LIFE CYCLE ASSESSMENT OF MUNICIPAL SOLID WASTE MANAGEMENT IN KHULNA CITY OF BANGLADESH

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ABSTRACT

Municipal solid waste management (MSW) is one of the principal environmental concerns for Khulna, the third largest city in Bangladesh. Khulna City Corporation (KCC) plays a significant role in managing MSW in Khulna city but lack of proper management, the desired outcome is not achieved which creates environmental and public health concerns. So, to ascertain a sustainable solution for the management and disposal of MSW in Khulna city, a life cycle assessment (LCA) has been approached by openLCA software which is an open-source software that provides a platform for creating and analyzing life cycle assessment models. The quantity of total generated solid waste in Khulna is approximately 641 tons per day which includes paper waste, sanitary waste, food waste, plastic waste, metal waste, rags, glass waste, etc. In this study, the LCA was adopted in Khulna for MSW to find the environmental impact of end-of-life (EOL) treatment of 1-ton/day MSW based on the Recipe Midpoint category. Six environmental impacts including climate change, fossil depletion, water depletion, human toxicity, freshwater eutrophication, and freshwater ecotoxicity are considered here to find the most sustainable way among four baseline scenarios including open dumping, sanitary landfilling and two combined scenarios. In summary, waste treatment by sanitary landfills has a lower impact than other considered scenarios. Regarding hotspot analysis, open dump contributes to climate change relatively much more than sanitary landfilling while sanitary landfills are a major contributor to water depletion. The open dump also has a slightly greater impact than a sanitary landfill in terms of human toxicity. The results from this study give in-depth insights about the waste management strategies which can be used to support future waste management decisions in Khulna as well as Bangladesh.

Keywords: *MSW, environmental impact, Khulna, Open dump, Landfill*

1. INTRODUCTION

Bangladesh is a country in South Asia with a population of around 165.1 million people. This country is struggling with a sharp increase in solid waste generation as one of South Asia's most rapidly urbanizing nations. Every fifteen years during the past three decades, trash volume has doubled. In metropolitan settings, 55% of solid garbage is often not collected, with collection efficiency ranging from 37% to 77% (Sirajul Islam et al., 2021). One of the key causes of Bangladesh's environmental decline is inadequate and inappropriate MSW management. This study has been carried out in a major divisional city of Bangladesh named Khulna. After Dhaka and Chittagong, Khulna is the third-largest city in Bangladesh. The current population of Khulna is approximately 1.3 million and the total generated MSW is almost 641 tons per day. Recently, there has been an increasing concern about the municipal solid waste management in Khulna city due to the rise in population after 2000 which creates a never-ending increase in MSW generation (Khandelwal et al., 2019).

MSW is a type of a large category of waste that is generated in households, businesses, institutions, and other non-industrial sources within a municipality. It is one of the greatest concerns for developing and underdeveloped countries. Proper management of MSW is crucial to reduce environmental impact, prevent pollution, conserve resources, and promote public health. Different types of waste management systems have been introduced in cities and towns. The waste management systems include waste collection, sorting, recycling, composting, or waste-to-energy facilities, and finally disposal of the residues to landfills. Recycling and composting efforts can help to divert a significant portion of municipal solid waste from landfills, reducing the overall environmental impact. Recycling of non-biodegradable organic wastes such as plastic (Alamgir et. al. 2005), paper (Tabassum et. al. 2017a), and garments (Tabassum et. al. 2017b) reduce the extraction of virgin materials. On the other hand, recovering the compost from biodegradable organic solid waste can apply to land for sustainable agriculture (Bari, 2011; Atauzzaman et. al. 2023). Environmental degradation results from the uncollected discharge of trash on roadways and other public spaces (Nahid et al., 2023). The current MSWM practice has resulted in several greenhouse gas (GHG) emissions, including methane from the decomposition of organic waste in landfills and carbon dioxide from the manufacture of new materials (Islam et al., 2019).

A life cycle assessment (LCA) of MSW is a systematic methodology used to evaluate the environmental impacts associated with the entire life cycle of municipal solid waste, from its generation to its final disposal or treatment. LCA is an important tool for assessing the environmental sustainability of waste management practices and identifying areas for improvement. The study has been carried out by an open-source LCA software named openLCA which provides a platform for creating and analyzing life cycle assessment models. This software allows users to define the life cycle stages, input/output flows, and other parameters related to a particular system being studied. Then it calculates various environmental factors including the eighteen prime factors such as Fine particulate matter formation, Fossil resource scarcity, Freshwater ecotoxicity, Freshwater eutrophication, Global warming, Human toxicity, Ionizing radiation, land use, Marine ecotoxicity, Marine eutrophication, Mineral resource scarcity, Ozone formation, Human health, Ozone formation, Terrestrial ecosystem, Stratospheric ozone depletion, Terrestrial acidification, Terrestrial ecotoxicity, and Water consumption. When it comes to waste management, LCA considers the possible environmental effects of the waste life cycle, from generation to disposal (Khandelwal et al., 2019).

LCA was used in this study to analyze the environmental effects of treating 1 kg of plastic waste at the end of its useful life in Indonesia and India using the EOL mix, which combines mechanical recycling, co-processing in open dumping, open burning, sanitary landfills, incineration, and cement kilns. HDPE, LDPE, PP, and PET plastic waste were mainly used. The result was that the recycled rate in India was higher than in Indonesia (Neo et al., 2021). The LCA study for solid waste treatment in Sweden was carried out in this paper (Finnveden et al., 2005) comparing landfilling, incineration, recycling digestion and composting. The result showed that incineration was more favorable than landfilling.

(Gomes et al., 2019) overviewed the LCA study for PET packaging on the basis of 2008 to 2017 results. Two different types of LCA have been discussed here which are the closed loop and the open loop LCA system, between them closed-loop LCA is an eco-friendlier option. It was quite clear from this study that PET bottle gives better environmental performance than glass bottle and aluminum cans. (Khandelwal et al., 2019) evaluated the LCA study for MSWM for Nagpur city in India where four different scenarios have been considered including landfilling, material recovery facility (MRF) & composting combined with landfilling, MRF & anaerobic digestion (AD) combined with landfilling and MRF, AD & composting combined with landfilling. The result showed that the second scenario has the least environmental impact on global warming, human toxicity, eutrophication, and photochemical ozone creation potential categories. (Natarajan et al., 2020) replaced ABS (Acrylonitrile Butadiene Styrene) plastic on behalf of PLA (Polylactic Acid) polymer and discussed the environmental impacts of LCA via openLCA software. The mechanical properties had also been compared and the LCA results showed that PLA plastic has the least environmental impact.

In this study, an LCA has been carried out to find the better option among the four considered scenarios which is mentioned in table 2 include S1 (open dump), S2 (sanitary landfill), S3 (40% open dump & 60% sanitary landfill), and S4 (10% open burn, 35% open dump & 55% sanitary landfill) of waste management system in Khulna City Corporation. There had never been an LCA for the MSWM in Khulna City carried out in all the studies. Various impact categories have been identified via hotspot analysis. Finally, the sensitivity analysis has been used to understand the variation in the calculated impact owing to possible questionable data points. These results may help to know which are the most feasible waste management practices and further investing in them.

2.METHODOLOGY

2.1 Study Area

Khulna is the third largest city in Bangladesh having a population of approximately 1.5 million. Previously Khulna was named Jahanabad. Khulna is located under the tropic of Cancer having a latitude of 22.49° N and longitude of 89.34° E. The total area of Khulna is almost 47 km^2. There are 31 wards in KCC as displayed in Figure 1 and the selected study area was KCC.

2.2 MSW Composition

The total generated waste in Khulna city is approximately 641 metric tons per day. The composition of MSW in Khulna is presented in Table 1 according to (Noman et al, 2023). The daily generated MSW in Khulna is composed of 81% biodegradable waste, 4.74% plastic material, 6.67% paper, and cardboard material, 0.67% glass, 1.49% textile and wood, 0.35% ceramic, 0.43% metals, 0.23% medical waste and 3.68% others. This indicates that a large amount of waste is organic in nature. And the others are inorganic wastes, recyclable and non-recyclable plastics, etc. Either an open dump or sanitary landfill is needed to manage this huge waste.

Table 1: MSW Composition in KCC

Composition of Waste	Percentage, %
Biodegradable Waste	81.00
Plastic	4.74
Paper & cardboard	6.67
Glass	0.67
Textiles & wood	1.49
Electric goods	0.35
Ceramic	0.74
Metals	0.43

Medical waste	0.23
Dust & others	3.68

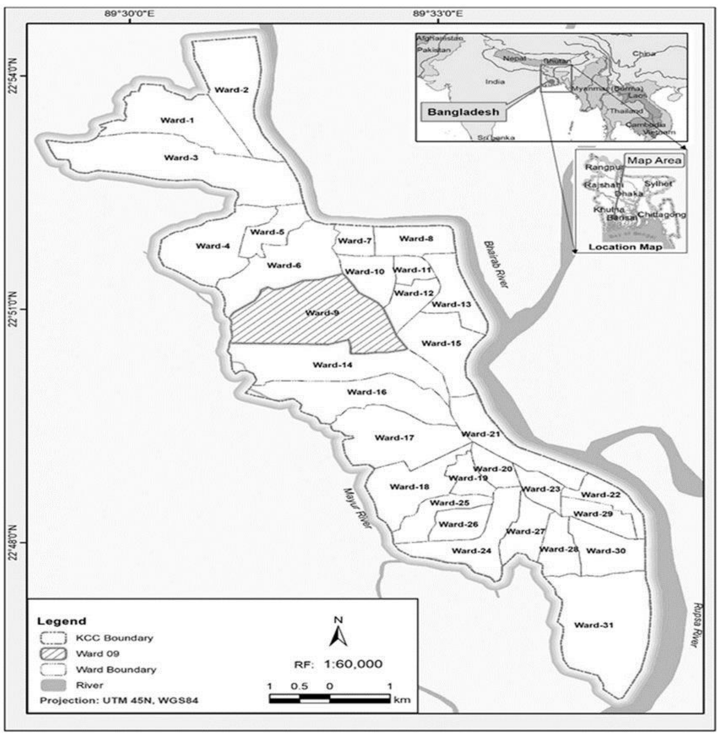


Figure 1: Study Area of Khulna City Corporation

2.3 Scope of the Study and Defining Goal

The aim of this study is to determine the environmental impacts of the four baseline scenarios mentioned in table 2 which include open dumping and sanitary landfilling of municipal solid waste in the Khulna city area. Comparing the different impact categories, the better option among the scenarios will be considered the most sustainable way to manage waste in Khulna city.

2.4 Functional unit

In this study, the objective is to quantify the environmental impacts of EOL treatment of MSW in Khulna city. The results can be of use for the recommendations to policymakers and investors to distinguish their efforts towards EOL fates which can help to decrease environmental impact (Neo et al., 2021). Here, the main four EOL fates include four baseline scenarios described in table 2. Ocean dumping is considered here within the umbrella of open dumping, as methodologies for quantifying the environmental impact of ocean dumping are still being developed (MariLCA 2019). The main functional unit is the EOL treatment of 1 ton of MSW from the point of its generation. This study solely focuses on finding the comparison between the two mentioned waste collection and treatment process only. The total generated MSW in Khulna city is approximately 641 tons and the mix of the 1 ton of solid waste is based on the MSW mix including paper waste, sanitary waste, food waste, plastic waste, metal waste, rags, glass waste, etc.

2.5 System boundary for MSW

The system boundary of this study as shown in Figure 2 will be focused only on the MSW collection by trucks from Khulna city, EOL treatment of the wastes, and its impact on the environment.

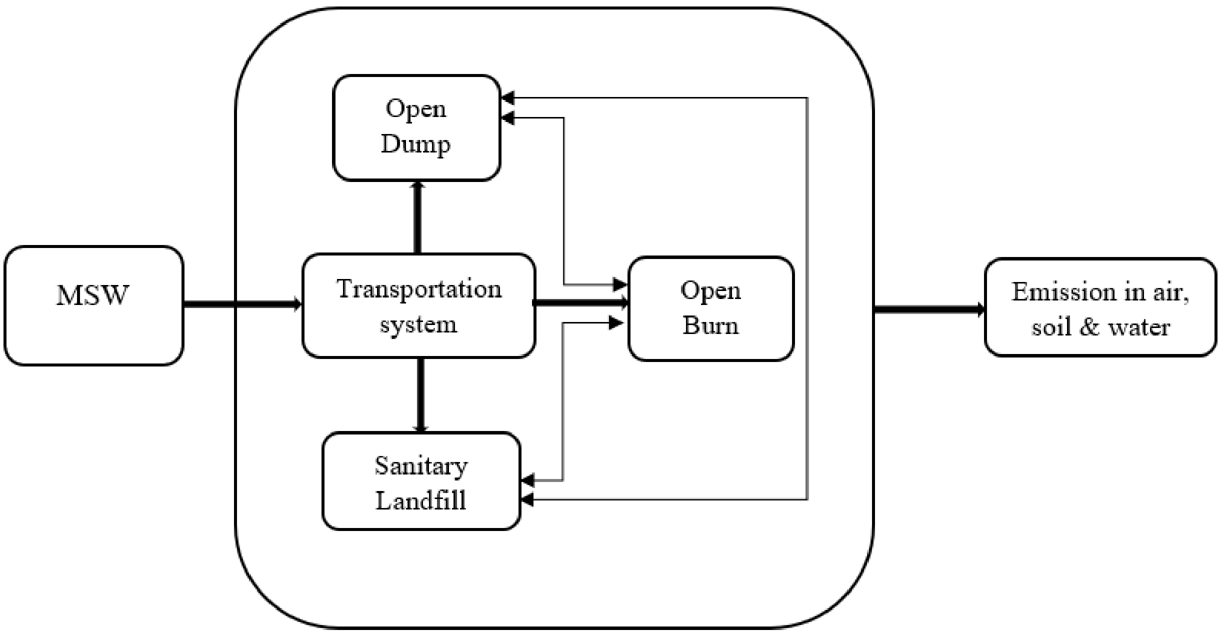


Figure 2: The system boundary of the present study

2.6 openLCA

openLCA is a robust, feature-rich, open-source program for LCA and Sustainability modeling. Since the creation of openLCA by GreenDelta in 2006, openLCA has been a professional Life Cycle Assessment (LCA) and Footprint program with a multitude of features and databases at its disposal. Creating a process of individual LCA for different corresponding scenarios provides comparative results for the different scenarios in terms of various impact assessment categories. The life cycle model seamlessly integrates social assessment and life cycle costing (openLCA, 2023). When it comes to waste management, life cycle assessment (LCA) considers the possible environmental effects of the waste life cycle, from generation to disposal (Khandelwal et al., 2019).

2.7 Baseline scenarios

The baseline scenarios for the management of MSW in Khulna city are presented in Table 2. The description of considered baseline scenarios is in the below sections.

Table 2: Description of the Baseline scenario and proposed scenarios

Scenarios	Description
S1	100% MSW to open dump
S2	100% MSW to sanitary landfill
S3	40% MSW to open dump & 60% MSW to sanitary landfill
S4	10% MSW to open burn, 35% MSW to open dump & 55% MSW to sanitary landfill

2.7.1 Scenario 1

Open Dump is the existing scenario (S1) of this study. There are various landfills in Khulna city. One of these is the Rajbandh landfill. It is Khulna's only operational open garbage dumping site (Nahid et al., 2023). Rajbandh has two dumping yards, both on the city's western outskirts along the Khulna-Satkhira highway.

2.7.2 Scenario 2

Currently, there is no sanitary landfill in Khulna city so in this study, a sanitary landfill is a proposed scenario (S2) considered to manage the whole MSW of Khulna city. For example, the Matuail landfill is supposed to be a sanitary landfill, the only one in Dhaka that is fully operational [source: the Daily Star]. When properly sited and administered, sanitary landfills have various advantages. Sanitary landfills are constructed with the intention of reducing threats to the environment and public health, in contrast to open dumps, which are merely locations where waste is dumped without any thought or infrastructure. There are liners and covers under and over the sanitary landfill to stop groundwater pollution which also lessen methane-related air pollution. The protection of sources of drinking water depends on this design. Sanitary landfill assist cities in methodically managing their garbage.

2.7.3 Scenario 3

This considered scenario is the combination of open dump & sanitary landfill. 40% of the total generated waste is to be managed through open dump and the rest is to be processed via sanitary landfill.

2.7.4 Scenario 4

In this proposed scenario, 10% of the total MSW is to be open-burned, 35% of them is to be open-dumped and the rest is to be sent to a sanitary landfill.

2.8 Inventory data

The datasets have been collected from the ongoing project named ‘SCIP plastic project’ KUET, Khulna. Some of them have been obtained via onsite investigation and various published literature. This part produces an inventory of environmental input and output by focusing on the identification and quantification of system-related environmental actions (Song et al., 2013). Ecoinvent_3.8_cutoff_regio_3011 database has been used here for detailed calculations in openLCA software. The impact assessment method category used here was the ‘Recipe Midpoint’. The total distance from the KCC center to the Rajbandh landfill is almost 11 km and for the major assumptions, the unit process for the transport selected from the openLCA database was ‘transport, freight, lorry 3.5-7.5 metric ton, EURO1’ considered here to carry the total waste from KCC to the Rajbandh landfill.

2.9 Life cycle assessment

A lot of methods and tools have been developed and initiated for the interpretation of different environmental categories for use in various decision parameters (Finnveden et al., 2005). In this study, LCA has been approached to know the most sustainable way among the four scenarios. Throughout the course of a product's life, the input, output, and environmental consequences are estimated and projected using a computer-based tool called LCA (Khandelwal et al., 2019).

LCA is a process to evaluate the environmental impacts associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment, and assessing the impact of those energy and materials used and released to the environment (Borodin et al., 2015). The methodology used here is based on profound methods and practices for both the inventory analysis and the sorting element of the life cycle impact assessment for waste treatment processes (Clift R et al., 2000). In performing the LCA of municipal solid waste, the individual LCA of the scenarios were first computed, then the results were compared under the "Recipe Midpoint Category".

3. RESULTS AND DISCUSSION

3.1 Climate Change

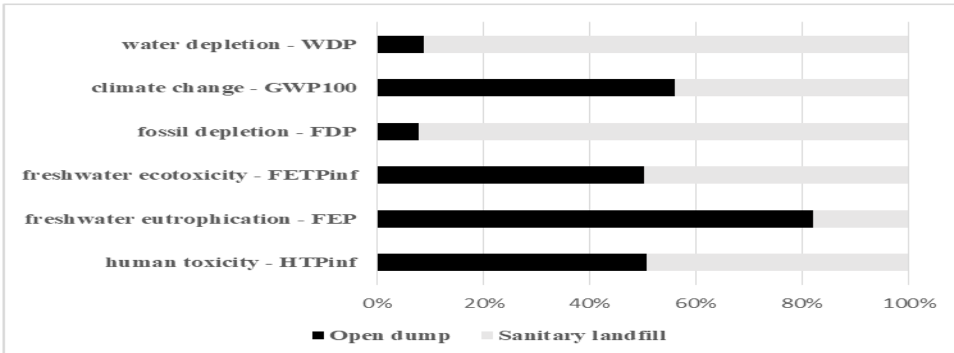
Climate change is a major contributor parameter in openLCA software and also a necessary decision-making criterion that helps to know which product has more adverse impact on the climate. LCA also concentrates on the rise in average global temperatures brought on by greenhouse gas (GHG) emissions in the context of climate change. A kilogram of carbon dioxide equivalent (kg CO2 eq) is used to calculate the global warming potential of all greenhouse gas emissions; that is, each GHG is compared to one kilogram of CO2. In Fig 3(a), between S1 and S2, open dump contributes more than sanitary landfill in terms of climate change impact category. Also S4 has more impact on climate than S3 as shown in Fig 3(b). In Fig 3(c), S3 is slightly greater than S2 which indicates the more adverse impact on climate change. The more the value rises, the greater its impact. Carbon dioxide (CO_2) and methane gas (CH_4) make up the majority of the biogas produced and released into the atmosphere by open dumps. These two gases are among those that tend to raise temperature and contribute to climate change (Dip et. al. 2023; Mamun & Bari 2023). In fact, waste is frequently burned at open landfills, causing harmful contaminants to be released into the environment. By 2025, landfill sites will generate 10% of greenhouse gas emissions if current patterns continue and action is not taken.

3.2 Human Toxicity

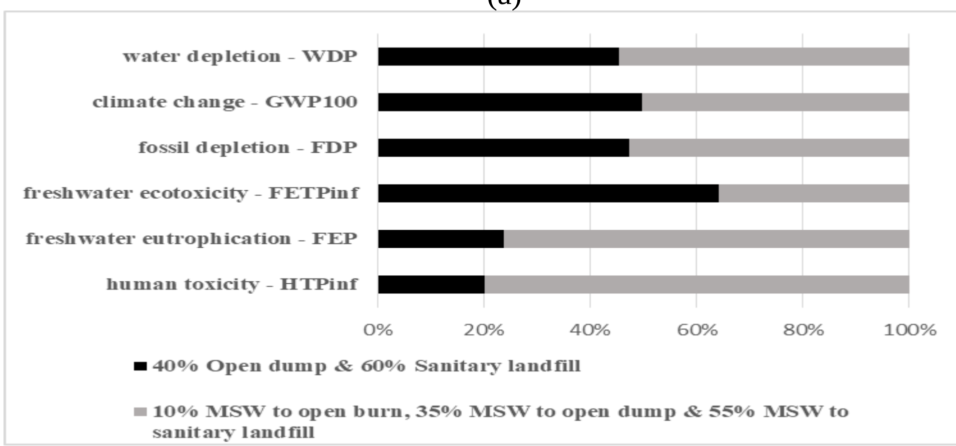
In LCA, "human toxicity" is a term that helps to evaluate the possible effects on health that could result from the release of hazardous elements during a product's or service's life cycle. The contribution of each factor to the overall variation of 10–12 orders of magnitude in impacts per kg across all chemicals is characterized by the intake fraction (the fraction of the emitted or applied chemical that the consumer and the general population take in), effect factor, and characterization factor across all chemicals and impact pathways (Jolliet O et al., 2015). In Fig 3(a), it can be easily understood that the impact of human toxicity is much higher for open dumps than sanitary landfills. Also, open burning has an adverse impact on the environment as well as it is heavily hazardous to human health. S4 has the highest amount of impact on human toxicity parameters suppressing all the scenarios. Also, it can be seen that sanitary landfill has the least impact on human toxicity.

3.3 Water Depletion

The withdrawal of water from lakes, rivers, or groundwater is known as "water depletion" in LCA and leads to the reduction of available water (Klinglmair et al., 2014). To offer a complete water footprint, techniques for evaluating the direct effects of emissions on water are being developed elsewhere and are utilized in conjunction with techniques for evaluating the impact of water consumption (Water Footprint, 2014). The impact results are relatively higher for sanitary landfills than open dumps. When solid waste breaks down, a liquid called leachate is created. Leachate penetrates the ground and accumulates in the groundwater causing serious contamination. If not properly contained and removed from the landfill, it may become a concern for the water's quality which is unsafe for human health. Leachate content, leachate levels, and surface water must all be monitored for a sanitary landfill to be managed effectively [Kamaruddin et al., 2021]. In Fig 3(b), S4 is deliberately higher than S3 where sanitary landfill is still the highest among the four scenarios on water depletion potential.



(a)



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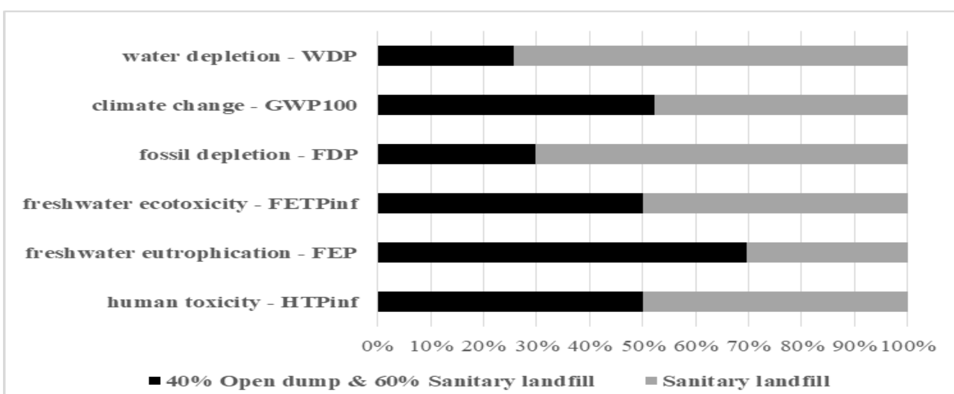


(c)

Figure 3: LCA Characterization of the Considered Impact Categories; a) Comparison of impact categories between S1 and S2, b) Comparison of impact categories between S3 and S4, c) Comparison of impact categories between S3 and S2

3.4 Fossil Depletion

In LCA, fossil depletion is known as the use of non-renewable resources like fossil fuels like coal, oil, and gas. This is one of the important impact categories in LCA. Increased extraction of fossil energy is suspected to raise future energy demand. Rendering the fossil fuel depletion indicator can be termed as an indicator of fossil energy scarcity (Arvidsson et al., 2021). The sanitary landfill has a higher impact on this category than open dumping, although S4 also contributes more than S3 as shown in Fig 3(b).

3.5 Freshwater Eutrophication

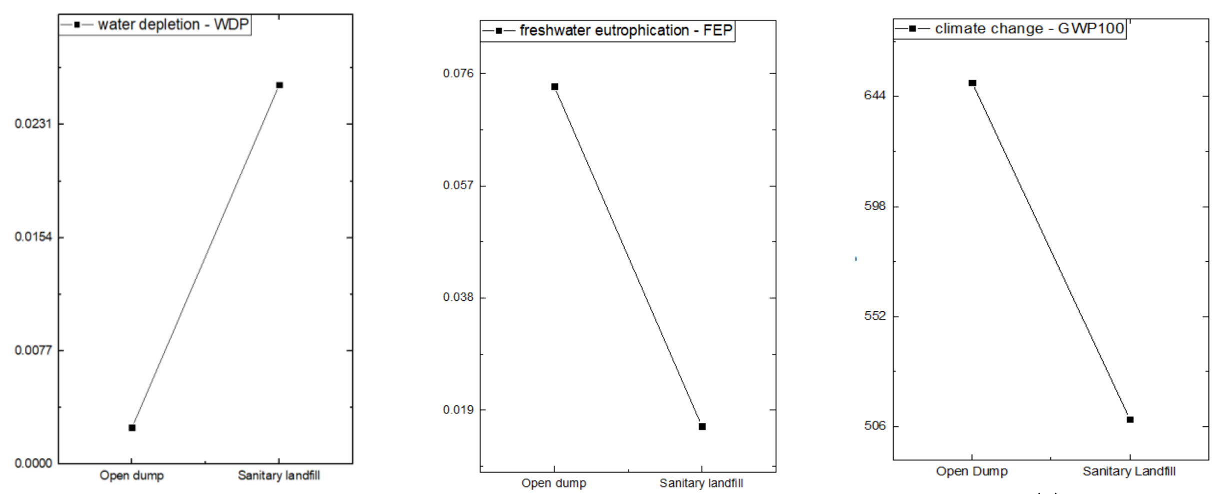
Freshwater eutrophication is a necessary impact category in LCA which indicates the possible environmental effects of nutrient inputs, primarily nitrogen (N) and phosphorus (P), into freshwater systems (Payen et al., 2021). Characterization factors (CFs) are employed to turn a measured emission or consumption into a probable environmental consequence, such as freshwater eutrophication. The open dump has a greater impact on freshwater eutrophication than sanitary landfills. Among all, S4 has the highest impact and sanitary landfill has the lowest impact.

3.6 Freshwater Ecotoxicity

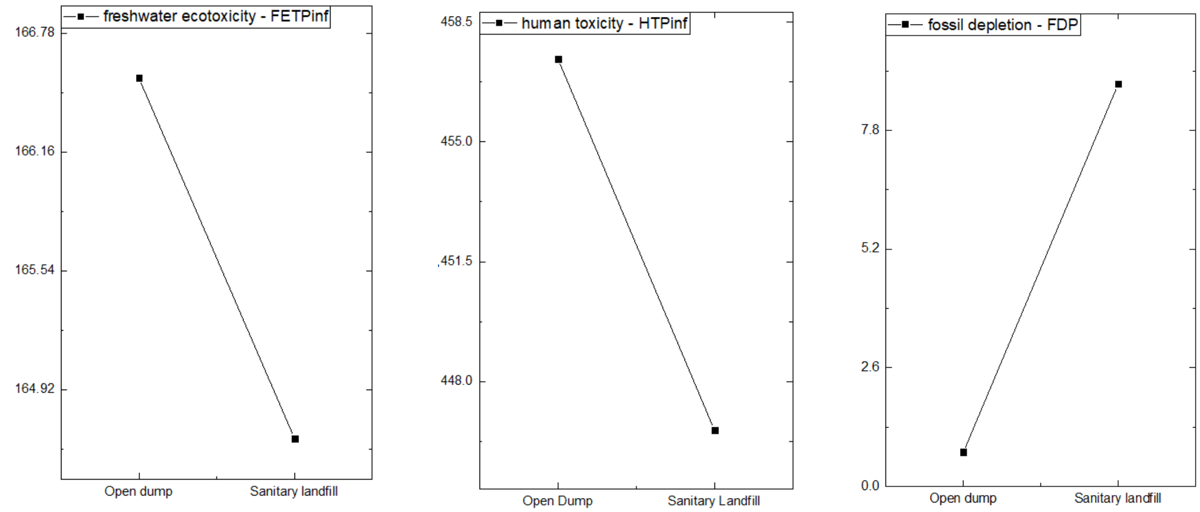
Freshwater ecotoxicity is an environmental impact category that assesses the potential ecotoxic impacts of chemicals on aquatic and terrestrial ecosystems. Ecotoxic material harms the environment by reducing the lifespan of aquatic animals, disintegrating the possible diversity of the species it indirectly causing harm to human health. In this study, the open dump has a slightly greater impact on this category than the sanitary landfill, whereas S4 has the lowest impact among all of the scenarios.

3.7 Relative Results

Comparative results of the impact categories in terms of four scenarios are illustrated in Figure 3. The analysis of the result indicates that in most of cases, the environmental impact of open dumps is much greater than sanitary landfills. Waste treatment by open dumps has much more adverse effects on the environment. As like in the 100% stacked column in Fig 3(a), open dump has a larger impact on human toxicity, freshwater eutrophication, and climate change than sanitary landfill. In terms of fossil depletion, sanitary landfill has more impact the open dump. But in freshwater ecotoxicity, the result came quite equal for the two scenarios, slightly larger for open dumps as well.
The variations in six environmental impacts according to open dumping vs sanitary landfill have been shown in Fig 4(a), 4(b), 4(c), 4(d), 4(e), and 4(f) from the data generated by openLCA software. On average, a higher peak point has been noticed in an open dump in four out of six categories. That indicates the more adverse environmental impact open dump contributes than sanitary landfill.



(a) (b) (c)



(d) (e) (f)

Figure 4: Variations of six impact categories on Open Dumping vs Sanitary Landfill; a) Water depletion, b) Freshwater eutrophication, c) Climate change, d) Freshwater ecotoxicity, e) Human toxicity, f) Fossil depletion

4. CONCLUSIONS

In this study, LCA has been carried out on MSW to find the most sustainable waste management practice in Khulna city of Bangladesh. Four baseline scenarios have been considered here for the study of LCA including open dumping, sanitary landfill, combined scenario for open dumping and the sanitary landfill (40% to open dump and 60% to sanitary landfill) and combined scenario for open burning, open dumping and sanitary landfill (10% to open burn, 35% to open dump and 55% to sanitary landfill). Among the four considered scenarios, sanitary landfills have shown the least average impact among the six environmental impact categories. The result showed that climate change, freshwater eutrophication, freshwater ecotoxicity, and human toxicity has a higher impact collaborated with solid waste treatment and management via open dumping than sanitary landfill. In average, sanitary landfill showed quite low impact according to the six impact categories. Water depletion rate was high in sanitary landfilling whereas, scenario 4 has the highest impact on climate change but sanitary landfilling was quite low in that case. Scenario 2 showed the significant amount of concern for fossil depletion providing the highest impact result but S3 imprinted the greatest result on freshwater ecotoxicity impact category. In freshwater eutrophication impact category open dump reflected the highest score and scenario sanitary landfill showed the lowest score. Scenario 4 has the greatest impact on human toxicity whereas scenario 2 has the lowest one. The results from this study can help to make necessary decisions for future solid waste management programs in Khulna city. Moreover, sanitary landfill has leachate collection system and liners which is not provided in an open dumping site, this includes also a matter of concern. So, installing a sanitary landfill in Rajbandh and Sholua instead of open dumping can be a better waste management scenario which is also more eco-friendly.

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