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Resource recovery from existing landfills: A Case study

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ABSTRACT

In developing countries, over 65 to 80 percent of municipal solid waste (MSW) is disposed of in landfills. The major fraction of the MSW (50-70%) is of organic origin, and the rest are recyclable components (20-30%) and an inert fraction (5-10%). Resource recovery from landfills includes converting the organic fraction into compost, separating recyclable components like paper, textiles, and plastics, and converting them into refuse-derived fuel (RDF) or new products. This paper looks at the potential of waste recovery from the Bellahali landfill in Bangalore, Karnataka. Landfilled waste from the site is sampled and characterized based on the physical composition, moisture content, volatile content, particle size and CHNOS analysis. The organic fraction of the MSW is 50.71 %, and RDF is around 36%, including paper, plastic, and textiles. Resource recovery potential is estimated based on compost and RDF production. Therefore, two scenarios were considered in the study, Scenario 1, landfilling of MSW, which represents the current practice and Scenario 2, the resource recovery from existing landfills and landfilling the reject. Later, the carbon dioxide equivalent emission rates are estimated from both scenarios. The emission rates were 2.75 times higher in the baseline scenario compared to Scenario 2. The study clearly shows that with minor changes in waste management practices, substantial reductions in carbon emissions can be attained in Bangalore City.

Keywords: Landfill, Resource recovery, Landfill mining, Characterization, Emissions

1 INTRODUCTION

Municipal solid waste management is a significant problem worldwide due to increased waste generation. MSW generation rate depends on factors like population growth, consumption pattern, season and climatic condition. Treatment of MSW is primarily inadequate due to insufficient budgetary allocation and low economic returns (Diaz-Barriga-Fernandez et al., 2018). Nevertheless, landfilling is considered the most economical means of waste disposal. Bangalore, the second-fastest-growing metropolis in India, generates around 5000 tons of solid waste per day at an average solid waste generation rate of 0.5 kg/capita/day. The Bruhat Bangalore Mahanagara Palike collects about 60% of the waste; only 15% is processed while the remaining waste is illegally dumped (Chanakya et al., 2017). In Bangalore's urban and rural areas, illegal dumping and burning waste are abundant, and recycling is limited. These unauthorized open dumpsites pose significant threats to health and the environment due to gas emissions and the release of contaminants into soil and groundwater. Open dumpsites and landfills have been the ultimate end-of-life sink for materials. On the other hand, these can be the potential secondary resource reservoirs that can be recovered by landfilling mining.

Landfill mining (LFM) is a process of extracting minerals or other solid natural resources from waste disposed of by burial in the ground(Krook et al., 2012). The benefits of the landfill mining process include an increase in resource recovery, financial gain, landfill volume recovery and an overall reduction in environmental risk (Parrodi et al., 2019; Quaghebeur et al., 2013). Implementing the remediation and resource recovery from landfills requires a thorough understanding of the quantities and qualities of landfilled waste (Edjabou et al., 2015). The extent of resource recovery from landfills depends on the waste management strategies adopted by the concerned authorities. The classic LFM approach aims to remediate the landfill site and minimize the cost of remediation by valorizing landfill waste. This approach is used to decrease the amount of waste re-landfilled by thermal and material valorization. Thermal valorizations include separation of high calorific materials such as plastic, paper, wood, and textiles among others for incineration or combustion. The moisture content, ash and metal content must be analyzed to ensure the energy conversion quality requirements (Yi, 2019). Material valorization is the separating of recycled material such as glass and metals from waste and transforming it into value-added products.

A comprehensive study of resource recovery potential from the Bangalore landfill site has been investigated as a sustainable waste management option. The emission rates from the existing landfill and the landfilled waste after resource recovery are estimated in the study. The potential for LFM was analyzed by characterizing the excavated MSW. Two scenarios considered in the study are: Scenario 1, landfilling of MSW, which represents the current practice and Scenario 2, the resource recovery from existing landfills and landfilling the reject.

2. METHODOLOGY

As the composition of waste varies from city to city within India, the results of a landfill mining study can differ significantly depending on the location. The characteristics of the waste being dumped depend on the initial segregation and handling of the waste, as well as the landfill design and management practices. Therefore, it is essential to conduct a site-specific study to understand the resource recovery potential of a landfill site. The factors that can affect the overall carbon emissions include the amount of biodegradable matter present in the waste, and the effectiveness of the landfill cover system in preventing the release of methane into the atmosphere. Climate conditions, such as temperature and precipitation, can also affect the rate of biodegradation and, therefore, the rate of methane emissions. Factors like the implementation of waste reduction and recycling programs, pre-processing of waste before landfilling, and post-closure management practices can affect the overall environmental impact of a landfill site. A site-specific study is essential to understanding the potential for methane emissions and carbon sequestration, and the overall environmental impacts associated with the landfill mining process in a particular location. Therefore, a preliminary reconnaissance survey was conducted at the site, followed by the collection of MSW samples for further physical and chemical characterization which will be explained in detail in the following sections. Subsequently, two scenarios were examined. The first scenario discusses the emissions resulting from the current landfilling practices, while the second scenario explores the potential for resource recovery from landfill sites. Both scenarios will be detailed in the following sections.

2.1 Site characteristics

Bangalore is located at Latitude 13°50′ North, Longitude 77°36′ East in Karnataka. The MSW generated in Bangalore from 2016 to 2019 was disposed of in one of the abandoned quarry sites in Bellahalli. The Bellahalli landfill site satellite image is given in Figure 1. The site investigation involves examining the waste to understand the extent of degradation, moisture content, and combustible fraction. The waste is excavated from the landfill by removing the landfill covers. The excavated waste is separated into biodegradable, recyclable, combustible, non-combustible or inert components. The biodegradable fraction includes soil-like material rich in carbon, nitrogen and microorganisms that can be used as compost, bio covers (landfill covers) or fill soil. The recyclable fraction includes glass and metals. Paper, plastics, textiles and wood are considered combustibles fraction. The residual waste is inert and re-landfilled.

2.2 Physical properties

The physical properties of the MSW are analyzed by representative sampling. The representative sample is collected by stacking and dividing the excavated waste into four quarters. One-quarter of the sample is taken for analysis and sorted into different fractions above 75 mm, between 20-75 mm and less than 20 mm. The physical composition was carried out by manual sorting into plastics, paper, organic, textiles, metal etc. Weight ratios of different components were estimated to calculate the moisture content, combustible fraction, and ash content. The size analysis of the waste was performed with a sieve ranging from 0.015 to 75 mm according to ASTM D422 (2007) standards. The moisture content of the MSW fractions was estimated by measuring the sample's weight difference after heating at 70°C.

Figure 1. *Bellahalli Landfill Satellite image*

2.3 Chemical properties

The combustible fraction was estimated by heating the sample for 2 hours at 550°C in a muffle furnace. The elemental analysis was carried out to determine the elemental carbon, hydrogen, oxygen, nitrogen and sulphur contents in the excavated waste. The modified Dulong formula was used to estimate the waste's energy content, which is as follows:

$$\text{Energy content} = 145\text{C} + 610 * \left(\text{H} - \frac{\text{O}}{2}\right) + 40\text{S} + 10\ \text{N} \qquad (1)$$

2.4 LandGEM emission model

The LFG emissions from Bellahalli landfills are estimated for 25 years using Landfill Gas Emissions Model (LandGEM). LanddGEM model estimates the emission rates for total landfill gas (TLFG), CH_4, CO_2, non-methane organic compounds (NMOCs) and individual air pollutants from MSW landfills. The LandGEM model was developed by US EPA (2005) and is based on the first-order decomposition as follows:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \frac{M_i}{10} e^{-kt} ij \qquad (2)$$

where Q_{CH4} is the annual methane generation in the year of calculation (m^3/year); i is the one-year time increment; n is equal to the year of analysis from the initial year of waste acceptance; j is the 0.1-year time increment; k is the methane generation rate ($year^{-1}$); L_0 is the potential methane generation capacity (m^3/Mg); M_i is the mass of waste accepted in the ith year (Mg); t_{ij} is the age of the jth section of waste mass received in the ith year.

The data used for the computation of LFG emission from landfills is given in Table 1. The landfilled waste, area and height are obtained from Bruhat Bengaluru Mahanagara Palike (administrative body responsible for Greater Bengaluru metropolitan area). The methane generation rate(k) and the potential methane generation capacity were obtained from Sughosh et al., (2019). The methane generation rate is primarily a function of four factors: availability of nutrients for microorganisms that break down waste to form methane and carbon dioxide, moisture content, pH and temperature of waste mass. The amount of methane (m^3) generated per Mg of decomposed MSW is known as methane yield. It depends on landfill type and composition. The model assumes 50% CH_4 and 50% CO_2, with traces of NMOCs and other air pollutants.

***Table 1.** LandGEM model input for Scenario 1*

Features		**Units**
Landfilled waste	12,77,500	Mg/year
Waste acceptance	2016 - 2019	year
Methane generation rate, k	0.039	per year
Potential methane generation capacity L_0	71.44	m^3/Mg
Methane content	50	%
Time frame	25	years
Area	1.01 x10^5	m^2
Average height (m)	25	m
Precipitation (mm/year)	905	mm/year

3. RESULTS AND DISCUSSION

3.1 Physical properties of landfilled MSW

The particle size distribution of the MSW excavated from the Bellahalli site is shown in Figure 2. Around 82 % of the particles were less than 20 mm, and only 6.46 % were greater than 75mm of the excavated fraction. The physical composition of MSW is represented in the three fractions i) greater than 75 mm, ii) greater than 20 mm (75mm -20 mm) iii) less than 20 mm (Figure 3). The major components in greater than 75mm fractions consist of plastics (38.84%), textiles (28.08%), organics (20.51%) and paper (10.96%). Plastics, textiles and paper are used to make RDF due to the high calorific value. A small fraction of the total waste (6.91%) has a particle size in the range of 75mm and 20mm, with organic matter (30.52%), plastics (16.29%), and paper (21.49%) as major constituents. The components dominating less than 20mm fractions are organic matter (57.97%), paper (10.13%) and plastics (8.56%). The inert materials include stone-11.58% and glass-1.72%. In large scale recovery, the efficiency depends on the physical and chemical conditions of landfill and efficacy of the equipment's used and the quantity of recovered fine soil fraction is a crucial factor in landfill mining, as it can be utilized for various purposes such as covering or lining of new landfills or backfilling in a more environmentally friendly manner (Krook et al., 2012).

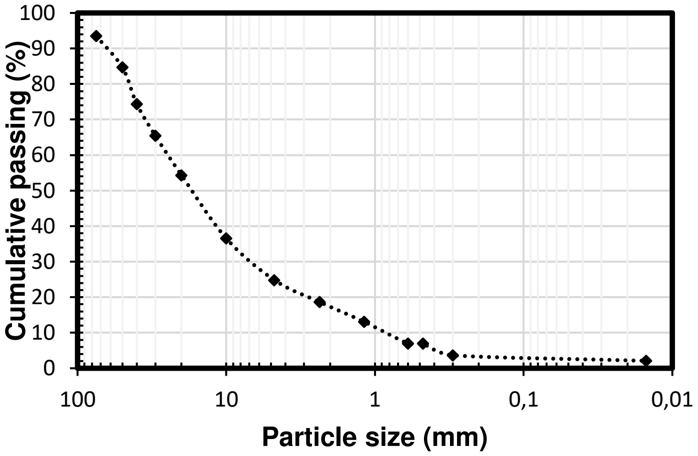

***Figure 2**. Particle size distribution of excavated waste*

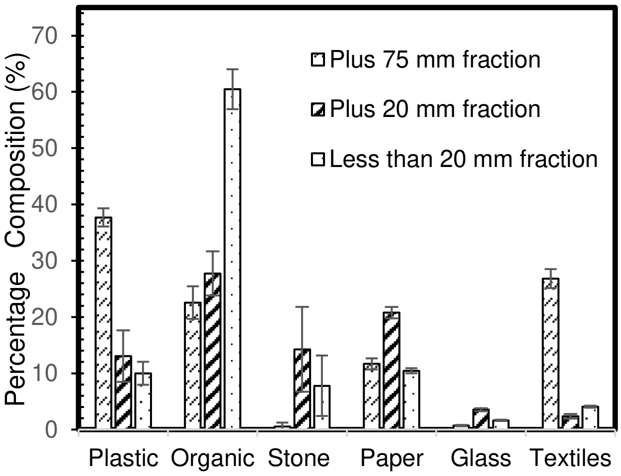

Figure 3. *Percentage composition of major components in MSW*

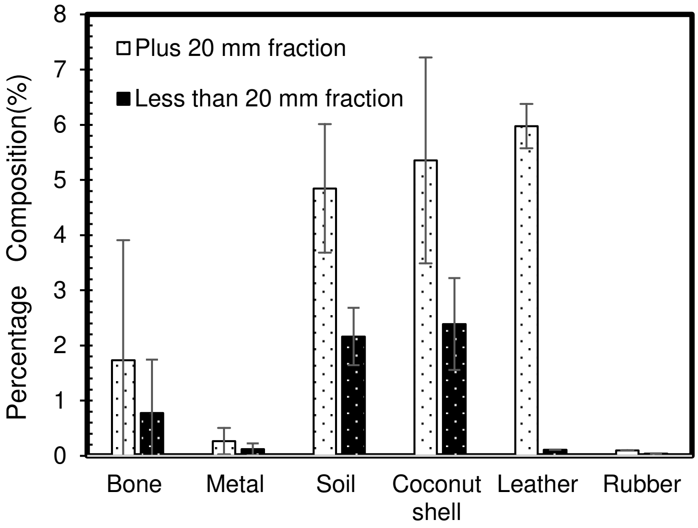

Figure 4. *Percentage composition of minor components in MSW*

3.2 Chemical properties of landfilled MSW

Excavated landfills have different moisture content due to several factors such as the quantity of daily and final cover material used, screen opening sizes, landfill type and waste type, compaction level, landfill age, and local conditions like moisture content and composition. Considerable variation in the moisture content of the individual MSW fractions is observed (Table 2); nevertheless, the average moisture content of the waste was around 40 %. The volatile solids (organic content) of the MSW fractions, such as the plastics, paper, textile, and wood, were in the range of 75.68 – 81.8 % (Table 2).

***Table 2**. Physical composition of excavated waste*

Waste component	**% By wet weight**		
	Moisture content	**Combustible**	**Total Solid**
Organic	41.81 ± 4.87	79.61 ± 5.55	58.82 ± 4.87
Plastic	-	79.52 ± 0.34	-
Paper	41.81 ± 6.09	77.83 ± 8.01	58.19 ± 6.09
Textiles	25.13 ± 6.36	81.80 ± 4.33	74.87 ± 6.36
Inert/ Incombustible	5.65 ± 0.27	-	94.35 ± 0.27

The amount of recovery also depends on the moisture content and decomposition rate. The carbon, hydrogen, nitrogen and oxygen content (CHNO) of MSW was found to be 41.34, 72.51, 2.64 and 23.37%, respectively. The energy content of the MSW calculated from the CHNOS value using modified Dulong's formula is around 2.326 kJ/kg of MSW.

3.3 Scenario 1

Scenario 1 represents the current practice of Bangalore city, which is landfilling of MSW. The LandGEM model was used to estimate the total landfill gas emission. Landfill gas (LFG) emission is one of the major environmental impacts of the landfilling activity, and its quantification for a period of 25 years constitutes the baseline scenario. The total LFG emission over a 25-year period is estimated as 4.81 x $10^{\wedge 8}$ m^3. The LFG emission is predicted to peak by 2020 (2.64 x $10^{\wedge 7}$ m^3/year) and gradually reduce thereafter (Figure 6).

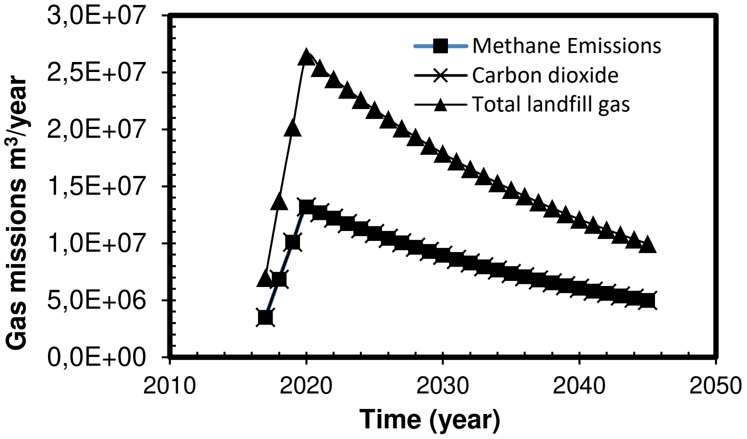

Figure 5. *LandGEM model output for scenario 1*

3.4 Scenario 2:

In this scenario, MSW is excavated, and resource recovery potential is estimated based on RDF production and composting of residual organic fraction, and the inert fraction is re-landfilled. Reusing soil fraction or compost poses a significant challenge due to the high risk of material contamination, which must comply with national or local criteria. Unfortunately, landfills may contain high levels of hazardous substances and heavy metals. Therefore, it is essential to conduct proper testing and analysis to determine the suitability of the recovered materials for other applications that are both safe and sustainable. The flow chart depicting scenario 2 is shown in Figure 6, assumes that material contamination is within the limit of national standards. The assumptions can be easily achieved by proper segregation of the hazardous waste before placing in landfills.

Based on the physical composition data, the RDF recovery potential from the mined waste is around 29.56%, amounting to 10,57,231 tons. Plastic and paper fractions constitute about 78.5% of RDF. The primary challenge when it comes to marketing RDF is necessary quality. Additionally, in some regions, a lack of waste-to-energy facilities to consume combustible materials serves as another obstacle. In most cases, the intermediate-sized and oversized materials that cannot be recycled are reburied within the landfill's mined area. Therefore, the fractions larger than 20 mm are assumed to be disposed of back into the landfill. The fractions less than 20 mm can be windrow composted to yield around 5,27,129 tons of compost. The compost rejects are further landfilled. The emission from the composting process is estimated using a stoichiometrically balanced aerobic equation. As per this equation, the carbon dioxide and ammonia emissions from the composting process are 26,86,921 tons and 63,614 tons, respectively.

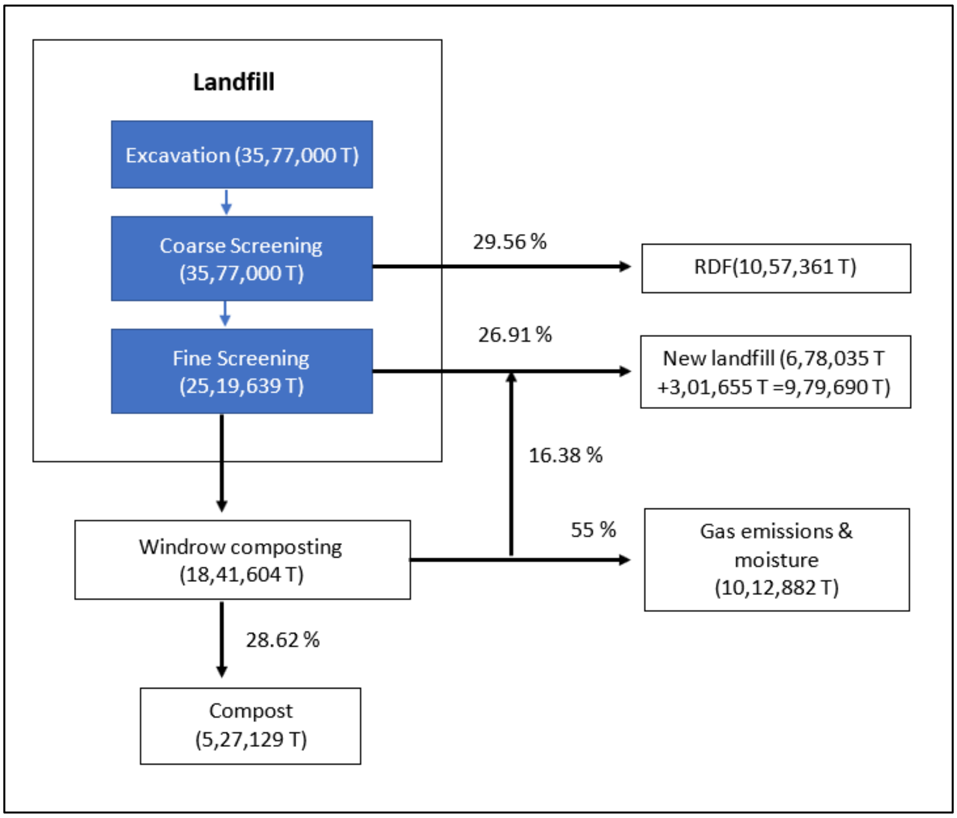

***Figure 6**. Material flow diagram of scenario 2*

The total emission from re-landfilled material is estimated using LandGEM and was found to be 1.77E+06 Mg (CO_2 equivalent) (Figure 7). The methane and CO_2 emissions contribute to global climate change, and the long-term impact of such emissions remains uncertain. However, the damage or economic value of landfill emissions can be offset by utilizing CO_2 credits to provide financial support for landfill mining projects and land reclamation efforts.

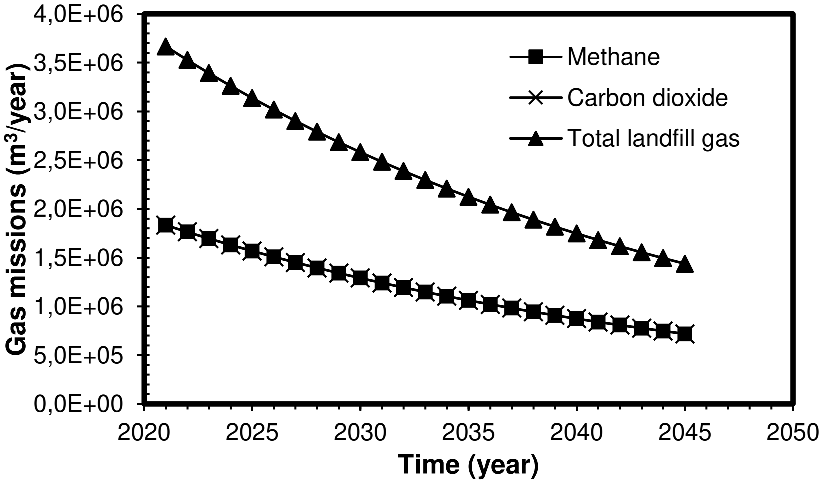

***Figure 7.** LandGEM model output for scenario 2 after re-landfilling the reject*

3.5 Estimation of total emissions

The total emission from each scenario is estimated and converted in terms of CO_2 equivalent. Compared to the baseline scenario, resource recovery from the existing landfill was found to reduce the emission by a factor of 2.75. Additionally, the byproducts, such as the compost and RDF, are recovered beneficially. Table 4 shows the total emission from both scenarios. The landfill emissions in scenario 2 is considerably reduced by 6.89 times due to the reduction in the quantity of waste landfilled.

Table 3. *Total emissions from scenarios (as CO_2 equivalent)*

	Composting CO_2 equivalent (Mg)	Landfilling CO_2 equivalent (Mg)	Total emissions CO_2 equivalent (Mg)	$\frac{\text{Scenario 1}}{\text{Scenario 2}}$
Scenario 1		1.22E+07	1.22E+07	2.75
Scenario 2	2.69E+06	1.77E+06	4.45E+06	

3.6 Landfill mining economic feasibility for developing nations

Landfill mining can be a costly process due to the large quantities of unprocessed waste that need to be excavated and processed. However, there are several economic benefits to performing landfill mining that can make it feasible for cities in developing nations.

- Landfill mining can recover valuable materials such as metals, plastics, and glass, which can be sold for a profit. These materials can be used as raw materials in new products, reducing the need for expensive mining and extraction of virgin materials. The refuse derived fuel (RDF) obtained from landfill mining can be sold to nearby cement plants. This can generate revenue and reduce the need for expensive fossil fuels in the cement-making process.
- Landfill mining can help to reduce the costs associated with waste disposal. By removing waste from the landfill, the remaining volume of the landfill is reduced, which can extend its lifespan and delay the need for costly expansion or construction of new landfill sites. Furthermore, preventing the contamination of new sites as well as handling the environmental and societal protests that can arise from the construction of new landfill sites.
- Landfill mining can help to reduce environmental pollution and associated costs. When waste is left unprocessed, it can release greenhouse gases, leachate, and other harmful pollutants into the environment, which can have negative impacts on human health and the environment. By removing and processing the waste, these harmful impacts can be mitigated.
- In some cases, governments or other organizations may provide financial incentives or grants to support landfill mining activities, further making it economically feasible for cities in developing nations. Overall, while landfill mining can be a significant investment, the potential economic and environmental benefits make it a viable option for cities in developing nations.
- Methane and CO_2 emissions play a significant role in global climate change, and the full extent of the cost of global warming is yet to be realized. However, it is possible to mitigate the damage or economic impact of landfill emissions by using CO_2 credits, which can be transferred to support financial initiatives for landfill mining projects and land reclamation efforts. Nonetheless, if implemented correctly, carbon credits can provide an incentive for companies to reduce their carbon footprint and invest in more sustainable practices.

The resource recovered from landfills must be carefully evaluated before being used in any application to ensure that it is environmentally friendly. Landfill materials may have come into contact with toxic components and may have a capacity for leaching, which can lead to environmental contamination if not handled properly. Additionally, the use of recovered materials should be considered within the larger context of sustainability. The goal should be to reduce the use of virgin materials and minimize the environmental impact of production processes. However, this must be balanced against potential risks associated with the use of recovered materials. Therefore, it is important to conduct a lifecycle analysis to understand the overall environmental impact of using recovered materials in any application. This analysis should take into account the potential for leaching, as well as the energy required for transportation, processing, and any necessary treatment of the recovered materials. The authors cannot claim that any placement of landfill material in any application is environmentally friendly without careful evaluation and testing to ensure that the recovered materials meet environmental and safety standards. In the absence of leachability test results, the safest use of recovered landfill materials is for daily cover for landfills. This helps prevent the mobility of contaminants from the site to other locations. It is important to note, however, that the use of recovered materials should be considered within the larger context of sustainability. While daily cover is a safe application, it is not a sustainable long-term solution. Therefore, it is essential to conduct proper testing and analysis to determine the suitability of the recovered materials for other applications that are both safe and sustainable.

4. CONCLUSION

In this paper, the resource recovery potential from the Bangalore landfill site has been investigated as a sustainable waste management option. The study showed that landfill resource recovery would be beneficial in reducing greenhouse gas emissions and simultaneously help recover secondary resources in the form of RDF and compost. The energy content of the MSW is estimated to be around 2.326 kJ/kg of MSW. The overall RDF recovery potential is found to be around 10,57,361 tons in Bellahalli landfill site. Scenario 2 (LFM + resource recovery + landfilling of rejects) is found to be 2.75 times better than the baseline scenario in terms of the emission over a 25-year time period. The study reveals the potential of landfills and open dumps in Bangalore as a source of energy and material valorization. The costs of land reclamation can often be mitigated through the sale or utilization of recovered materials, which may also be used as a fuel source. In addition to these benefits, landfill mining can help to avoid liability through site remediation efforts, reduce closure costs, and reclaim land for alternative uses. The study can be further extended to estimate the life cycle assessment of environmental and health impacts associated with the process of waste excavation handling and material recovery.

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