generation per day stands at 0.46kg (Oluwanisola, 2017)

In order to obtain the projected population for 2036 (t = 20), we have

$$\begin{aligned} P_{2036} &= P_{2016} e^{rt} \\ &= 285,130 \times 2.71828^{0.0318 \times 20} \\ \therefore P_{2036} &= 538,584.71 = 538,585 \end{aligned}$$

Thus, the estimated population projection for Ilorin East Local Government Area in 2036 is 538,585.

$$\begin{aligned} \therefore \text{Future waste generation for the population of Ilorin East LGA in 2036} &= \\ &= 538,585 \times 0.46 \text{ kg/day} \\ &= 247,749.10 \text{ kg/day} \\ &= 247.75 \text{ ton/day} \end{aligned}$$

(d) Modeling of parameters with software GaBi₆

Landfill and Incineration were the two scenarios employed in this study. The environmental impact indices are Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP) and Ozone Depletion Potential (ODP). Modeling parameters of the study includes data compilation, analysis and quantification based on International Reference Life Cycle Data System (ILCD) recommendations. Average waste composition by mass obtained were fed to the GaBi₆ LCIA software through the two scenarios (models) that were developed.

(I) Model 1: landfill scenario

This scenario includes collection, transportation and landfilling. In GaBi₆, LCA modelling is achieved using plan, process and flow. The plan represents the system boundary of the LCA, process represents real life activities in the life cycle of the product being analysed (e.g transportation), while flow represents the materials and energy in the system. The flow in the model follows the direction of the arrow. Figure 3 shows the LCA model of the MSW developed using GaBi₆ for Scenario One.

Figure 3: LCA model of MSW developed using GaBi₆ (Scenario One)

(iii) Model 2: incineration scenario

For this second scenario, collection; transportation; and incineration was considered. The flow within the system is in the direction of the arrow. Figure 4 shows the LCA model of the MSW developed using GaBi₆ for Scenario Two.

Figure 4: LCA model of MSW developed using GaBi₆ software (Scenario Two)

(e) Gas monitoring

The gas monitors were used to detect the gases present on the dumpsite. The gases measured are CO₂ and CH₄ (*in ppm*), and SO₂ and CO (*in mg/m³*). The time intervals for the readings were measured in seconds. Table 1 shows the different dumpsites with respective GPS points, and figure 5 presents their satellite image.

Table 1: Dumpsites and their GPS points

<i>S/No</i>	<i>Dumpsite Name</i>	<i>GPS Points</i>
1	Apado	8°41'42.13"N 4°52'22.11"E
2	Agbeyangi	8°33'52.25"N 4°47'23.54"E
3	Oke-Oyi	8°33'16.91"N 4°41'48.19"E

3. Results and Discussions

(a) Projected population of the study area for twenty years

Population as at 2006,

$$P_{2006} = 207,462$$

According to the report on the census 2006 final results, the annual exponential population growth rate is 3.18%.

t = 10 years

$$P_{2016} = P_{2006}e^{rt}$$

$$= 207462 \times 2.71828^{0.0318 \times 10}$$

$$= 285,130.79 = 285,130$$

The volume of wastes generated in residential buildings in the city is proportional to the population density of the occupants; therefore waste future prediction can be projected using population projection figure say 20 years.

$$\text{Waste generated in 2016} = 285,130 \times 0.46\text{kg/day}$$

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Per capital waste generation per day stands at 0.46kg (Oluwanisola, 2017)

In order to obtain the projected population for 2036 (t = 20), we have

$$P_{2036} = P_{2016}e^{rt}$$

$$= 285,130 \times 2.71828^{0.0318 \times 20}$$

$$\therefore P_{2036} = 538,584.71 = 538,585$$

Thus, the estimated population projection for Ilorin East Local Government Area in 2036 is 538,585.

$\therefore$ Future waste generation for the population of Ilorin East LGA in 2036 =

$$= 538,585 \times 0.46\text{kg/day}$$

$$= 247,749.10\text{kg/day}$$

$$= 247.75\text{ ton/day}$$

(b) The monitored gas emission: Tables 2 - 4 show the gas readings at each dumpsite. In all dumpsites studied the order of gas concentration was summarily observed to be $\text{CO}_2 > \text{CH}_4 > \text{CO} > \text{SO}_2$. This pattern may be attributed to the considerable dominance of biodegradable wastes in the selected dumpsites.

Table 2: Gas Readings from Apado Dumpsite

<i>Intervals (sec)</i>	<i>Temp. (°C)</i>	<i>CO₂ (ppm)</i>	<i>CH₄ (ppm)</i>	<i>SO₂ (mg/m³)</i>	<i>CO (mg/m³)</i>
30	44.2	600	35	1.3	9
60	45.5	700	11	0.9	11
90	45.6	1000	27	2.7	10
120	50.5	700	12	2.3	16
150	45.4	600	35	3	14
180	47.2	800	20	4.6	12
210	47.6	500	18	2.6	9
240	45.0	800	28	1.2	21
270	46.6	600	15	1.4	13
300	44.6	700	58	4	15

Table 3: Gas Readings from Agbeyangi Dumpsite

<i>Intervals (sec)</i>	<i>Temp. (°C)</i>	<i>CO₂ (ppm)</i>	<i>CH₄ (ppm)</i>	<i>SO₂ (mg/m³)</i>	<i>CO (mg/m³)</i>
30	17.68	800	24	0.5	12
60	36.4	500	22	0.4	10
90	36.48	800	32	1.1	7
120	40.4	600	19	0.9	19
150	36.32	700	45	1.2	11
180	37.76	1200	14	1.9	13
210	38.08	900	30	1.3	19
240	36.00	1000	15	0.5	17
270	37.28	500	38	0.6	12
300	35.68	800	23	1.6	9

Table 4: Gas Readings from Oke-Oyi Dumpsite

<i>Intervals (sec)</i>	<i>Temp. (°C)</i>	<i>CO₂ (ppm)</i>	<i>CH₄ (ppm)</i>	<i>SO₂ (mg/m³)</i>	<i>CO (mg/m³)</i>
30	30.94	900	37	0.6	10
60	31.85	800	13	0.4	12
90	31.92	900	29	1.2	11
120	35.35	600	14	1	17
150	40.86	700	37	1.4	15
180	42.48	900	22	2.1	10
210	33.32	700	20	1.2	7
240	31.5	1200	30	0.5	19
270	41.94	900	17	0.6	11
300	40.14	1000	60	1.8	13

c) Life cycle impact assessment (LCIA) of the wastes

The results of the LCIA of both TRACI and CML methods for landfilling scenarios are presented in Table 5. These results are categorized under GWP, AP, EP, and ODP environmental impact indices.

Scenario one: landfilling using the CML method

From Table 5, the results and the findings can be summarized as follows:

GWP: Biodegradable > Wood > Paper > Textile > Plastic > Metal > Glass

AP: Biodegradable > Wood > Paper > Textile > Plastic > Metal > Glass

EP: Biodegradable > Textile > Wood > Paper > Plastic > Metal > Glass

ODP: Biodegradable > Plastic > Paper > Wood > Textile > Metal > Glass

Scenario one: landfilling using the TRACI method

From Table 5, the results and the findings can be summarized as follows:

GWP: Biodegradable > Wood > Paper > Textile > Plastic > Metal > Glass

AP: Biodegradable > Wood > Paper > Textile > Plastic > Metal > Glass

EP: Biodegradable > Textile > Wood > Paper > Plastic > Metal > Glass

ODP: Biodegradable > Plastic > Paper > Wood > Textile > Metal > Glass

The observed trends for the TRACI and CML methods are similar. As earlier found that with the help of the CML and TRACI methods more than a thousand substances are classified and characterized according to the extent to which they contribute to a list of environmental impact categories (PE International, 2011). LCA had been used to validate the waste hierarchy for solid waste management systems in Sweden (Moberg, *et al.*, 2005; Finnveden *et al.*, 2005) and in determining the environmental load of food product consumption and processing (Roy *et al.*, 2009, Chen *et al.*, 2009 and Dahl *et al.*, 2009). For this scenario, it shows that Biodegradable components constitute the highest impact while glass has the least noticeable impact on landfilling. Food, as the dominating waste here, could be responsible for this trend. Since landfilling is unsuitable for metal and glass disposal, the trend observed is justifiable.

Figures 5 to 8 are charts which show the differences under both CML and TRACI methods for each waste. The variability of the wastes under each method can be understood from these charts. TRACI method gives the overall respective values for GWP (CO₂ equiv.), AP (SO₂ equiv.), EP (phosphate equiv.) and ODP as 2.63, 0.1, 1.36E-3, and 1.06E-11 respectively. Using the CML method, the overall values for GWP, AP, EP, ODP are given as 2.63, 1.50E-3, 3.22E-3 and 9.98E-12 respectively.

Table 5: LCI for landfilling scenario/ model one (CML and TRACI)

<i>Waste</i>	<i>GWP</i>		<i>AP</i>		<i>EP</i>		<i>ODP</i>	
	<i>CML</i>	<i>TRACI</i>	<i>CML</i>	<i>TRACI</i>	<i>CML</i>	<i>TRACI</i>	<i>CML</i>	<i>TRACI</i>
Glass	4.46E-03	4.46E-03	2.76E-05	1.65E-03	3.99E-06	2.63E-06	7.38E-14	7.85E-14
Textile	0.436	0.436	1.21E-04	7.53E-03	6.39E-04	2.64E-04	1.18E-12	1.25E-12
Paper	0.491	0.491	1.39E-04	8.61E-03	1.7E-4	7.34E-05	1.36E-12	1.45E-12
Metal	0.0206	0.0206	6.23E-05	3.54E-03	7.45E-06	4.73E-06	8.70E-13	9.25E-13
Biodeg.	0.869	0.869	3.38E-04	0.0203	1.57E-3	6.79E-04	3.84E-12	4.09E-12
Wood	0.676	0.676	1.49E-04	9.57E-03	5.4E-4	2.21E-04	1.27E-12	1.32E-12
Plastic	0.0339	0.0339	9.94E-05	5.53E-03	9.26E-05	4.45E-05	1.46E-12	1.55E-12
Diesel	0.00739	0.00739	5.22E-05	2.79E-03	4.43E-06	1.94E-06	4.40E-15	4.67E-15
Truck	0.0555	0.0555	4.86E-04	3.91E-02	1.28E-04	4.37E-05	-	-
TOTAL	2.59	2.59	1.47E-03	9.86E-02	3.15E-03	1.33E-03	1.01E-11	1.07E-11

Figure 5: Global warming potential for landfilling scenario (CML and TRACI)

Figure 6: Acidification potential for landfilling scenario (CML and TRACI)

Figure 7: Eutrophication potential for landfilling scenario (CML and TRACI)

Figure 8: Ozone depletion potential for landfilling scenario (CML and TRACI)

Scenario two: Incineration using both TRACI and CML methods

The results of the LCIA of both TRACI and CML methods for incineration scenario (Collection; Transportation; Incineration), are presented in Table 6. These results are categorized under GWP, AP, EP, and ODP environmental impact indices. For this scenario, the ranking of the wastes based on the values in descending order are the same in both TRACI and CML methods and are presented below:

GWP: Plastic > Biodegradable > Wood > Textile > Paper > Glass > Metal

AP: Biodegradable > Textile > Wood > Plastic > Paper > Glass > Metal

EP: Biodegradable > Textile > Wood > Plastic > Paper > Glass > Metal

ODP: Metal > Biodegradable > Plastic > Wood > Textile > Glass > Paper

In this scenario, all the impact indices except ODP indicate biodegradable wastes as having the highest contribution. Metal however, has the lowest contribution to the GWP, AP, and EP of this scenario. Using TRACI method in the GaBi₆ database, the overall results for GWP (CO₂ equiv.), AP (SO₂ equiv.), EP (phosphate equiv.) and ODP are given as 3.32, 9.04E-2, 1.47E-4 and 2.73E-8 respectively. CML method in this scenario gives the overall results for GWP (CO₂ equiv.), AP (SO₂ equiv.), EP (phosphate equiv.) and ODP as 3.32, 9.20E-4, 3.72E-4 and 2.49E-8 and 3.058E-8 respectively. For both the TRACI and CML methods, values of the GWP and ODP values of incineration exceeded those of landfilling. For both methods, values of the AP and EP of the landfilling scenario are higher than those of incineration. The landfilling scenario was therefore found to pose lesser GWP and ODP threats than the incineration. Also the GWP, AP, EP and ODP effects of biodegradable wastes from landfilling exceed those from the incineration processes. This finding agrees with an earlier one by Mendes, et al (2004) that landfilling poses higher environmental threats than biogasification and composting. Figures 9 to 12 show the differences under both CML and TRACI methods for each waste. The variability of each waste under each method can be observed. Table 7 presents the summary of the impacts of the two scenarios. It is observed that both the TRACI and CML methods yield same GWP values. The findings from present study further confirm an earlier report by Ojoawo and Gbadamosi (2013) that in a dumpsite dominated by biodegradable wastes, landfilling of wastes poses a lesser burden on the environment, using the ODP index, as compared to incineration. The findings from present research is however satisfactory due to the fact that Al-Salem and Lettieri (2009) performed a comparative assessment of solid waste management Scenarios for the State of Kuwait with the revelation that the recycling stage of all the three scenarios have the highest environmental burdens while anaerobic digestion process was reported to have lowest contribution to global warming.

Table 6: LCI for incineration scenario/ model two (CML and TRACI)

GWP		AP		EP		ODP	
CML	TRACI	CML	TRACI	CML	TRACI	CML	TRACI
2.05E-02	2.05E-02	4.72E-05	3.60E-03	1.13E-05	4.11E-06	9.24E-10	1.01E-09
0.566	0.566	3.45E-04	2.53E-02	7.71E-05	2.86E-05	1.10E-09	1.21E-09
0.47	0.47	6.15E-05	5.33E-03	2.05E-05	7.54E-06	3.67E-10	4.06E-10
-0.327	-0.327	-1.13E-03	-6.09E-02	-9.43E-05	-3.52E-05	1.58E-08	1.73E-08
0.841	0.841	5.69E-04	0.0397	1.10E-04	4.11E-05	3.95E-09	4.33E-09
0.669	0.669	2.50E-04	1.84E-02	5.71E-05	2.12E-05	1.17E-09	1.27E-09
1.07	1.07	1.87E-04	1.32E-02	3.89E-05	1.45E-05	1.27E-09	1.41E-09
0.0054	0.0054	5.55E-05	2.96E-03	1.21E-05	1.67E-05	2.49E-13	2.65E-13
0.0555	0.0555	4.86E-04	3.91E-02	1.28E-04	4.37E-05	-	-
3.37E+00	3.37E+00	8.71E-04	8.67E-02	3.61E-04	1.42E-04	2.46E-08	2.69E-08

Figure 9: Global warming potential for incineration scenario (CML and TRACI)

Figure 10: Acidification potential for incineration scenario (CML and TRACI)

Figure 11: Eutrophication potential for incineration scenario (CML and TRACI)

Figure 12: Ozone depletion potential for incineration scenario (CML and TRACI)

Table 7: Summary of the impacts of the two scenarios

Index/LCIA Method	LANDFILL SC.		INCINERATION SC.	
	TRACI	CML	TRACI	CML
GWP (CO ₂ equiv.)	2.63	2.63	3.32	3.32
AP (SO ₂ equiv.)	1.00E-01	1.50E-03	9.04E-02	9.20E-04
EP (P equiv.)	1.36E-03	3.22E-03	1.47E-04	3.72E-04
ODP	1.06E-11	9.98E-12	2.73E-08	2.49E-08

Conclusion

The level of concentration of gases varies from one dumpsite to another and this has adverse effects on man's health living in this environment. The Life Cycle Impact Assessment indices (i.e Global Warming, Acidification, Ozone Depletion and Eutrophication Potentials) using TRACI and CML methods, indicate that landfilling of the wastes poses a lesser burden on the environment, using the ODP index, as compared to incineration. For effective solid waste management in Ilorin East Local Government and its environs, it is recommended that landfilling

method owing to its environmental friendliness should be adopted for waste disposal.

References

- Al-Salem, S.M and Lettieri, P. (2009) "Life Cycle Assessment (LCA) of Municipal Solid Waste Management in the State of Kuwait," *European Journal of Scientific Research*, Vol. 34, No. 3, pp. 395-405. <http://www.eurojournals.com/ejsr.htm>.
- Chen, B., Chen, Z.M., Zhou, Y., Zhou, J.B., and Chen, G.Q. (2009) "Energy as Embodied Energy Based Assessment for Local Sustainability of a Constructed Wetland in Beijing," *Communications in Nonlinear Science and Numerical Simulation*, Vol. 14, No. 2, pp. 622-635. doi:10.1016/j.cnsns.2007.05.035.
- Dahl, U., Lind, C.R., Gorokhova, E., Eklund., B and Breitholz, M. (2009) "Food Quality Effects on Copepod Growth and Development: Implications of Bioassays in Ecotoxicological Testing," *Ecotoxicological and Environmental Safety*, Vol. 72, No. 2, pp. 351-357. doi:10.1016/j.ecoenv.2008.04.008.
- Finnveden, G., Johansson, J., Lind, P., and Moberg, A. (2005). "Life Cycle Assessment of Energy from Solid Waste-Part 1: General Methodology and Results," *Journal of Cleaner Production*, Vol. 13, No. 3, pp. 213-229. doi:10.1016/j.jclepro.2004.02.023.
- GaBi Paper Clip Tutorial, Introduction to LCA and Modelling using GaBi Part 1. PE International (2011).
- Ibrahim, S.I., Awomuti, A.A. and Ajibade, I.T. (2012). Storage and treatment of solid waste as strategy for sustainable environmental development in Ilorin Metropolis, Nigeria. *Advances in Applied Science Research*, 3(2):801-808.
- International Organisation for Standardisation (1997). ISO 14040:1997. Environmental management–Life Cycle Assessment–Principles and Framework.
- ISO, (2006). Environmental Management – Life Cycle Assessment – Principles and Framework (ISO 14040: 2006). European Standard EN ISO 14040. The International Organization for Standardization, Geneva, Switzerland.
- Kwara State Ministry of Environment and Forestry (2013). Unpublished report on waste management in Ilorin.
- Mendes, M.R., Aramaki, T., & Hanaki, K. (2004) Comparison of the environmental impact of incineration and landfilling in Sao Paulo city as determined by LCA Resources. *Conservation and Recycling*, 41, 47-63.
- Moberg, A., Finnveden, G., Johansson, J., and Lind, P. (2005). "Life Cycle Assessment of Energy from Solid Waste-Part 2: Landfilling Compared to Other Treatment Methods," *Journal of Cleaner Production*, Vol. 13, No. 3, pp. 231-240. doi:10.1016/j.jclepro.2004.02.025.
- NPC (2006). Official gazette for 2006 population census. National Population Commission, Abuja.
- Odita, C.O. (1987). "Land use and Solid Waste Generation in Ilorin" M.Sc Project, University of Ilorin, Ilorin, Nigeria.
- Ogola, J. S., Chimuka, L. and Tshivhase S. (2011). Management of Municipal Solid Wastes: A Case Study in Limpopo Province, South Africa, Integrated Waste Management - Volume I, Mr. Sunil Kumar (Ed.), ISBN: 978-953-307-469-6, InTech, Available from: <http://www.intechopen.com/books/integrated-waste-management-volume-i/management-of-municipal-solid-wastes-a-case-study-in-limpopo-province-south-africa>
- Ojoawo, S.O, Agbede, O.A. and Sangodoyin, A.Y (2011) On the physical composition of solid wastes in selected dumpsites of Ogbomosoland, South-Western Nigeria. *Journal of Water Resource and Protection*, U.S.A, 3 (9): 661-666.
- Ojoawo, S.O. and Gbadamosi, A.A. (2013). Application of TRACI and CML Modeling Tools in Life Cycle Impact Assessment of Municipal Wastes. *Journal of Environmental Protection*, Volume 4, Pp 602-617.
- Okeola, O.G. (2014). *Solid Waste Management*, lesson notes, Civil Engineering Services (CVE582), University of Ilorin. Retrieved from <http://www.docshare.tips/civil-engineering-services-58bef3eeb6d87fb0d8b508d>.
- Oluwanisola, R.T (2017) Life Cycle Impact Assessment of Urban Solid Wastes In Ilorin East Local Government Area, Nigeria. An unpublished M.Tech Thesis, Department of Civil Engineering, LAUTECH, p. 58.
- OSRAM (2013). "Environmental Impact Categories | OSRAM", available at: http://www.osram.com/osram_com/sustainability/sustainable-products/life-cycleanalysis/method-and-definitions/environmental-impact-categories/index.jsp (accessed 10 August 2014).
- PE-International, "Introduction to LCA and Modelling Using GaBi Part 1," 2011, pp. 19-23. <http://pe-international.com>
- Priestly, J.J. (1968). *Civilization, Water and Wastes, Chemistry and Industry*, March 23.
- Roy, P., Ijiri, T., Nei, D., Orikasa, T., Okadome, H., Na-kamura, N and Shiina, T. (2009). "Life Cycle Inventory (LCI) of Different Forms of Rice Consumed in Households in Ja-pan," *Journal of Food Engineering*, Vol. 91, No. 1, pp. 49-55. doi:10.1016/j.jfoodeng.2008.08.005.
- U.S. Environmental Protection Agency USEPA (2012). Landfills. <http://www.epa.gov/osw/nonhaz/municipal/landfill.htm> (Last assessed on 12th, August, (2015)).