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Life Cycle Assessment of Municipal Solid Waste Management in Minna, Niger State, Nigeria

Ogundipe F.O.[1*] and Jimoh O.D.[2]

[1]National Water Quality Reference Laboratory Minna, Federal Ministry of Water Resources, Nigeria
[2]Department of Civil Engineering, Federal University of Technology, Minna, Nigeria

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ABSTRACT: Waste is a by-product of our daily activities, which poses a serious threat to societies all over the world. In this study, life cycle assessment (LCA) methodology was used to determine municipal solid waste (MSW) management strategy for Minna, Niger State, Nigeria. Three scenarios were modelled as alternatives to the current waste management system in Minna. The current waste management in Minna city was developed in this research work as baseline scenario. The baseline scenario was the existing open dumping waste management strategy operating in Minna presently and this was used as the reference and chosen as the benchmark in which all the three modeled scenarios were measured and compared. One tone of municipal solid waste of Minna was selected as the functional unit. The life cycle inventory analysis was carried out with the aid of SimaPro 7.2 educational software. The environmental impact parameters dealt with were: carcinogen, ecotoxicity, acidification, eutrophication and global warming. In the context of the five impact parameters considered, scenario 1 is the best and most favourable alternative in term of ecotoxicity, eutrophication, acidification, carcinogen and global warming potentials in Minna city. This research work showed that modeled scenario 1 had a greatest reduction in global warming, carcinogen, ecotoxicity and acidification potentials in Minna city.

Key words: Solid Waste, Minna City, Nigeria, Management, Life Cycle

INTRODUCTION

We live in a changing world. One driving force for these changes is the threat of global climate change caused by increasing concentrations of carbon dioxide (CO_2), methane (CH_4) and other greenhouse gases (Agunwamba,1998). Solid waste management in Minna remains an environmental problem that is becoming more complex on daily basis (NISEPA, 2010). Minna generates about 90 tons per day, equivalent to 32,850 tonnes/yr. Waste generation falls into the national average of 0.4 to 0.6 kg/capital/day (NISEPA, 2010). Waste in Minna generally has high food content because of the predominance of agricultural activities (NISEPA, 2010). The aim of this project is to select a waste management system for Minna city by evaluating three alternative scenarios to the existing waste management system. The specific objectives are to identify the overall environmental burdens of solid waste management in Minna, to appraise three solid waste scenarios and assess the potential environmental impacts of each scenario using SimaPro 7.2 educational software and to identify the solid waste management system for Minna city using environmental indices. Life cycle assessment (LCA) is a useful tool to identify the overall environmental burdens and to assess the potential environmental impacts of municipal solid waste (MSW) management systems (Emilia and Luizm, 2006; Al – Salem and Lettieri, 2009; Audsley *et al.*, 1994; Chalita and Shabbir, 2004; Christensen *et al.*, 2007; Dean and Gary, 1996; Doka, 2003; Finnveden *et al.*, 1995; Finnveden *et al.*, 2000; Janus, 2005; McDougall *et al*, 2001). In this study, waste management alternatives are investigated from only an environmental point of view. Three different scenarios of Municipal Solid Waste Management System (MSWMS) that include different municipal solid waste processing are developed and then compared with baseline scenario in respect to their environmental burdens/benefits. In other to achieve environmental sustainability, MSWMS are compared in a LCA context. SimaPro 7.2 educational software is run to perform life cycle assessment (LCA) study in this project (Mark *et al.*, 2008; Mark and Michiel, 2007; Mark and Renilde, 2001; Pre Consultant, 2008a; Buwal 250 Library, 2004; Finnveden and Moberg, 2009; Earth Shift, 2011). The

*Corresponding author E-mail: ogundipefelixo@yahoo.com

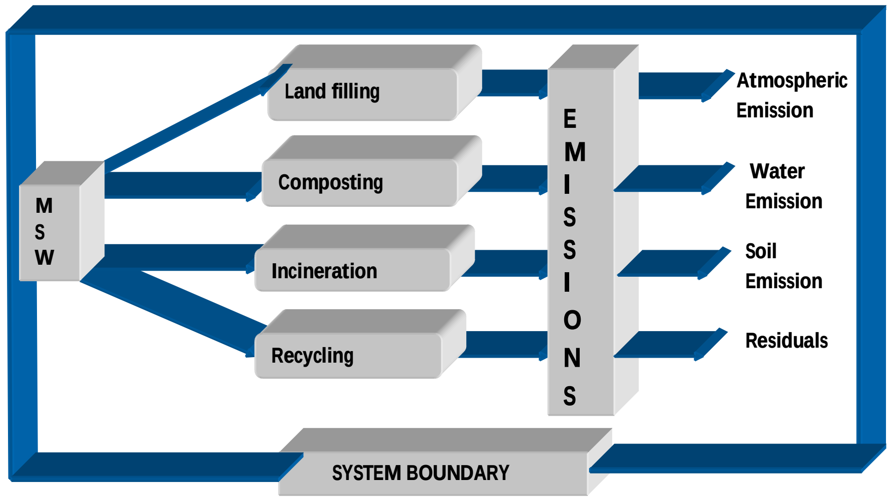

Fig. 1. System Boundary for the Solid Waste Treatment Alternatives

system of the study includes waste treatment alternatives (landfill, composting, incineration and recycling). Fig. 1 is showing the system boundary for the solid waste treatment alternatives.

MATERIALS & METHODS

Life cycle inventory (LCI) data for this study was collected through laboratory determination of solid waste composition, leachate analysis and personal communication with the residents and staff of Niger State Environmental Protection Agency in Minna. Solid wastes were collected in five different locations in October, 2010 and analyzed to get percent composition of MSW in Minna. The peak of rainy season in Minna is September, and after that rain begins to recede in October. Thus concentrated leachate sample is expected to be high in October (Personal Communication with Sub municipalities). Five locations were strategically chosen and they are as follows; (1). Federal university of Technology (FUT) Bosso Campus, opposite M Block, (2). Government Reserved Area, (3). Abdusallam Motor Pack, (4). FUT Main Campus, Gidan Kwano, (5). Minna city main dumping site, Kampala Village.

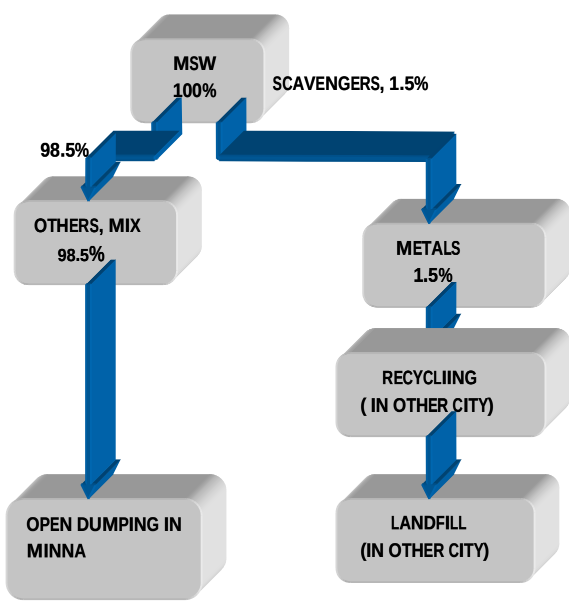

Fig. 2. Flow Chart for Baseline Scenario

One litre of leachate sample was collected from Minna city main dump site, Kampala Village, along Zungeru road in 1 litre polyethylene container that had been cleaned with chromic acid and rinsed with distilled water (APHA, 1995; Adams, 1990; Chapman and Kimstach, 1992; Bertram and Balance, 1996). The leachate sampling expedition was performed in the month of October 2010. Leachate analysis sample was analysed in the laboratory and the data were inputted into the alternative scenarios developed as emission to soil and air under waste treatment processes of SimaPro 7.2 educational software.

Trucks are used to collect wastes in plastic bags, which have been dumped by residents at selected points on the streets in Minna. The wastes are transported by the trucks to unregulated dump site. The unregulated dump site is an open area where the recyclable components (only metals) of the waste are partially separated manually under unhygienic conditions by scavengers and piled up there waiting to be transported to other cities for recycling (Agunwamba, 1998; Ogwueleka, 2009b).

Baseline Scenario has 1.5% Scavenging and 98.5% Open dumping. The baseline scenario was the existing open dumping waste management strategy operating in Minna presently and this was used as the reference against which modeled scenarios 1, 2 and 3 were measured. Fig. 2 is showing flow chart for the baseline scenario.

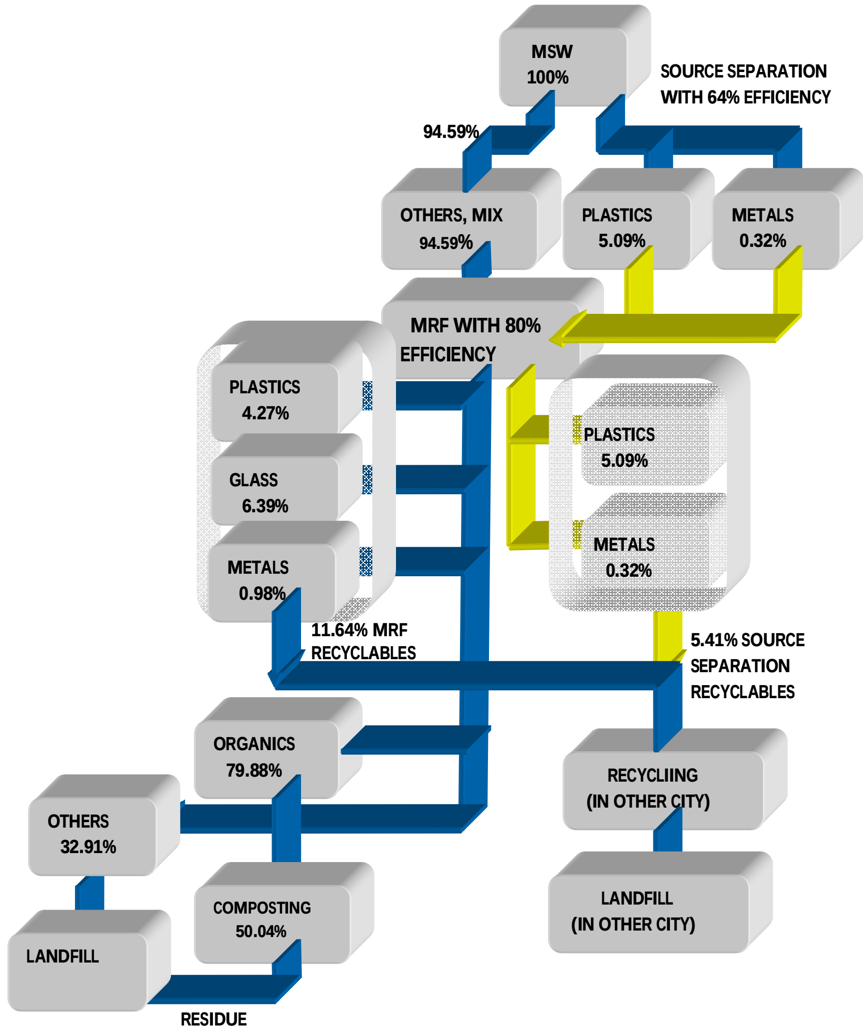

Fig. 3. Flow Chart for Scenario 1

17.05% Recycling (9.36% plastics, 1.30% metals and 6.39% glass), 50.04% Compost and 32.91% Landfill were considered for Scenario 1 in solid waste management in Minna. The Scenario emphasizes the recovery of the biologically degradable fraction (Jones *et al*, 1987; Banar M. *et al.*, 2008; Al – Salem and Lettieri, 2009). Fig. 3 is showing flow chart for scenario 1.

17.05% Recycling (9.36% plastics, 1.30% metals and 6.39% glass) and 82.95% incineration were considered in scenario 2. An incineration process was added to the system instead of a composting facility (Manar M. *et al*, 2008; Al – Salem and Lettieri, 2009; U.S Army Corps of Engineer, 2004). Fig. 4 is showing flow chart for scenario 2.

17.05% Recycling (9.36% plastics, 1.30% metals and 6.39% glass) and 82.95% landfill were considered for scenario 3 in solid waste management in Minna. Fig. 5 is showing flow chart for scenario 3.

The description of the modelled scenarios along with baseline scenario is summarized in Table 1.

Impact 2002+ was chosen from SimaPro 7.2 educational software for environmental analysis of solid waste in Minna city and the characterisation results per each impact category/parameter considered were presented both inform of tables and graphs. The impact parameters that are of significance to this project were selected. Carcinogen was selected in other to assess damage to human health, global warming was selected based on climate change, acidification, ecotoxicity and eutrophication were selected to assess damage to ecosystem. The geographic scope of these indicators/parameters selected was at local scale (Pre Consultant, 2008b). Five impact categories were selected as the environmental indices for Minna city and were subsequently analyzed by impact 2002+ method. The five impact categories/parameters investigated were: carcinogen, eutrophication, acidification, ecotoxicity and global warming.

The results of scenario 1, scenario 2 and scenario 3 were compared with baseline scenario. The percent

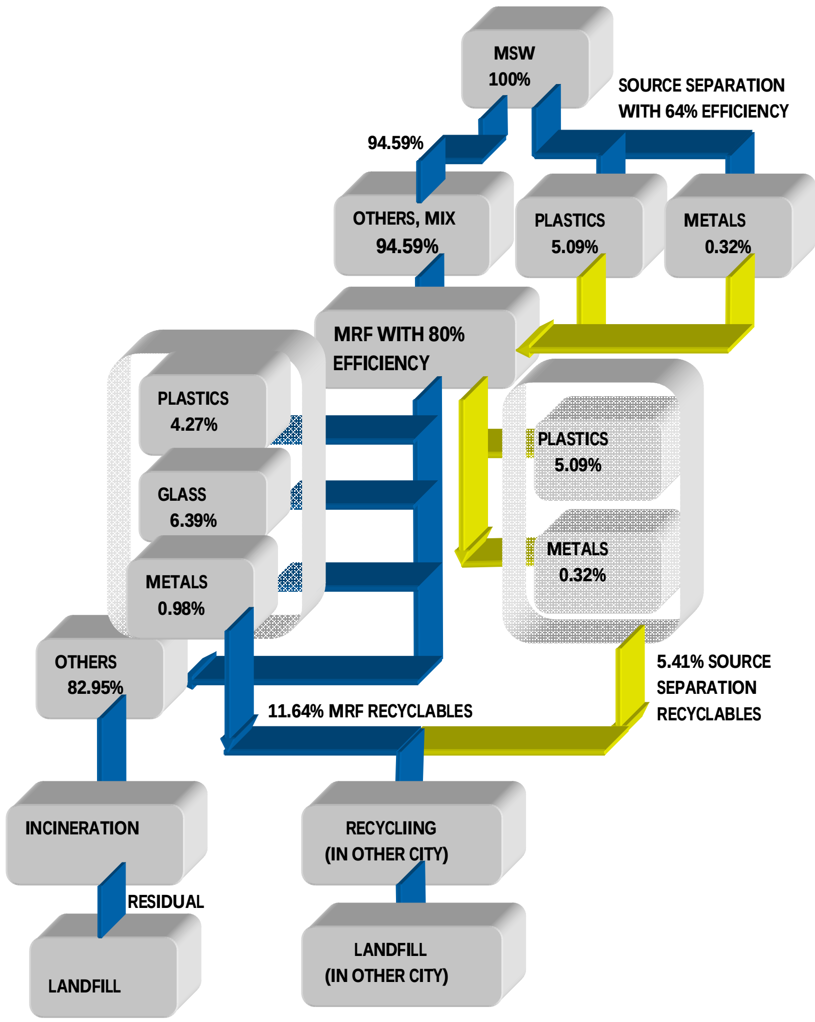

Fig. 4. Flow Chart for Scenario 2

reduction of the modeled scenario from baseline scenario was calculated from characterisation analysis results using the following formula:

$$\% \text{ Reduction} = \frac{\text{Modeled Scenario} - \text{Baseline Scenario}}{\text{Baseline Scenario}} \times 100\%$$

RESULTS & DISCUSSION

The mean percent composition of solid waste in Minna is presented in Table 2. Food waste (46.85%) had the highest mean percent composition.

Chemical formula of compostable waste in Minna with sulphur as a base was formulated and written as CH_4O_4NPS. Table 3 shows the estimated weight of compostable elements while Table 4 shows the normalized mole ratio of the compound.

Table 5 shows the estimated amount of MSW generated per each component from all residential area in Minna from 2011 to 2015. The amount of waste generated in Minna in 2010 was 32,850tonnes while the projected 2015 waste generated for Minna is 36,163tonnes. The growth rate adopted for estimating the population was 2% (CIA, 2011; NISEPA, 2010; NDHS, 2003; MapXL, 2011).

Table 6 shows the estimated amount of municipal solid waste landfilled, composted, incinerated and recycled at a glance in each of the developed scenarios. The amount managed for baseline scenario is also presented in the table. Input and recycled amounts of waste were similar (32,850 tonnes for year 2010).

Leachate data contributing to ecotoxicity, acidification, eutrophication and carcinogen in modelled scenarios are presented in table 7.

The results of the characterisation analysis for the baseline and the three scenarios are presented in Table 8. The characterisation results gave an in-depth view of the environmental burdens of the scenarios modelled.

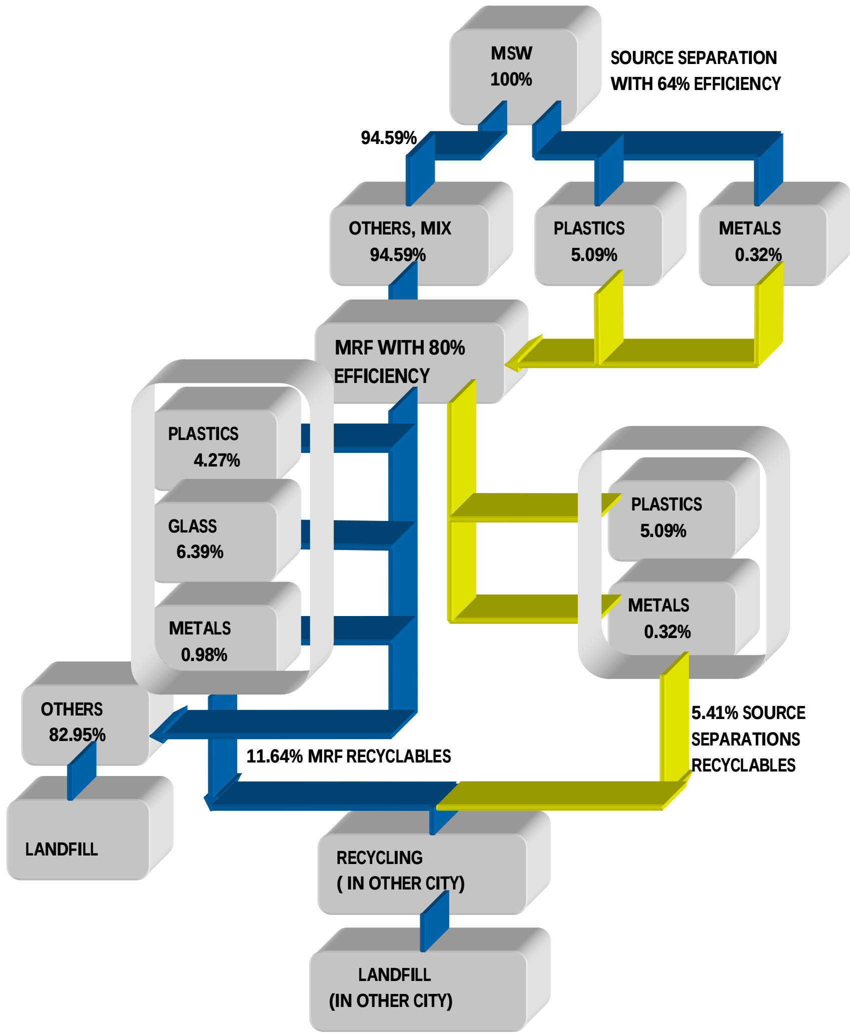

Fig. 5. Flow Charts for Scenario 3

Table 1. Description of the Modeled Scenarios

Scenario	Recycling (%)			Scavenger (%)	Composting (%)	Landfilling (%)	Incinerating (%)	Open dumping (%)
	Metals	Plastics	Glass					
Scenario 1	1.30	9.36	6.39	-	50.04	32.91	-	-
Scenario 2	1.30	9.36	6.39	-	-	-	82.95	-
Scenario 3	1.30	9.36	6.39	-	-	82.95	-	-
Baseline Scenario	-	-	-	1.5	-	-	-	98.5

Extracted From The Flow Chart Of The Modelled Scenarios

The comparison of the modelled scenarios is presented in Fig. 6 while the percent reduction of the modeled scenarios is presented in Table 9. The baseline scenario is chosen as the benchmark in which modeled scenarios were compared. Carcinogen was measured and classified as damage to human health; global warming potential was measured and classified as contributions to climate change while acidification, ecotoxicity and eutrophication were measured and classified as damage to ecosystems. The percent environmental burden of the baseline scenario is 100%. This implies the baseline scenario is considered as a worst case scenario of solid waste management strategy (McDougall *et al.*, 2001) in which all other modeled scenarios were benchmarked for the city of Minna. The modeled scenarios were compared and discussed as follows:

i. Characterisation results were expressed as global warming potential for time horizon of 100 years (GWP100) in kg carbon dioxide per kg emission (Pre

Table 2. Composition of MSW in Minna City

Components	FUT Bosso campus (g)	GRA (g)	Abdusallam garage (g)	FUT Minna dump site, GK (g)	Minna main dump site (g)	Mean compositio n (wt%)
Paper/ Cardboard	650	450	13	1,800	345	21.59
Plastics	135	145	280	296	1,150	13.29
Metals	28	18	22	148	45	1.73
Glass	60	12	13	626	495	7.99
Food	650	2,020	750	1,650	2,000	46.85
Textiles	99	320	56	213	425	7.38
Others	13	7	90	19	48	1.17
		Mean % composition				**100**

Laboratory compositional Analysis of Minna MSW

Table 3. Estimated Weight of Compostable Elements in Minna

Compostable component	% weight composition	Actual weight (tons)	Dry weight (tons)	Wet weight (tons)	Weight of each element					
					C	**H_2**	**O_2**	**N_2**	**P**	**S**
Paper/ Cardboard	21.59	19.43	7.77	11.66	0.88	0.074	1.17	1.03	2.27	2.35
Food	46.85	42.17	16.87	25.30	1.91	0.16	2.53	2.23	4.93	5.10
Textiles	7.38	6.64	2.66	3.98	0.30	0.025	0.40	0.35	0.78	0.80
Others	1.17	1.05	0.42	0.63	0.04 8	0.004	0.06 3	0.06	0.12	0.13
Compostable Total	**76.99**	**69.29**	**27.72**	**41.57**	**3.14**	**0.26**	**4.16**	**3.67**	**8.10**	**8.38**
			Recyclable components							
Plastics	13.29	11.96	4.78	7.18	0.54	0.045	0.72	0.63	1.40	1.45
Metals	1.73	1.56	0.62	0.94	0.07	0.0059	0.093	0.08	0.18	0.19
Glass	7.99	7.19	2.88	4.31	0.33	0.027	0.43	0.38	0.84	0.87
Recyclable Total	23.01	20.71	8.28	12.43	0.94	0.078	1.24	1.09	2.42	2.51
Overall Total	**100%**	**90**	**36**	**54**	**4.08**	**0.34**	**5.4**	**4.76**	**10.52**	**10.89**

Calculated from Laboratory Compositional Analysis of Minna MSW

Table 4. Estimated Molar Composition of Compostable Elements

Element	Atomic weight	% Atomic weight	Total composition of the compostable waste with water (tons)	Moles of the element with water	Sulphur = 1 with water	Normalized mole ratios
Carbon	12.01	11.32	3.14	0.261	1.0	1
Hydrogen	1.01	0.95	1.03	1.02	3.90	4
Oxygen	16.00	15.09	16.47	1.030	3.95	4
Nitrogen	14.00	13.20	3.67	0.262	1.00	1
Phosphorous	30.97	29.20	8.1	0.262	1.00	1
Sulphur	32.07	30.24	8.38	0.261	1.0	1
Total	**106.06**		**45.61**			

Calculated from Estimated Weight of Compostable Elements in Minna

Table 5. Amount of Waste Generated in Minna

Year	Type of waste (tonnes/year)							Total	Population
	Paper/ Cardboard	**Plastics**	**Metal**	**Glass**	**Food**	**Textiles**	**Others**		
2007	6,683.18	4,113.92	535.52	2,473.30	14,502.42	2,284.48	362.18	30,955	304,113
2008	6,818.99	4,197.51	546.40	2,523.56	14,797.10	2,330.90	369.54	31,584	310,287
2009	6,955.22	4,281.37	557.32	2,573.98	15,092.73	2,377.46	376.92	32,215	316,492
2010	7,092.32	4,365.77	568.31	2,624.72	15,390.23	2,424.33	384.35	32,850	322,727
2011	7,229.84	4,450.42	579.33	2,675.61	15,688.66	2,471.34	391.80	33,487	328,988
2012	7,370.18	4,536.81	590.57	2,727.55	15,993.18	2,519.31	399.40	34,137	335,370
2013	7,513.10	4,624.79	602.02	2,780.44	16,303.33	2,568.17	407.15	34,799	341,877
2014	7,658.84	4,714.50	613.70	2,834.37	16,619.56	2,617.98	415.05	35,474	348,509
2015	7,807.60	4,806.06	625.62	2,889.42	16,942.37	2,668.83	423.10	36,163	355,270

Estimated from Amount of Solid Waste Generated per Year and Population

Table 6. Amount of MSW Managed

Scenario	Amount of MSW landfilled (tonnes/yr)	Amount of MSW composted (tonnes/yr)	Amount of MSW incinerated (tonnes/yr)	Amount of MSW recycled (tonnes/yr)	Open Dumping (tonnes/yr)	Scavenger (tonnes/yr)	Total (tonnes/yr)
Baseline	-	-	-	-	32,357.25	492.75	32,850
Scenario							
1	10,810.93	16,438.14	-	5,600.93	-	-	32,850
2	-	-	27,249.07	5,600.93	-	-	32,850
3	27,249.07	-	-	5,600.93	-	-	32,850

Calculated Based on the Modelled Scenarios

Table 7. Composition of Leachate at Minna Main Dump Site

Parameters	Value (mg/L)
Chromium (Cr^{6+})	0.025
Copper	0.2
Iron	9.25
Zinc	0.6
Manganese	7.1
Chemical Oxygen Demand	2,390
Phosphate	0.12
Nitrate	90.61
Ammonia	33.33
Nitrate as Nitrogen	20.5
Sulphate	45
Temperature (^oC)	33.42

Laboratory Leachate Analysis of MSW in Minna

Table 8: Characterisation Analysis for the Baseline and Three Scenarios

Impact category	Unit	Baseline Scenario	Scenario 1	Scenario 2	Scenario 3
Global warming	Kg CO_2 eq	14.01×10^9	5.4×10^9	8.4×10^9	8.4×10^9
Carcinogens	kg C_2H_3Cl eq	10.00×10^6	4.2×10^6	5.80×10^6	5.80×10^6
Acidification	kg SO_2 eq	11.89×10^7	4.60×10^7	7.13×10^7	7.13×10^7
Ecotoxicity	kg TEG eq	71.73×10^7	71.46×10^7	71.54×10^7	71.54×10^7
Eutrophication	kg PO_4 eq	24.16×10^3	24.04×10^3	24.05×10^3	24.05×10^3

Source: SimaPro 7.2 Educational Software

Table 9. Percent Reduction of the Modeled Scenarios

Environmental Indices	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)
Global Warming	61.72	40.11	40.11
Carcinogen	58.24	42.12	42.12
Ecotoxicity	0.38	0.27	0.27
Acidification	61.63	40	40
Eutrophication	0.50	0.49	0.49

Calculated from Characterisation Analysis

Consultant, 2008a). Methane from landfill is the most important compound contributing to global warming potential of scenario 3. Both methane and carbon dioxide (CO_2) from waste compost contributed to global warming effect of scenario 1. The global warming effect for scenario 2 mostly results from CO_2 as a result of waste incineration. Scenario 1 is the best alternative in this impact category with 61.72% reduction in global warming potential of municipal solid waste management presently operating in Minna when compared with baseline scenario environmental burden.

ii. Carcinogen potential was expressed as kg chloroethylene equivalents into air (written “kg C_2H_3Cl eq”). Carcinogen effect was due to emissions of carcinogenic substances to air from waste treatment process(Pre Consultant, 2008a). Scenario 1 is the best alternative in this impact category with 58.24% reduction in environmental burden when compared with baseline scenario.

iii. Characterisation results are defined for acidification potential as kg of sulphate (SO_{2-}) equivalents into air (written “kg SO_2 eq”). The major acidifying pollutants

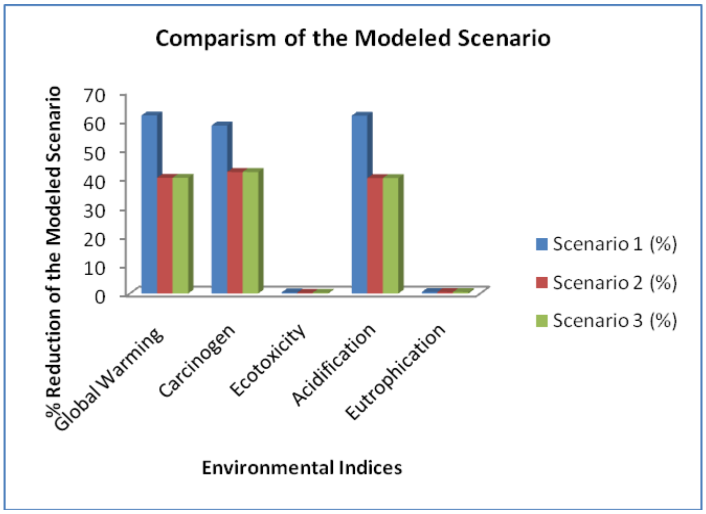

Fig. 6. Comparison of the Modelled Scenarios

are SO_2, nitrates oxides (NOx), hydrochloric acid (HCl) and ammonia (NH_3). What acidifying pollutants have in common is that they form acidifying hydrogen (H^+) ions (Pre Consultant, 2008a; Tchobanoglous and Kreith, 2002; Ogwueleka, 2009a; UNEP, 2005; Doka and Hischier, 2005; Franchett, 2009; Olaiya *et al*, 2009). A pollutant's potential for acidification was measured by its capacity to form H^+ ions. Scenario 2 and 3 had the highest acidification potential of 71,298,582.3kg SO_2 eq and 71,298,581.5kg SO_2 eq respectively. Scenario 1 with acidification value of 45,631,979.2kg SO_2 eq is the most favourable alternative in this impact category with 61.63% reduction in the environmental burden.

iv. Characterization results are expressed as kg of triethylene glycol equivalents into soil (written "kg TEG soil") describing exposure and effects of toxic substances for an infinite time horizon (Pre Consultant, 2008a). Scenario 2 has the highest ecotoxicity effect of 715,366,631 kg TEG eq. Scenario 1 with ecotoxicity value of 714,596,372kg TEG eq is the most favourable alternative in this impact category with 0.38% reduction in environmental burden.

Eutrophication potential is expressed as kg phosphate (PO_4^{3-})equivalents into a Phosphorous-limited water or soil (written "kg PO_4 eq). nitrogen (N) and phosphorus (P) are the two nutrients most implicated in eutrophication (Pre Consultant, 2008a). The contribution to eutrophication effect for Scenario 1 and Scenario 3 is shared by chemical oxygen demand and ammonia. Nitrogen dioxide is the dominant substance for the eutrophication effect of Scenario 2. There was no significant difference between environmental burden of eutrophication potential of scenario 1, 2 and 3 when compared with baseline scenario. Scenario 1 with eutrophication value of 24,043.789kg PO_4 eq is the most favourable alternative in this impact category while scenario 3 with eutrophication value of 24,045.8426kg PO_4 eq is the least favourable scenario when compared with baseline scenario of 24,163.39165kg PO_4 eq eutrophication value.

CONCLUSIONS

In the context of the five impact parameters considered, scenario 1 with 17.05% Recycling (9.36% plastics, 1.30% metals and 6.39% glass), 50.04% Compost and 32.91% Landfill is the best and most favourable alternative in term of ecotoxicity, eutrophication, acidification, carcinogen and global warming potentials in Minna. This research work showed that scenario 1 had a greatest reduction in global warming, carcinogen, ecotoxicity and acidification potentials of Minna city when the recycling was increased from baseline of 1.5% to total recycling of 17.05% (9.36% plastics, 1.30% metals and 6.39% glass).

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