Eutrophication impact potential of solid waste management options in Harare

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ABSTRACT: Six municipal solid waste management options (A1– A6) in Harare were developed and analyzed for their eutrophication impact potentials under the Life Cycle Assessment (LCA) methodology. All the options started with waste collection and transportation to a centralized waste treatment centre where a combination of various municipal solid waste management and treatment methods were considered under the different options. Results show that landfilling and material recovery for reuse and recyle are the only MSW management processes that contributes to negative eutrophication potential giving options that had landfilling (A1, A4 and A6) an overall edge. The doubling of recycling rate under A5 and increasing it to atleast 25% under A6 result in below zero eutrophication impact potentials. Results reveal that anaerobic digestion and incineration contribute to increased eutrophication potential under all the options they were considered hence need for further assessments considering other impact categories to determine the most sustainable option.

1 INTRODUCTION

Harare, the capital city of Zimbabwe is experiencing enormous water challenges with regards to quality and quantity. The city is failing to consistently supply its residents with safe and clean potable water. Some residential areas are experiencing dry tapes for weeks or even months. Nhapi (2009) argued that these challenges are largely attributed to increased population, lack of necessary maintenance works on wastewater infrastructure, use of technologies that are expensive and institutional framework deficiencies. Residents have resorted to the drilling of boreholes and shallow groundwater wells at their households. However groundwater is not as safe as perceived due to nutrients, metals, acidity and coliform bacteria contamination emanating from diffuse pollution (Love et al., 2006, Eukay and Kharlamova, 2014, Kharlamova et al., 2016). The diffuse pollution largely results from poor Municipal Solid Waste (MSW) management practices and like any other urban environments in developing countries; Harare is facing MSW management challenges due to to rapid population growth and increased volumes of waste being generated by the public causing its failure to sustainably manage. Only 60 per cent of the MSW generated in Harare is collected and disposed of at dumpsites with the remaining 40% usually dumped illegally in open spaces, road verges, alleys and drainages for storm water (Tanyanyiwa, 2015, PASA, 2006, Jerie, 2006, Saungweme, 2012, Chirisa, 2013). This threatens the water situation in Harare and has been cited as the major cause of the annual outbreaks of Cholera and Typhoid in Harare (Manzungu and Chioreso, 2012, Tanyanyiwa and Mutungamiri, 2011, Chirisa, 2013).

The pollution of surface and groundwater in Zimbabwe's urban environments is a direct result of municipal solid waste management specifically MSW dumping in waterways and leachate from MSW dumpsites (Mangizvo, 2007, Mangizvo, 2010, Tsiko and Togarepi, 2012) together with the discharge of untreated or partially treated sewage into river systems (Nhapi et al., 2004). This has led to the high level eutrophic status of Lake Chivero, the source of potable water to Harare and Chitungwiza. The eutrophication of Lake Chivero is not a welcome development considering its threats to the availability of potable water for Harare and Chitungwiza. It has led to increased costs for potable water production partly contributing to the erratic potable water supplies in most parts of Harare currently being experienced. Bauman and Tillman (2004) described eutrophication as a phenomenon with the potential of affecting terrestrial and aquatic ecosystems due to nutrient enrichment namely Nitrogen (N) and phosphorus (P) in water systems. The MSW generated in Harare has an excess of biowaste constituting over 60% (UNEP, 2011) hence if improperly managed can lead to nutrient enrichment in water bodies leading to eutrophication. Magadza (2003) reported that the breakdown in hygiene has led to nutrient rich surface run-off from uncollected MSW and illegal MSW dumps significantly contributing to Lake Chivero eutrophication.

The design and development of sustainable MSW management option for Harare becomes a necessity to address the human health challenges and availability of freshwater that guarantee the long term consistent supply of potable water for Harare residents. Life Cycle Assessment (LCA) has proven to be an effective tool for designing and developing sustainable and integrated MSW management as it aids the assessment of environmental loads of different MSW options (Miliute and Kazimieras Staniškis, 2010; Rives et al., 2010; Koci and Trecakova, 2011; Stucki et al., 2011; Gunamantha and Sarto, 2012; Fernández-Nava et al., 2014). Therefore, this work is an LCA based comparative study to assess the eutrophication impact potential of different MSW management options for Harare. The objective being to determine the option with the least eutrophication impact potential in light of the reported eutrophic status of the potable water sources in Harare.

2 MATERIALS AND METHODS

2.1 *Description of study area*

The study area is Harare the capital city of Zimbabwe with an estimated population of 1,485,231 (Zimstat, 2013) and covering an area of 960.6 km^2 at an altitude of 1483 m. An estimate of 325,266 tons of MSW is generated per year (Mshandete and Parawira, 2009, Muchandiona et al., 2013, Pawandiwa, 2013, Mbiba, 2014, Hoornweg and Bhada-Tata, 2012, Emenike et al., 2013) in Harare with 60% indiscriminately collected and dumped at Pomona dumpsite the only official dumpsite whose capacity is exhausted by 2020 (Chijarira, 2013). The waste that is generated in Harare is estimated to have average composition of 42% biodegradable waste, 33% plastics, 8% metals, 14% paper and 3% glass (Nyanzou and Steven, 2014, Mudzengerere and Chigwenya, 2012). Harare sits upstream and on the catchment of its potable water source (Lake Chivero) making all the MSW management activities in Harare contributing towards the reported super eutrophic levels of the Lake. Underground water in Harare has also been reported to have been contaminated with nutrients, metals, acids and coliform bacteria (Muchandiona et al., 2013, Love et al., 2006, Eukay and Kharlamova, 2014, Kharlamova et al., 2016).

2.2 *MSW management option 1 – A1*

The entire 325,266 tons of MSW generated per year in Harare is indiscriminately collected before any treatment (both biodegradable and nonorganic MSW) and landfilled in a sanitary landfill with biogas recovery and landfill leachate treatment. The recovered biogas is fed into Combined Heat and Power (CHP) plant to produce electricity.

2.3 *MSW management option 2 – A2*

The entire 325,266 tons of MSW generated per year in Harare is indiscriminately collected before any treatment (both biodegradable and nonorganic MSW) and incinerated in an incinerator with energy recovery, flue gas treatment and treatment of leachate produced during the recovery of the incinerator bottom ash. The incinerator bottom and fly ash is used as material for road construction considering the road infrastructural needs of the country.

2.4 *MSW management option 3 – A3*

Biodegradable MSW generated amounting to 136,612 tons is digested in an anaerobic digester producing biogas. The biogas is fed into Combined Heat and Power (CHP) generation plant to produce heat and electricity. The remaining non-biodegradable fraction 188,654 tons mixed bag MSW (107,338 tons plastics, 26,021 tons metals, 45,537 tons paper and 9,758 tons glass) is incinerated as in A2 with energy recovery, flue gas treatment and treatment of leachate produced during the recovery of the incinerator bottom ash. The incinerator bottom and fly ash is used as material for road construction considering the road infrastructural needs of the country.

2.5 *MSW management option 4 – A4*

As in A3 difference being that the remaining non-biodegradable fraction 188,654 tons mixed bag MSW (107,338 tons plastics, 26,021 tons metals, 45,537 tons paper and 9,758 tons glass) is landfilled as in A1 with biogas recovery and landfill leachate treatment. The recovered biogas is fed into Combined Heat and Power (CHP) plant to produce electricity.

2.6 *MSW management option 5 – A5*

20% of the non-biodegradable MSW amounting to 37,731 tons (21,468 tons plastics, 5,204 tons metals, 9,107 tons paper and 1,952 tons glass) are recovered in the material recovery facility or sorting plant for reuse and recycling. The 80% non-biodegradable MSW remaining from the material recovery facility amounting to 150,923 tons (85,870 tons plastics, 20,817 tons metals, 36,430 tons paper and 7,806 tons glass) is incinerated as in A2 with energy recovery, flue gas treatment and treatment of leachate produced during the recovery of the incinerator bottom ash. The incinerator bottom and fly ash is used as material for road construction considering the road infrastructural needs of the country.

2.7 *MSW management option 6 – A6*

20% of the non-biodegradable MSW amounting to 37,731 tons (21,468 tons plastics, 5,204 tons metals, 9,107 tons paper and 1,952 tons glass) are recovered in the material recovery facility or sorting plant for reuse and recycling. The 80% non-biodegradable MSW remaining from the material recovery facility amounting to 150,923 tons (85,870 tons plastics, 20,817 tons metals, 36,430 tons paper and 7,806 tons glass) is landfilled as in A1 with biogas recovery and landfill leachate treatment. The recovered biogas is fed into Combined Heat and Power (CHP) plant to produce electricity.

2.8 *Life Cycle Assessment*

The eutrophication impact potential for the six MSW management options was estimated using the LCA methodology with the ISO 14040 standards applied as the basis of the LCA. Simapro version 8.5.2 analyst software and update 852 database were used for the LCA under the ReCiPe 2016 v1.02 endpoint method. The yearly MSW generation of 325,266 tons was used as the functional unit (Fernández-Nava et al., 2014, Beigl and Salhofer, 2004, Cherubini et al., 2009). Waste collection and transportation, landfilling, incineration, anaerobic digestion material recovery, CHP generation, landfill leachate treatment and incineration flue gas treatment were the considered life cycle stages.

3 RESULTS AND DISCUSSIONS

Figure 1 shows the LCIA results with regards to the eutrophication impact potential of the six MSW management options. MSW management options A1and A4 leads to reduced extinction rate of species thus reduced eutrophication impact potential with A2 to A6 bringing about an increased species extinction rates.

Table 1: Process Contributions to eutrophication

Process	MSW management options					
	A1	A2	A3	A4	A5	A6
	Species.yr					
Waste transportation	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04
Landfilling	-1.53E-02	-	-	-8.87E-03	-	-2.09E-03
Anaerobic digestion of biowaste	-	-	5.43E-03	5.43E-03	5.43E-03	5.43E-03
Incineration	-	6.96E-06	4.04E-06	-	9.51E-07	-
Materials recovery	-	-	-	-	-2.78E-03	-2.78E-03
Total	-1.52E-02	1.46E-04	5.57E-03	-3.30E-03	2.79E-03	6.99E-04

MSW option A4 is the most favorable with eutrophication impact potential reduction of -3.30E-02 species.yr. Figure 2 and Table 1 shows detailed contribution of the processes constituting the six MSW management options to the eutrophication potential. An assumption was made that all the waste is collected and transported to a central MSW management facility where the various MSW management options were considered giving a constant waste collection and transportation impact potential. The collection and transportation of 325,266 tons of MSW generated in Harare per annum contributes to increased eutrophication potential of 1.39E-04 species.yr. Need for alternative MSW collection and transportation rather than the household to household collection system currently being practiced arise. Such strategies include the use of centralized or decentralized waste transfer stations, higher volume trucks or trains and citizens waste disposal facilities which will result in increased MSW collection and transportation efficiency from sources and per day collections. In addition, the distance travelled by the MSW trucks is also reduced by implementing these alternative MSW collection and transportation strategies.

The anaerobic treatment of biodegradable MSW fraction (136,612 tons per annum) is part of MSW management options A3 – A6 and results indicate it contributes to increased eutrophication of 5.43E-03 species.yr for all the MSW management options. This was also observed by Bernstad and la Cour Jansen (2011) and Mendes (2003). Bernstad and la Cour Jansen (2011) cited digestate use as biofertiliser substituting inorganic fertilisers as the driver for increased eutrophication potential. Improper handling of AD feedstock is also another source of the eutrophication potential.There is however need to assess the trade-off between the eutrophication increase and the benefits derived from the biogas derived renewable electricity that has been found to be environmentally sustainable compared to fossil fuels derived electricity and organic fertilizer from the anaerobic digestion of biodegradable waste. With regards to landfilling, results indicate that for the three MSW management options A1, A4 and A6, there is reduced eutrophication in the magnitudes of -1.52E-02 and -3.30E-03 for A1 and A4 respectively with A6 bringing about increasing eutrophication of 6.99E-04 species.yr. Landfilling associated with the recovery of energy (biogas) and the treatment of landfill leachate is environmentally favorable as observed by Zaman (2010) and Hong et al (2010) despite its threat to land availability. Incineration which is considered under MSW management options A2, A3 and A5 contributes towards the increase in the species extinction rate of 6.69E-06, 4.04E-06 and 9.51E-07 species.yr respectively due to ammonia emissions despite the associated energy recovery and reduction of waste volume. Material recovery brings about the reduction in species extinction rate of -2.78E-03 species per year for the two MSW Management options considered namely A5 and A6. Doubling recovery rate of recoverable materials under A5 and increasing it to atleast 25% under A6 results in below zero eutrophication impact potential.

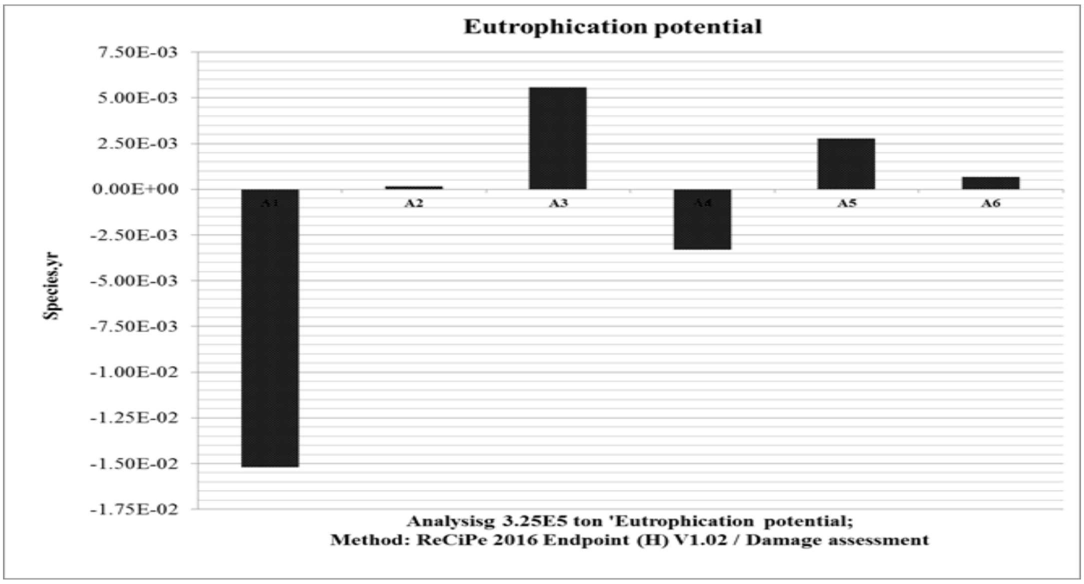

Figure 1. Eutrophication impact potential of MSW management options

4 CONCLUSION AND RECOMMENDATIONS

The study results show that landfilling and material recovery for reuse and recyle are the only MSW management processes that contributes to negative eutrophication potential i.e reduction in potential extinction rate of species due to its associated energy recovery and landfill leachate treatment. However, threats to land availability have led to increased global concern on waste landfilling. The anaerobic digestion, waste collection and transportation and incineration contribute to increased eutrophication potential. However in the case of anaerobic digestion of biodegradable MSW fraction other factors such as the benefits derived from the production of renewable electricity and the production of an organic fertiliser in the form of the digestate need also to be taken into consideration in opting for the best MSW management option as they have proved to be environmentally sustainable. Overally MSW management option 1 (A1) proved to be the best MSW management option when considering the eutrophication potential despite its threat to land availability and increasing global concerns on waste landfilling. However, there were limitations with regards to data availability on actual MSW generation and composi tion as well as transportation distance. Hence, this study utilized estimates from literature. De

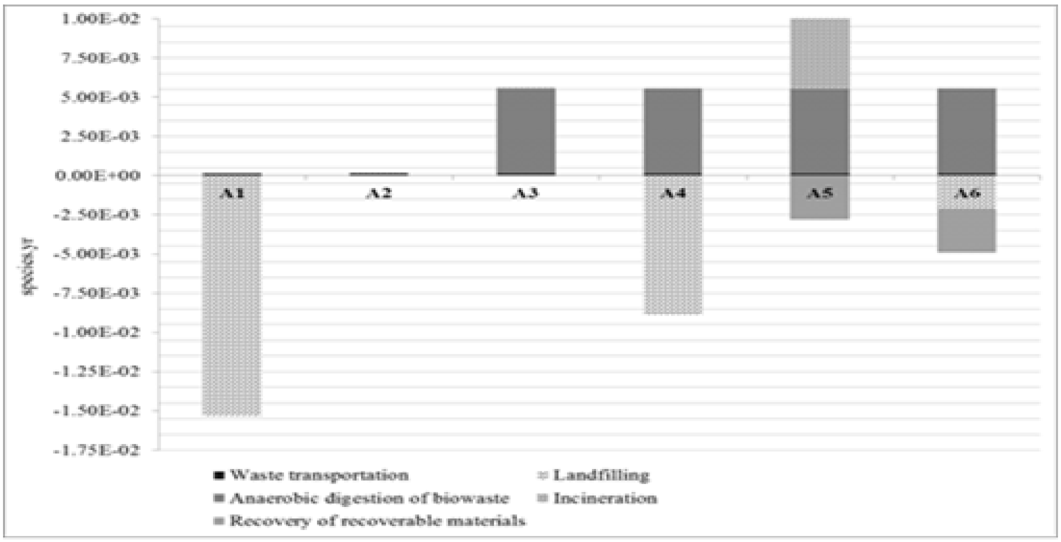

Figure 3. MSW management process contribution to eutrophication impact potential

tailed studies to quantify the MSW generation and composition in Harare as well as further life cycle assessments considering other impact categories to determine the most sustainable option are therefore recommended.

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