

# INVENTORY OF ENVIRONMENTAL IMPACTS OF MUNICIPAL SOLID WASTE IN YOLA DUMPSITES USING LIFE CYCLE ANALYSIS

A. H. Abba

Department of Agricultural and Environmental Engineering Modibbo Adama University of  
Technology Yola

Email: [ahmad.halilu@yahoo.com](mailto:ahmad.halilu@yahoo.com); +2349039007413

## ABSTRACT

*Solid waste disposal sites in Yola are characterized by odour, smoke and greenhouse gas emissions causing pollution problems to the environment. The impacts are hardly paid attention to by the communities on one hand and by the authorities on the other. This can lead to serious health hazards to humans and to the environment as well. Taking an inventory of the impacts and advancing them to both the stakeholders will highlight the need of the desired attention to reduce them. Elements considered include leachate (heavy metals, organic loading), emission to the air (methane, other hydrocarbons). Life Cycle Analysis (LCA), an environmental impact assessment tool is used to develop the impacts. ISO 14040 standards were used in selecting the impact category as contained in a typical LCA methodology. Global warming is chosen for example as one impact category with direct implication to the study area. The choice of the impact category is made because emissions contributing to global warming in landfill or dumpsite are high. Inventory results showed that the emissions from the dumpsites (methane and leachates) contribute tremendously to global warming potential. Based on standard leachate data for Nigeria, Pollutant concentrations in leachates such as copper (0.2 mg/L), zinc (0.6 mg/L) and phosphate (0.12 mg/L) were found to fall less than the minimum emissions standard value and hence pose less impact to the environment. While sulphate (SO<sub>4</sub>), total Nitrogen and chemical oxygen demand (COD) contents could be potential primary pollutant of both surface and underground water.*

**Keywords:** Solid waste, Life Cycle Analysis, impact category, global warming, pollution concentration, leachates

## 1 INTRODUCTION

It is widely accepted that the management of solid waste is a global problem. This problem is more pronounced in developing countries such as Nigeria where solid waste management can be said to be in a state of emergency [1]. Urban centres are experiencing an increased rate of environmental deterioration and health hazard as a result of indiscriminate dumping of solid waste [2, 3, 4]. Improper handling has resulted in adverse effects as a result of pollution to land, air and water [5]. Waste collection rates in Nigeria are low, below 50% on average especially, in states of Adamawa, Borno, Gombe Yobe and Taraba. Authorities use dumpsters (communal waste storage facilities) ranging from 8% to 15% waste collection, a rate consistent among communities, IDPs and locals [5]. Local waste authorities share common challenges: increased waste generation from households, lack of funds, lack of equipment, and low waste collection coverage and frequency [4, 6].

The Adamawa State Environmental Protection Agency (ASEPA) is responsible for environmental sanitation and solid waste collection and disposal, particularly in the state capital. It can count on a staff structure of 28 persons. In some areas, dump containers are provided at strategic locations along the streets, wherein waste that is generated from households, commercial businesses, public buildings and recreational areas is directly dumped by members of the general public [7]. ASEPA in turn collects these wastes at intervals or as the situation may demand and transports the waste to an open space approximately 3 km from the city centre. Field survey reveals that there are 36 waste depots and 3 open dump sites (transfer station) in Yola. The purpose of the depots and transfer stations/sites is to compress and separate waste to ensure efficient transport and a sufficient recycling rate [8]. This objective has not been achieved as there are no waste compressing machines nor recycling plants/equipments at these locations. Above all, there is no single landfill in Yola. Figure 1 shows waste deposited openly in a street of densely populated Bmamoï ward in Yola town. The solid waste is seen to blockade the whole street.



Figure 1. Waste openly deposited along a street of Mbamoï

It is reported that improper treatment or disposal of waste, such as open-air burning can constitute a significant source of pollution to the environment through the release of heavy metals, such as lead, cadmium, chromium, mercury [5]. The open and unsafe dumpsites contain domestic, municipal, industrial and medical wastes; a common practice in most cities in developing countries [9, 10]. These dumpsites have become feeding ground for diseases breeding animals especially rats, birds, and stray animals, thereby contributing greatly to their nourishment and growth [11]. Waste pollutants can decompose and increase in volume if exposed to rainfall and have the potential to pollute soil and ground water [12].

## 1.2 Life Cycle Analysis (LCA)

LCA is defined as a technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environment impacts associated with those inputs and outputs; and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study [13]. It therefore, constitutes a methodology that considers the entire life cycle of products or services – from cradle to grave (from raw material acquisition through production, use and disposal). The concept (LCA) is currently being studied and used in several countries to evaluate

treatment options for specific waste fractions. Thus, LCA is a holistic assessment methodology and a valuable tool to document the environmental consideration that need to be part of decision making toward sustainability [3]. While environmental consequences of products, services, processes or systems are determined, their effects in terms of material consumption, energy usage and environmental emission on human and eco-system during the life cycle of each contributing actor is as well determined.

There are two LCA standards created by the International Organization for Standardization (ISO): the ISO 14040 and ISO 14044 [14]. According to the ISO standards on LCA, it can assist in:

- i. Identifying opportunities to improve the environmental aspects of products at various points in their life cycle;
- ii, Decision making in industry, governmental or non-governmental organizations (e.g. strategic planning, priority setting, product and process design or redesign);
- iii, Selection of relevant indicators of environmental performance, including measurement techniques; and
- iv, Marketing (e.g., an environmental claim, eco-labeling scheme or environmental product declarations).

Life Cycle Assessments are conducted according to the ISO 14040 and ISO 14044 standards. LCAs consist of four steps, as shown below:

1. Goal and Scope Definition
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

### **1.3 Goal and Scope Definition**

According to the ISO 14040 standard the first phase of an LCA is the definition of the goal and scope. In this step all general decisions for setting up the LCA system are made. The goal and scope should be defined clearly and consistently with the intended application.

#### **1.3.1 Goal**

In the goal definition, the following points need to be determined:

The *intended application* of an LCA study - An LCA can be used for many different applications such as marketing, product development, product improvement, strategic planning, etc.

The *purpose* of an LCA study – The purpose of an LCA can also vary greatly and will dictate the scope of the study. If the study is intended to be published, the scope will be more comprehensive and include a greater data collection effort and a formalized review process. If the LCA will be used internally, no critical review is necessary; the scope will be dictated by the company's objective and their access to data.

The *intended audience* of an LCA report – The audience can be the shareholders, executives, engineers, consumers, etc. Depending on the client's objectives.

Usage for *comparative* analysis – If the LCA results are intended to be used for comparative reasons

must be determined. If they are going to be published a critical review is obligatory.

### 1.3.2 Scope

During the scope definition the product or process system under study is characterized, all assumptions are detailed and the methodology used to set up the product system is defined.

Life Cycle Inventory

### 1.4 Life Cycle Inventory

The Inventory Analysis is the LCA phase that involves the compilation and quantification of inputs and outputs for a given product system throughout its life cycle or for single processes. The inventory analysis includes data collection and the compilation of the data in an Life Cycle Inventory (LCI) table.

### 1.5 Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) identifies and evaluates the amount and significance of the potential environmental impacts arising from the LCI. The inputs and outputs are first assigned to impact categories and their potential impacts quantified according to characterization factors. Figure 2 shows the conversion from emissions to impact potentials via *classification* and *characterization*.

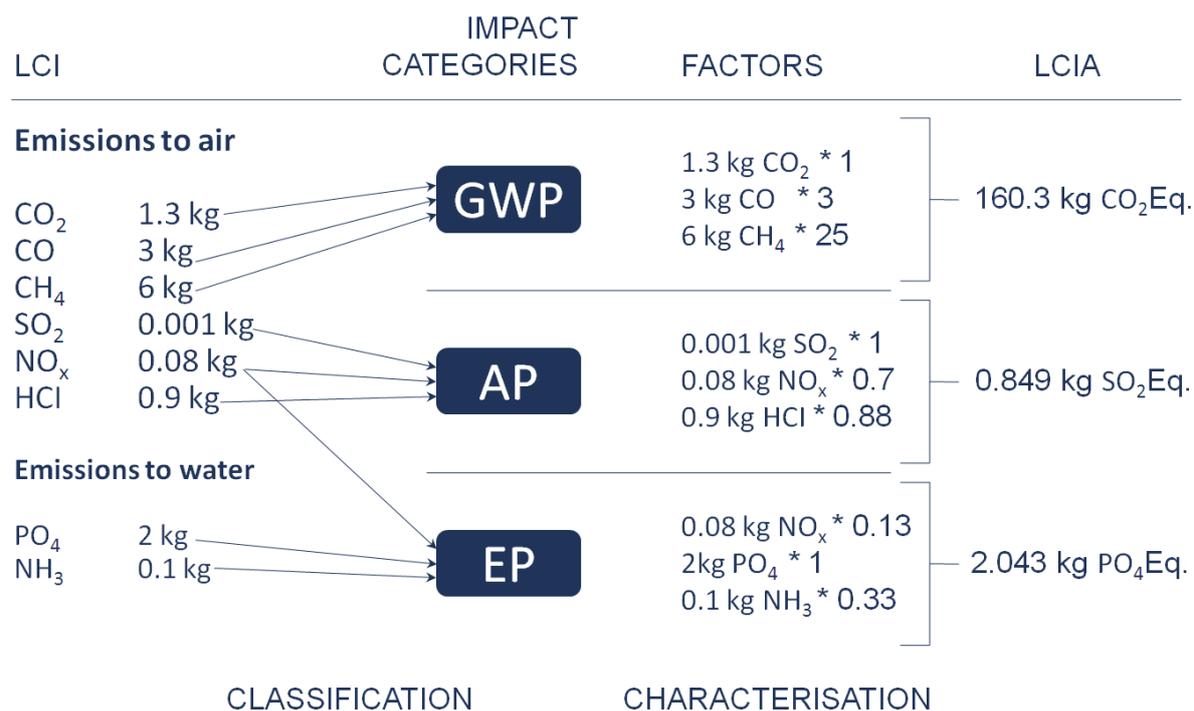


Figure 2. Classification and Characterization [14]

Within the scope of a study certain elements are defined for the LCIA. Mandatory elements include the selection of relevant impact categories, classification and characterization. The optional elements of the study are normalization, grouping and weighting.

#### 1.5.1 Impact Assessment Methods

There are different methods that can be used to perform a Life Cycle Impact Assessment.

These methods are continuously researched and developed by different scientific groups based on different methodologies. This research work does not explain the development of the different methods, but it does describe them. In life cycle impact assessment methods, such as TRACI or CML, two main approaches are used to classify and characterize environmental impacts: the problem-oriented approach (mid point) and the damage-oriented approach (end point) [14]. The so-called CML method is the methodology of the Centre for Environmental Studies (CML) of the University of Leiden and focuses on a series of environmental impact categories expressed in terms of emissions to the environment. The CML method includes classification, characterization, and normalization. For the two methods, refer to Table 1. The impact categories for the global warming potential and ozone layer depletion are based on IPCC factors. Further information is available at the Centre for Environmental Studies (CML), University of Leiden. Another method is the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts, called TRACI. This problem-oriented method is developed by the U.S. Environmental Protection Agency (EPA) and is primarily used in the US.

Table 1. Comparison of the TRACI and CML Methods [14]

CML	Unit	TRACI	Unit
Global Warming Potential (GWP 100 Years)	Kg CO <sub>2</sub> -Equiv	Global Warming Air	Kg CO <sub>2</sub> -Equiv
Ozone Layer Depletion (ODP, steady state)	Kg R11-Equiv	Ozone Depletion Air	Kg CFC11-Equiv
Acidification Potential (AP)	Kg SO <sub>2</sub> -Equiv	Acidification Air	Mol H <sup>+</sup> -Equiv
Eutrophication Potential (EP)	Kg phosphate-Equiv	Eutrophication Air Eutrophication Water	Kg N-Equiv
Photochem Ozone Creation Potential (POCP)	Kg Ethene-Equiv	Smog Air	Kg Nox-Equiv
Human Toxicity Potential (HTP inf.) Terrestrial Ecotoxicity Potential (TETP inf.)	Kg DCB-Equiv	Human Health Cancer Air Human Health Cancer Water	Kg Benzene Equiv

### 1.5.2 Selection of Impact Categories

A number of impact categories are typically chosen as the focus of an LCA study. This choice of impact categories depends on the goal of the study. The selected impact categories should cover the environmental effects of the analyzed product system. The choice of impact categories and the choice of the impact assessment method should be documented in the goal and scope definition.

### 1.5.6 Classification

The results of the Life Cycle Inventory phase include many different emissions. After the relevant impact categories are selected, the LCI results are assigned to one or more impact categories. If substances contribute to more than one impact category, they must be classified as

contributors to all relevant categories. For example, CO<sub>2</sub> and CH<sub>4</sub> are both assigned to the impact category “global warming potential”. NO<sub>x</sub> emissions can be classified to contribute to both eutrophication and acidification and so the total flow will be fully assigned to both of these two categories. On the other hand, SO<sub>2</sub> is apportioned between the impact categories of human health and acidification. Human health and acidification are parallel mechanisms and so the flow is allocated between the two impact categories.

### 1.5.7 Characterization

Characterization describes and quantifies the environmental impact of the analyzed product system. After assigning the LCI results to the impact categories, characterization factors have to be applied to the relevant quantities. The characterization factors are included in the selected impact category methods like CML or TRACI [14]. Results of the LCI are converted into reference units using characterization factors. For example, the reference substance for the impact category “global warming potential” is CO<sub>2</sub> and the reference unit is defined as “kg CO<sub>2</sub>-equivalent”. All emissions that contribute to global warming are converted to kg CO<sub>2</sub>-equivalents according to the relevant characterization factor. Each emission has its own characterization factor.

## 2 METHODOLOGY

### 2.1 Developing Impacts for the Dumpsite Life Cycle Assessment (LCA) in the Study Area

Landfilling is generally of uncontrolled dumpsites and engineered sanitary landfill with leachate treatment and landfill gas capturing for energy complementing purposes [6]. Major inputs of a sanitary landfill include MSW, energy inputs (fuel and electricity) and landfill construction material inputs such as HPDE liner, clay, top soil and gravel. However, inputs for the construction of the landfill will not be used in the current impacts inventory. Outputs include leachate (heavy metals, organic loading), emission to the air (methane, other hydrocarbons). Organic matter Carbon dioxide emitted is biogenic and not considered for the landfill or dumpsite LCA output as well. Thus methane from gas utilisation emission and leachate generation are the main focus. Additional data is obtained from literature, dump site visit information. For energy consumption, fuel (diesel) and electricity consumption during the operation (consisting of estimated energy consumed in terms of kWh of electricity as well as the amount of fuel (diesel) for depositing one tone of solid waste in the dumpsite).

Information gathered from the case study site (Yola) indicated that there are vehicles used for packing and transporting solid waste to dump sites. The amount of fuel consumption in terms of diesel/gasoline is estimated to be 0.7 of a Litre to 1Litre to deposit 1tonne of MSW (adopted from landfill fuel consumption of [15; 16], a typical landfill fuel consumption), since data for fuel used by the heavy duty in Yola is not readily available now. This consist of the amount of diesel consumed by transport/heavy duty machineries used for transport, placing, spreading, compacting and providing daily soil cover for 1 ton of MSW in the dumpsite. The electricity consumed is from leachate treatment plant and assumed as adopted from the works of [15, 16]. The energy input is therefore 665kWh/t for 1 ton of typical MSW. Other assumptions relating to the emissions in the landfill model include: 1percent of carbon content in biodegradable waste is emitted in the form of COD in leachate; where 1g of carbon is assumed as equivalent to 3g of COD. 50 percent of the nitrogen content in biodegradable waste is assumed to be emitted as total-nitrogen within the leachate, 3 percent of emitted sulfur as H<sub>2</sub>S and 1 percent to the leachate. Leachate treatment procedures are also based on conventional leachate treatments; thus used leachate data for Yola as

observed by [15] conform to these standards. The estimation of the quantity of landfill gas generated can be conventionally computed by the use of triangular gas production model in [6].

However, the use of this model requires data from landfill or health authorities. There is no such data for Yola hence adopted data had to be used [15]. Leachate amount generated, normally characterized by high organic and inorganic compounds, toxic substances and high vulnerability [17], can be estimated using water balance method [12]. In the current work, data on the Yola dump sites leachate is scarce; hence data adopted from [18] is hereby used. Missing data is filled by data from similar scenarios elsewhere such as those in the works of [15: 16; 18, 19]. Table 2 present emissions to air, water and their allocated impacts equivalence. This characterization procedure is inbuilt in GaBi for all impacts categories (Refer to Table 2).

Table 2. Inventory for landfilling 1 tonne of MSW

<b>Inputs</b>	<b>Quantity</b>
Energy (kWh)	$665^c + 7.7\text{MJ}$ (2.44 kWh) <sup>c</sup>
Diesel (l)	$1^d + 10.4^e$
<b>Outputs</b>	
<b>Emissions to air</b>	
Carbon dioxide (fossil) (kg)	$2^c + 19.242^e$
Hydrogen chloride (g)	$6^c$
Hydrogen fluoride (g)	$1^c$
Hydrogen sulfide (g)	$18^c$
Methane (g)	$37849.5^a$
Nitrogen oxide (g)	$41^c + 209^e$
Nitrous oxide (g)	$2^c$
Sulfur dioxide (g)	$32^c + 6.1^e$
Carbon monoxide (g)	$23.6^e$
Particles (g)	$7.4^e$
<b>Emissions to water</b>	
Total nitrogen (g)	$1003^c$ from 1 tonne of MSW
Hg	$1.40\text{mg/kg}^b$
Cd	$0.06\text{mg/kg}^b$
Fe	$35.1\text{mg/kg}^b$
Mg	$1.60\text{mg/kg}^b$
Zn	$1.33\text{mg/kg}^b$

<sup>a</sup>Estimated methane gas for Yola (landfill data form [5], [15], [16], [18]. and mostly emitted during collection

The values in the above table were mostly computed using GaBi data base, software used for LCA modeling (Table 3).

Table 3. Impact categories, emissions, and equivalent factors [15]

Global warming (kg CO <sub>2</sub> )		Acidification (g SO <sub>2</sub> )		Nutrient enrichment (g NO <sub>3</sub> )	
Emissions	Equivalency factor	Emissions	Equivalency factor	Emissions	Equivalency factor
CO <sub>2</sub> <sup>a</sup>	1	SO <sub>2</sub> <sup>a</sup>	1.00	NO <sub>2</sub> <sup>a</sup>	1.35
CH <sub>4</sub> <sup>a</sup>	25	NO <sub>2</sub> <sup>a</sup>	0.70	NH <sub>3</sub> <sup>a</sup>	4.43
N <sub>2</sub> O <sup>a</sup>	320	H <sub>2</sub> S <sup>a</sup>	1.88	N <sup>b</sup>	3.64
-	-	HF <sup>a</sup>	1.60	P <sup>b</sup>	32.03
-	-	HCl <sup>a</sup>	0.88	-	-
-	-	NH <sub>3</sub> <sup>a</sup>	1.88	-	-

<sup>a</sup>Emissions to air, <sup>b</sup>Emissions to water

A complete model inputs and outputs for Yola Dumpsite impacts to land, water and air are shown in Table 4.

Table 4. Summary of input and output inventory for the disposal of 1 t of MSW of an average composition in the Dumpsite scenarios

Inputs	Landfilling
Energy (kWh)	667.44
Diesel (l)	11.4
Heat energy (MJ)	-
Lube oil (l)	-
Moist air (kg)	-
Process water (kg)	-
Limestone (kg)	-
NH <sub>3</sub> (kg)	-
NaOH (kg)	-
Activated coke (kg)	-
<b>Outputs</b>	
<b>Emissions to air</b>	
Carbon dioxide (fossil) (kg)	21.24
Hydrogen chloride (g)	6
Hydrogen fluoride (g)	1
Hydrogen sulfide (g)	18
Methane (g)	21500

Ammonia NH <sub>3</sub>	-
Nitrogen oxide (g)	250
Nitrous oxide (g)	2
Sulfur dioxide (g)	38.1
Carbon monoxide (g)	23.6
Particles including VOCs (g)	7.4
Total nitrogen (g)	1003
Hg	1.40 mg/kg
Cd	0,06 mg/kg
Fe	35.1 mg/kg
Mg	1.60 mg/kg
Zn	1.33 mg/kg
Cu	-

## 2.2 Selection of Impacts Categories

Environmental impacts categories are effect derived from the activities of human or natural sources based on their effects to the environment such as global warming potential, human health potential, and acidification potential and so on. Global warming is chosen as impact category for the LCA of the study. The choice of the impact category is made because emissions contributing to global warming in landfill or dumpsite are high. The contributing elements are mainly CO<sub>2</sub>, CH<sub>4</sub>, No and traces of H<sub>2</sub>S, CO, HCl, SO<sub>2</sub>, HF and NH<sub>3</sub>. [16, 19], and heavy metals released to atmosphere mostly Cadmium (Cd), the most volatile [19]. While Ferrous (Fe), Zinc (Zn), COD are from Leachates. The method adopted for the study for the amount of methane was estimated based on the IPCC, 2006 methodology in the GaBi software. Air emissions in the dumpsites are dominated by methane constituting about 50-70%. CO<sub>2</sub> constitutes 30-50%, while the remaining comprises: H<sub>2</sub>S, CO, HCl, SO<sub>2</sub>, HF and NH<sub>3</sub>. [16, 19] and heavy metals released to atmosphere mostly Cadmium (Cd), the most volatiles [19]. While Ferrous (Fe), Zinc (Zn), Manganese (Mn) are released through leachates. It is assumed that the quantities are much below emission standards and hence are insignificant in the LCI. During the combustion of natural gas and diesel for landfill electricity and machinery usage, most expected emissions consist of CO<sub>2</sub>, CO, NO<sub>x</sub>, SO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and dioxins.

## 3 DISCUSSION

### 3.1 Life Cycle Assessment of (LCA) of Yola Dumpsite

It is observed that the energy input to the dumpsites is amounting to 667.44 (Table 4). In a typical dumpsite of African setting, this may seem to be high. However, this is expected because of its demand on the landfill/ dumpsites. In a typical engineered landfill, electricity is highly utilized for leachate treatments and other light activities such as lightning, weighing and storage activities. Another aspect that requires energy utilization is the collection and transportation of waste (11.4litres of diesel, Table 4). This is the fuel used by trucks and heavy duty machine to landfill 1 ton of MSW. What the LCA is presenting here is the inventory of power requirements of activities conducted in the

dumpsites or an engineered landfill as the case may be. These are one of the most important inputs in a typical dumpsite LCA inventory.

The next aspect is the output inventory. Inventory of dumpsite/landfill involve two chief emissions. Those to air (mainly emitted in form of gases) and those released to the environment (mainly leachates and other elements). In the current study, these emissions are presented in Table 4 as well. Chief air emissions are carbon dioxide and methane as noted earlier. Carbon dioxide is shown to be about 21.24 kilograms. It is this much because of the burning of fossil fuel from the activities of trucks, heavy duty and electricity usage. Global warming potential is measured based the amount of the carbon dioxide released to the environment. In the current study, global warming potential is expected to manifest. This is typical of releases from a site where the gas is not captured as observed by a lot of authors including [5, 13, 16, 19) among others. Meanwhile, Emission from diesel oil combustion of trucks and bull dozers are estimated using the coefficient factors for combustion of diesel oil reported by [15].

The amount of methane emitted is high 21500 g/ton which could highly contribute to the global warming. This value is 25 times the amount of carbon dioxide in terms of contributing to global warming potential as reported by several authors [5, 14, 20]. The value is also expected and could be due to the following reasons:

- i. Free release of the gas to the atmosphere.
- ii. Major part of the waste is biodegradable waste (food, paper, yard waste and wood) which consists of 65.43 percent of the total waste.
- iii. Engineered landfill is not used hence gas capturing for utilization is not practiced.

Other emissions such as Nitrogen oxide and Sulfur dioxide have minimal effects to the environment. The LCA also showed the remaining emissions comprising HCL, HF, NO and H<sub>2</sub>S are insignificant as shown in the Table.

Emissions to water from the dumpsites are also presented. Total Nitrogen, sulphate and other emissions in the form of chemical oxygen demand (COD) are emitted within the leachate and they are primary pollutant of both surface and underground water. According to standard leachate data [8], the standard for copper is 2.3 – 17.3 mg/l and sulphate ranges from 30.2 – 946.3 mg/L. Zinc and phosphate were reported to have standard ranges of 7.7 – 129.8 mg/L respectively. There were no standard for ammonia and iron. Based on standard leachate data for Nigerian from [18], copper (0.2 mg/L), zinc (0.6 mg/L) and phosphate (0.12 mg/L) were found to fall less than the minimum value standard and therefore have less impact to the environment. The LCA inventory also showed that sulphate (45 mg/L) has impact to the environment since it falls within the range of the standard

#### **4 CONCLUSIONS**

Inventory of environmental impacts of the dumpsites in Yola town was conducted using life cycle analysis. A procedure for putting the inventory was developed and presented. Carbon dioxide, methane and total nitrogen were found high. Carbon dioxide and methane were seen to pose global warming potential. This is as a result of major part of the waste is biodegradable waste (food, paper, yard waste and wood) which consists of (65.43%) and also engineered landfill is not used hence gas capturing for utilization is not practiced. Based on standard leachate data for Nigeria, copper (Cu), zinc (Zn) and phosphate were found to fall less than the minimum value standard while sulphate

(SO<sub>4</sub>), total Nitrogen and other emissions in the form of chemical oxygen demand (COD) are emitted from the leachate and they are primary pollutant of both surface and underground water.

## REFERENCES

1. Kadafa, A.A. Idris, N.M. Walters, A. and Abba, A.H. (2018). A Review of Waste Management Assessment Methods. *NSUK Journal of Environmental Management & Sustainability*, vol. 1, no. 1.
2. Amasuomo, E., Omagbemi, J.A.T. & Hasnain, S.A.,( 2015). Analysis of Public Participation in Sustainable Waste Management Practice in Abuja, Nigeria. *Journal of Environmental Management and Sustainable Development*, vol. 4, no. 1, pp. 180-193.
3. Ahmad Halilu Abbaa, Zainura Zainon Noora,, Rafiu O. Yusuf, Mohd Fadhil M.D. Dinb, Mohd Ariffin Abu Hassana (2013). Assessing environmental impacts of municipal solid waste of Johor by analytical hierarchy process. *Resources, Conservation and Recycling*, vol. 73, pp. 188– 196.
4. Imam A, Mohammed B, Wilson DC, Cheeseman CR. Solid waste management in Abuja, Nigeria. *Waste Management* 2008; vol. 28, pp. 468–72.
5. Ahmad Halilu Abba, Adamu Saleh, Ahmadu Umaru Babayi and A.A. Kadafa (2018). Impact Assessment of Clinical Waste on Yola North Soils, Adamawa State. *NSUK Journal of Environmental Management & Sustainability*. vol. 1, no. 1.
- 6/ Tchobanoglous, G., Theisen, H. and Vigil, S. (1993) *Integrated solid waste management: Engineering principles and management issues*. McGraw Hills. International Edition Singapore. ISBN 00728654.
7. Ishaku, H.T., Sahabo, A.A. & Yerima, B.D.,( 2015). Assessment of Municipal Solid Waste Management Practices in Jimeta-Yola Adamawa State Nigeria. *Open Journal of Water Pollution and Treatment*, vol. 2, no. 1, pp.1-7.
8. Ahmad Halilu Abba (2014). Assessment of Municipal Solid Waste Disposal Options Using Analytical Hierarchy Process and Life Cycle Analysis. PhD Thesis, Submitted to the Faculty of Chemical Engineering, Universiti Teknologi Malaysia.
9. World Health Organization (WHO) (2016). *Waste and human health: Evidence and needs*. WHO Meeting Report 5–6 November 2015 Bonn, Germany.
10. Goddu, V. K., Duvvuri, K., and Bakki, V. K. (2007). A critical analysis of healthcare waste management in developed and developing countries. Case studies from India and England. *Journal of Waste Management*, vol. 7, no. 2, pp. 134-141.
11. Clarke, J. (2008). Clinical waste in developing countries. *Journal of Nepal Health Research Council*, vol. 28, no. 1, pp. 44-67.
12. Adewuyi, G. O. and Opasina, M. A. (2010). Physicochemical and heavy metals assessments of leachates from aperiodic abandoned dumpsite in Ibadan City. *Journal of Waste Management*, vol. 7, no. 3, pp. 89-97.
13. Siti Nadzirah Othman, Zainura Zainon Noor, Ahmad Halilu Abba, Rafiu O. Yusuf, Mohd. Ariffin Abu Hassan(2013). Review on life cycle assessment of integrated solid waste management in some Asian countries. *Journal of Cleaner Production*, vol. 41, pp. 251-262.

14. PE-International (2011). *GaBi Paper Clip Tutorial: Handbook for Life Cycle Assessment (LCA) Using the GaBi Software*. PE INTERNATIONAL GaBi Software University of Stuttgart.
- 15./ Mendes, M.R., Toshiya, A. & Keisuke, H.(, 2004). Comparison of the Environmental Impact of Incineration and Landfilling in Sao Paulo City as Determined by Life Cycle Assessment. *Resources Conservation and Recycling*, vol. 41, no. 1, pp.47-63.
16. Hong, R. J., Wang, G. F., Guo, R. Z., Cheng, X., Liu, Q., Zhang, P. J. and Qian, G. R. (2006). Life Cycle Assessment of BMT-based Integrated Municipal Solid Waste Management: Case Study in Pudong, China. *Resources, Conservation and Recycling*, vol. 49, no. 2, pp. 129-146.
17. Saheri, S., Masoud, A. M., Noor, E. A. B., Noor, Z. B. M. and Begun, R. A. (2012). Life Cycle Assessment for Solid Waste Disposal Options in Malaysia. *Pol. J. Environ. Stud.* Vol. 21, no. 5, pp. 1377-1382.
18. Ogundipe, F.O. & Jimoh, O.D.,( 2015). Life Cycle Assessment of Municipal Solid Waste Management in Minna, Niger State, Nigeria. *Environmental Resources*, vol. 9, no. 4, pp. 1305-14.
19. Cherubini, F., Bargigli, S. and Ulgiati, S. (2009). Life Cycle Assessment (LCA) of Waste Management Strategies: Landfilling, Sorting Plant and Incineration. *Energy*. 34(12), 2116-2123
20. Olmo Forni, Ben Grundy, Martin Bjerregaard (2016). North – East Nigeria Waste & Debris Assessment Final Report UNDP Nigeria.