ESTIMATION OF LANDFILL GAS EMISSIONS, ENERGY RECOVERY POTENTIAL AND LCA TO ASSESS THE WASTE MANAGEMENT PRACTICES IN BANGALORE CITY

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Abstract - *Bengaluru produces around 5,500 tonnes of municipal solid waste every day with a collection efficiency of 80%. Bengaluru's urban population and waste-generating resources have increased rapidly in the last decade. Gas emissions from landfills were estimated using LandGEM-3.02 version. Methane production rate constant (k) and methane production potential (L_0) were determined using the theoretical method. The estimated maximum buried gas volume is 3,083 × 10^7 cubic meters/year, and methane emission is 1,542 × 10^7 cubic meters/year. The energy recovery capacity of Bengaluru's MSW can produce 1724.2 TJ of methane and 54 MW of electricity. Life cycle analysis is done to understand which management is better. In the study, existing conditions such as open dumps and waste storage areas were considered. Traditional disposal options have proven to be the better option between the two options. On the other hand, research predicts that choosing traditional landfills instead of open landfills can reduce global warming potential (GWP). Therefore, a waste management system that includes waste materials and energy recovery is not only a good choice for the environment, but also a sustainable, robust and useful choice.*

***Key Words*: LandGEM model, Energy recovery potential, Life cycle analysis.**

1.INTRODUCTION

Municipal solid waste (MSW) is a general term used for wastewater generated from household waste, construction and demolition waste, wastewater treatment, and municipal waste. The resulting waste must be stored, treated, transported and disposed of in regular landfills. Landfills are low-level places used for the disposal of waste. In India, SWM still operates illegally. As of 2023, India's population is 1.42 billion, 31% of whom live in cities. Additionally, half of India's population is expected to live in cities by 2050. As the country's population increases, municipal waste management has become a major problem, not only due to environmental and aesthetic concerns, but also because large amounts of waste are produced every day.

Bangalore produces around 5500 tonnes of waste every day and the waste rate is 85%. Waste generation is 0.6 kg/person/day (BBMP 2022). Municipal solid waste per capita is expected to increase by 1-1.33% per year (BBMP). After municipal waste is recycled and composted, the remaining waste goes to landfills. After a while, waste rots in landfills and harms the environment by releasing pollution and greenhouse gases. During rain, leachate is produced and pollutes the soil. Landfill gas (LFG) is produced as a result of the decomposition and biochemical reactions of solid waste in landfills. The main gas composition is 40-50% carbon dioxide and 50-60% methane (Ramprasad et al. 2022). Garbage thrown into landfills undergoes anaerobic decomposition by microorganisms and emits landfill gases. Gases such as methane and carbon dioxide found in the soil are important in terms of greenhouse gas production. Methane emissions and energy potential of a landfill can be estimated by various methods. The most commonly used models are the IPCC preset method, Yedla S method, first-order attenuation model and LandGEM model. Geological Geological Survey (LandGEM) has been investigated and reported as a suitable model for estimating oil and energy recovery (Ramprasad et al. 2022).

Bengaluru's waste disposal system was developed from open landfills. Waste management systems including separation, composting and controlled burial have been implemented at the existing landfill. Examining the impact of current or past waste management in Bangalore will help in understanding the environmental burden associated with the waste management process. Life cycle assessment (LCA) of processes operating in waste treatment plants will help understand their impacts and therefore make important policy decisions (Sughosh et.al. (2019).

Various lifecycle research studies on open dumping, composting and landfilling (known) practices are reported in the literature. Sharma et al. (2017) examined six solid waste management options in Mumbai, India, and concluded that options combining recycling, composting, and disposal had the least eutrophication and minimal human potential toxicity. They also say that significant environmental savings can be achieved through energy recovery from all waste management options.

Scientists studied gas pollution in Bengaluru and other parts of the country. Landfills emit greenhouse gases that affect the environment and affect health by causing global warming. Using different models to understand carbon emissions from landfills, scientists conducted research and found that recycling reduces global carbon emissions due to combining, burning and recycling. In this study, LandGEM is a practical tool used to estimate the total waste emissions, methane, carbon dioxide, non-methane organic compounds (NMOC) and energy potential of Bangalore landfills left in the city. A life cycle assessment approach was used to evaluate the effectiveness of the currently proposed waste management system in Bangalore city. This study focuses on the analysis of emissions and energy recovery from landfills and LCAs using the LandGem tool to evaluate waste management practices in landfills.

2. METHODOLOGY

The Figure 1 shows the complete methodology adopted in the present study.

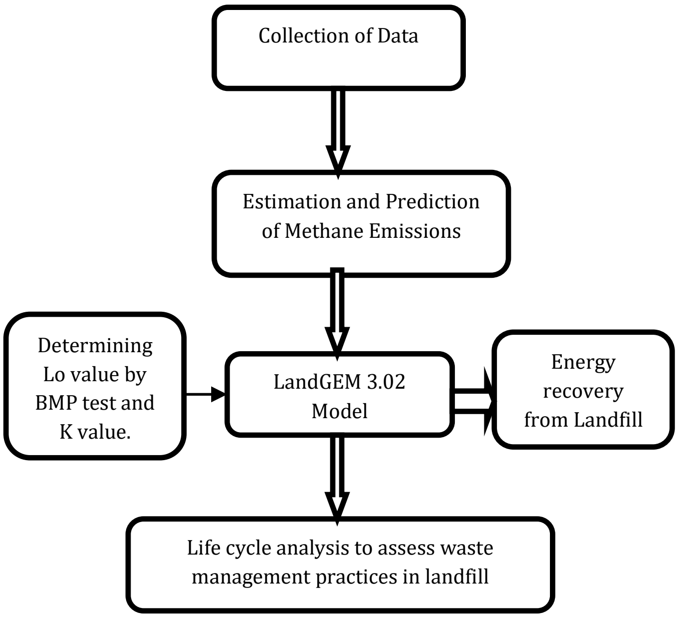

Figure 1: Methodology Flowchart

2.1 Study Area

Bangalore is situated in the southeast of Karnataka, at an average elevation of 920mabove mean sea level. It is positioned at 12.9716° N latitude, 77.5946°E longitude and covers an area of 1741sq.km. According to Census 2011 information the location code or village code of Mittaganahalli village is 613065. Mittaganahalli village is located in Bangalore East taluka of Bangalore district in Karnataka, India. It is located 13.1090° N latitude and 77.6622° E longitude. The total geographical area of village is 135.24 hectares. Mittaganahalli has a total population of 1,010 peoples, out of which male population is 545 while female population is 465. Literacy rate of mittaganahalli village is 39.90% out of which 44.40% males and 34.62% females are literate. There are about 266 houses in mittaganahalli village. Pincode of mittaganahalli village locality is 562149.The environmental conditions of mittaganahalli are Temperature -30.0°C, Humidity -44.0%. The dumping site at Mittaganahalli village which is located 0.6 km from Kannur Road at Bangalore. The site is spread about 10 acres area and it has capacity of 2800-3000 TPD (Tonnes per day). The waste is received from 198wards from Bangalore in 372-380 vehicles and capacity of vehicle is 8-9 tonnes, Maximum distance travelled by vehicles is 56-60km (BBMP 2022). Fig:2 shows the location map of the study area. Table 1: Composition of MSW.

Figure 2: shows the location map of the study area.

Table 1: Composition of MSW

Waste type	Percentage (%)
Clothes	6.34
Plastics and papers	28 &12
Leather	0.8
Glass	1.28
Rubber	0.88
Metals	0.23
Stones	1.96
Organic waste	42-48

(source: BBMP report, 2022)

2.2 LandGEM Model

Landfill Gas Emission Model (LandGEM) version 3.02 is a Microsoft Excel-based software for estimating the LFG, CH4 and CO2 content of municipal solid waste. It was established by the United States (US) Environmental Protection Agency (EPA). The software uses a first-order equation. Equation (1) shows that the first-order decomposition value equation is as follows:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k * Lo * \frac{Mi}{10} * e^{-k*ti,j} \qquad (1)$$

where

Q_{CH_4}= annual methane generation in the year of the calculation (m3/year)

i = year wise increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1-year time increment

k = methane generation rate (year-1) and it is determined by following formula equation 2:

$$k = 3.2 \times 10^{-5} (R) + 0.01 \qquad (2)$$

Where R is the average annual precipitation in mm. The average annual precipitation of Bangalore is 1958.6mm (India Meteorological Department 2022) respectively

Lo = potential methane generation capacity (m3/Mg) and it is determined by BMP test.

Mi = mass of waste accepted in the ith year (Mg)

tij = age of the jth section of waste mass Mi accepted in the ith year (decimal years, e.g.,3.2 years).

Biochemical methane potential (BMP) Test

Biochemical methane potential (BMP) testing is a method to determine the methane potential (Lo) of the substrate under anaerobic conditions.

Materials and methods

The Sludge samples and wastes were collected from STP plant kengeri and Lingendarhalli processing plants. Parameter analysis of sludge samples is shown in Table 5. Biochemical methane potential (BMP) testing is a preliminary study designed to investigate the ability of the substrate to produce methane. This test was performed using 70% of the working volume and leaving 30% headspace. The substrate/inoculum ratio (SIR) was set to 1:2. From the vial volume of 125 ml, a working volume of 87.5 ml is represented by 58.5 ml of inoculum and 10 g/L substrate concentration (substrate and distilled water). The vial contains substrate and vaccine. Before capping each vial with a rubber cap, nitrogen gas (N2) was blown into each vial for approximately three (3) minutes to ensure an anaerobic environment (Rodrigues et al., 2019). Place all bottles in the oven at 37°C (medium temperature). Shake each bottle gently by hand for two (2) minutes once a day. According to Wang et al. (2017) noted that vibration affects the distribution of bacteria, bacteria, and temperature in the bottles and helps release bubbles in the solution into the head of the bottle water. The incubation period of this test is 3040 days. Methane gas was measured qualitatively by extraction with a syringe at a gas thickness of 1 ml and injected into an Agilent 8890A gas chromatography-flame ionization detector (GC-FID) instrument.

2.3 Energy Recovery Potential

This paper follows the method of Yedla S (kumar et al (2014)) to estimate the energy and associated electricity produced by methane. The total energy produced annually from waste using LFSGR is given by Equation 3:

$$E_r = (W_a \times f_{1f} \times f_{a-doc})(r_{1fg} \times f_{methane})\,\Psi \times \omega \qquad (3)$$

where, E_r, energy potential from gas recovery (kcal); W_a, annual waste generated (tons); f_{1f}, fraction of waste to be land filled; f_{a-doc}, fraction of assimilable organic carbon in the degradable waste; r_{1fg}, methane generation rate (m3/t); $f_{methane}$, fraction of methane in landfill gas; Ψ, gas collection efficiency; ω, calorific value of methane (kcal/m3). Eq. (3) was used to estimate energy potential from methane for MSW in Bangalore.

2.4 Life Cycle Analysis

Life cycle assessment (LCA) can be used as a decision-making tool to select the most sustainable, economic and environmental land disposal options. It is a tool used to analyse the environmental burden posed by a product or activity throughout its life cycle, or "cradle to grave" (Finnveden, 1999). LCA has four phases: Purpose Definition and Scoping, Product Analysis, Life Cycle Assessment, Interpretation or Development Assessment.

Two MSW treatments are discussed here. The first option considers treating only a small part (10%) of the collected waste by mixing, with the remainder (90%) being disposed of directly through open landfill. This was very common in Bengaluru in the early 2000s. The second option is to consider treating waste through mechanical and biological (such as mechanical analysis and aeration) pretreatment before burial. This represents the current situation of Bangalore city, where solid waste treatment is almost equal to electricity generation capacity. Gases from traditional landfills are emitted directly into the atmosphere. Compare the impact of each disposal method and choose the best option with the least impact on the environment.

Scenario 1:

An open dump is a place where no power lines are installed and is used as a temporary or permanent dump. This approach has no initial cost, but its environmental impact is serious because water leaks can damage soil and groundwater, and emissions can also harm the air. The limit in this example is landfill and transportation cost only. Minor compaction and leveling works were carried out on the field. Figure 3 shows the system boundary for the open dump.

Scenario 2: Conventional landfill

Municipal waste is fed into drum screens of different sizes (200 and 100 mm) to recover recyclables and electronic products. Municipal waste passing through a 100 mm drum sieve is composted. This waste is passed through a 16 - 4 mm drum sieve. The collected material (waste material) is then disposed of in landfills. The product from 4mm is compost sold as natural fertilizer. In the landfill, before the waste enters the landfill, a 200 GSM geomembrane is first placed on the ground and then the waste layer is placed at a height of 18 m. When the waste reaches a height of 18 m, 200 GSM geotextile is placed on the waste. A 300 mm layer of gravel was placed on top of the geotextile layer to control the gas. Then soil layer is placed, then 150 gsm layer is placed on which 200 gsm geotextile liner, HDPE line and then 200 mm gravel layer is placed, then another 200 gsm geotextile layer is placed and then soil is placed and then 450 mm thick soil is placed. The top layer is covered with grass. HDPE liner reduces the upward movement of embedded gas and the downward movement of rainwater. Figure 4 shows the system boundary of a Conventional landfill, and Figure 5 shows the landfill liner system.

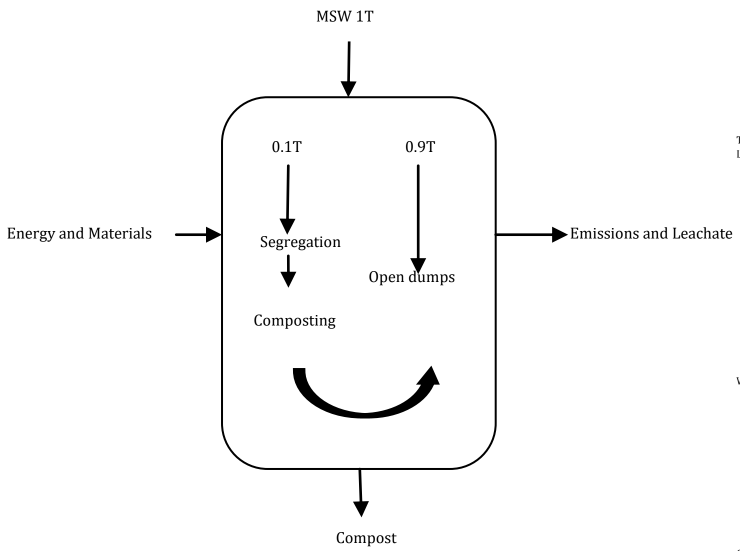

Figure 3: shows the System Boundary of open dump.

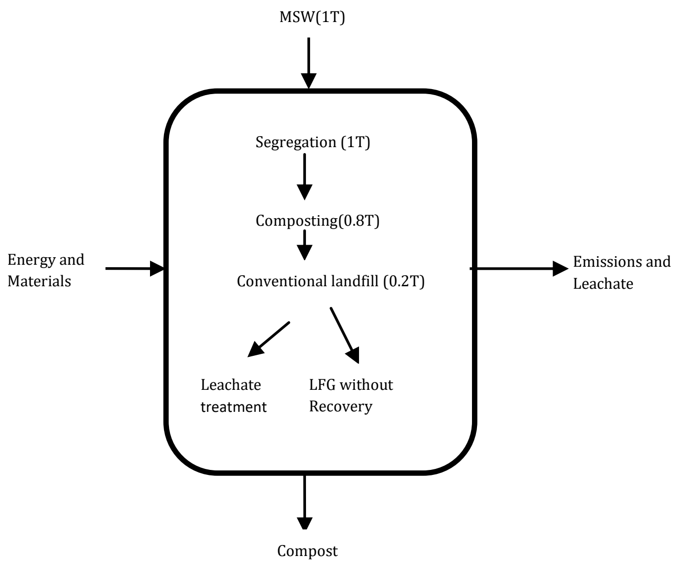

Figure 4: shows the System Boundary of Conventional landfill.

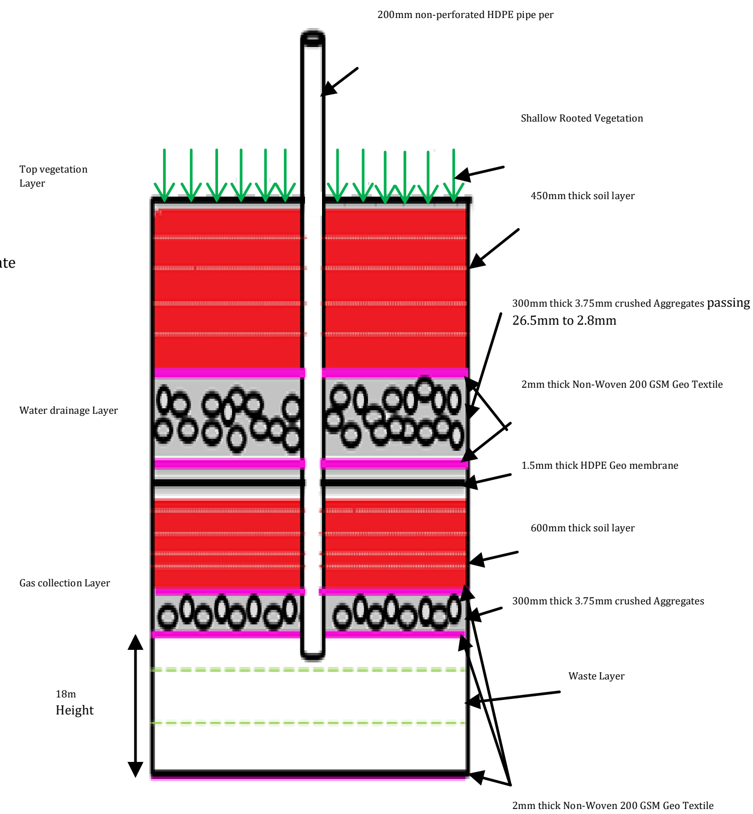

Figure 5: shows the landfill liner system.

Goal Definition and Scoping

The aim of this study is to evaluate the above-mentioned waste management in the city using the LCA method and estimate their impact on the environment. One ton of

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municipal waste was selected as a reference to compare municipal waste management practices. The diagram above shows the system limits for each scenario.

Current life assessment is done by taking inventory of materials and equipment related to Bangalore burial. Municipal waste, raw materials (lining, clay, petroleum products and solid waste) and energy (electricity and gas) are considered inputs to the body. The results of the system are compost, gas emissions and leaks from compost sites/open dumps/landfills. Table 2 shows the material/energy flow in the different processes included in the study.

IPCC		Eco-Indicator 95			
Resources	**Characterization Factors**	**Resources**	**Characterization Factors**	**Resources**	**Characterization Factors**
Global Warming Potential (GWP)		**Acidification potential (AP)**		**Photochemical ozone creation potential (POCP)**	
H_4	62	**Ox**	0.7	CH_4	0.007
O_2	1	**Ox**	1	Benzene	0.189
O	1.57	**H_3**	1.88	Ethene	1

Table 2: Unit processes showing the material/energy flow in different scenarios of LCA.

Life Cycle Inventory Analysis

Input analysis

The energy input comes from non-renewable energy (diesel). Fuel requirements for transportation and management, electrical requirements for operation and maintenance, cover and coating systems, leachate collection and treatment systems, gas collection systems and conversion systems are considered as inputs to the system. The first condition does not cover all of these except soil. This study focuses on the importance of materials that pose a threat to the environment by being released into the atmosphere and hydrosphere. The composition of waste produced in the city is shown in Table 1. After waste enters the body, it undergoes physical, mechanical and biological treatment and turns into different products. The demand for generators for open dumps and landfills is 0.88 L/T and 1 L/T respectively (BBMP Report, 2022). In recycling units and composting units, the amount of diesel and electricity required for one ton of waste is increased to 3.2L and 3.2kWh, 0.45L and 0.90 kWh, respectively (Sharma et al., 2017).

Output analysis

The results of this system are garbage emissions, open dump emissions, emissions, waste emissions as shown in Tables 7, 8, 9, 10 taken from the BBMP report (2022).

Table 3: Characterization factors based on equivalency factors from IPCC 2001 GWP for 20 years and Eco-indicator 95

Process	Material/Energy		Scenario
	IN	OUT	
Segregation	MSW Electricity: 3.2KW/T Diesel: 3.20 L/T	<100mm MSW Indirect emissions Gaseous emissions	1,2 1,2 1,2
Composting	<100mm MSW Electricity:0.90KW/T Diesel: 0.45 L/T	Compost Gaseous emissions; ammonia gas Indirect emissions	1,2 1,2 1,2
Open dumping	MSW waste Diesel: 0.88 L/T	Leachate; COD, BOD, NH_3, Ni, Zn Gaseous emissions LFG; CH_4, CO_2, SO_2, NOx, H_2S and VOCs	1 1
Conventional landfill	MSW waste Diesel; 1 L/T Liners Covers	Leachate; COD, BOD, NH3, Ni, Zn LFG; CH_4, CO_2, SO_2, NOx, H_2S and VOCs	2 2
Leachate Treatment	Leachate Electricity:0.25 MJ/T of waste	Treated Leachate Indirect emissions	2 2

Life Cycle Impact Assessment

Based on the life cycle characteristics of waste/waste treatment, consider environmental impacts such as global warming potential (GWP), acidification potential (AP), and photochemical ozone generation potential (POCP). Transportation of municipal solid waste often promotes acidification. The impact of each event is calculated by multiplying the equation (given in Table 3) by the equation.

3.RESULTS AND DISCUSSION

Landgem Results

Input Review:

- Landfill characteristics: Landfill Open Year: 2019, Landfill Closure Year (with 80-year limit): 2023, Actual Closure Year (without limit): 2023, Waste Design Capacity: 48,26,683

- Model parameters: k = 0.070/yr., Lo =66m3 /M, NMOC concentration =4,000ppmv as hexane, Methane Content: 50%.
- Gases / pollutants selected: Total landfill, Methane, carbon dioxide, NMOC.
- Waste Acceptance Rates

Waste Accepted		Waste-In-Place	
(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*
7,21,093	7,93,202	0	0
8,01,214	8,81,335	7,21,093	7,93,202
10,57,170	11,62,887	15,22,307	16,74,538
11,76,301	12,93,931	25,79,477	28,37,425
10,70,905	11,77,996	37,55,778	41,31,356

Table 4: Waste acceptance rates

- Graph

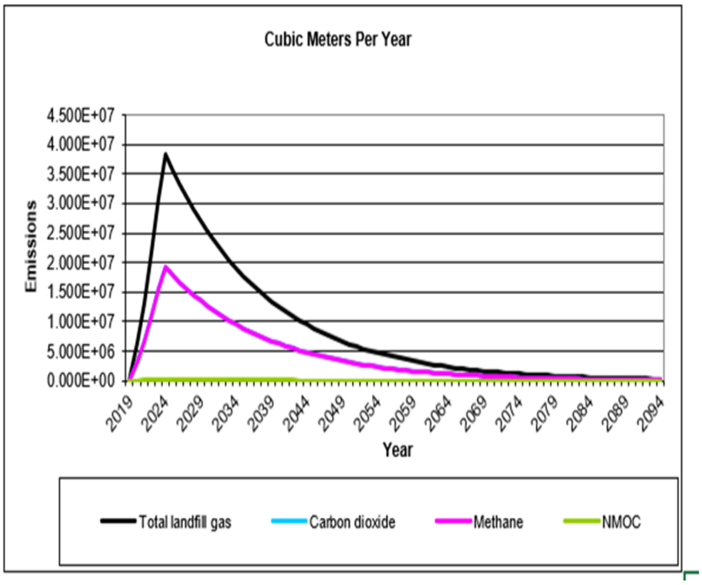

Figure 6: Total Landfill gas and Methane emissions from LandGEM model.

Biomethane potential test Results:

Table 5: **Analysis of parameters of sample for BMP.**

Sl.No.	Parameter	Protocol	Unit	Result
1	Colour	IS 3025 (Part 4) (Reaffirmed-2021)	Hazen	20
2	Odour	IS 3025 (Part 5) (Reaffirmed-2018)	-	Disagreeable
3	pH value @ 25°C	IS 3025 (Part 11) (Reaffirmed-2022)	_	6.5
4	Alkalinity	IS 3025 (Part 23) (Reaffirmed-2023)	mg/L	45
5	Bio-Chemical Oxygen Demand as O_2 (3 days @ 27°C)	IS 3025 (Part 44) (Reaffirmed-2023)	mg/L	4788
6	Chemical Oxygen Demand	IS 3025 (Part 58) (Reaffirmed-2023)	mg/L	13680
7	Total solids	IS 3025 (Part 15) (Reaffirmed-2019)	mg/L	18100
8	Volatile and fixed solids	IS 3025 (Part 18) (Reaffirmed-2022)	mg/L	8860
9	Ammonia	IS 3025 (Part 34)(Reaffirmed-2019)	mg/L	45.9

Result: The methane gas generation from BMP test was 66 m3/Mg.

ENERGY RECOVERY POTENTIAL RESULTS:

- Total waste collected (W_a): Bangalore produces 5,500 ton/day of waste and extent of waste collected (collection efficiency) ranges from 76 to 90 % of the waste generated. Taking value of 80 % as collection efficiency W_a =5,500× 365 × 0.80 = 1,606,000 tons.
- Fraction to be land filled (f_{1f}): composting accounts for 9-10 % of total waste and extent of recycling in Bangalore is very small. Neglecting recycled waste, a value of 0.9 is used for f_{1f} .
- LFG generation rate ($r_{1f,a}$): generation rate for methane was directly taken from L0 value. It may be noted that $r_{1f,a}$ reflects generation rate of methane directly and hence fraction of methane in LFG ($f_{methane}$)neglected. Table 6 presents the list of all parameters used for computations.

Table 6: Parameters adopted for Equation.

Parameters	Values
W_a t	1,606,000
f_{1f}	0.9
f_{a-doc}	0.6
r_{1fg} , m^3/t	66
$f_{methane}$	0.55
Ψ, %	80
ω, kcal/m^3	9,000

(Source: BBMP Report,2022)

The energy potential (kcal) was calculated as 1724.2 TJ. The equivalent power generated is P=54 MW.

Life Cycle Analysis Results:

Output analysis

Composting emissions: CO2= 2.45kg/T, CH4= 3.4kg/T, NH3= 0.11kg/T.

Table 7: Emissions from open dumps

Air environment		Leachate Emissions	
Pollutants	Emissions (Kg/T)	Pollutants	Emissions(mg/l)
Hydrogen	0.00475	Ammonia	240
Ammonia	6.89	zinc	1.7
Methane	736	nickel	0.2
NOx	0.00129	BOD	420
SO_2	0.00475	COD	1980
CO_2	630	-	-
CO	0.00276	-	-
Hydrogen sulphide	0.312	-	-

Table 8: Environmental emissions due to landfilling without energy recovery

Pollutants	Emissions (Kg/T)
VOC	0.0238
Methane	230
NOx	$8*10^{-2}$
SO_2	2
CO_2	370
HC	0.0071
Hydrogen sulphide	1.3
Carbon monoxide	0.0485

Table 9: Leachate emissions

Leachate emissions	
Pollutants	Emissions(mg/l)
Ammonia	500
zinc	0.32
nickel	0.02
BOD	280
COD	800

Table 10: Impact assessment results for scenarios

Impacts	Scenario 1(in kg)	Scenario2 (in kg)
Global Warming Potential (GWP) (relative to CO_2)	45632	14260
Acidification potential (AP) (relative to SO_2)	0.00475	2
Photochemical ozone creation potential (POCP)	5.152	1.61

DISCUSSIONS

- Landfill gases (LFG), such as methane, carbon dioxide, non-methanogenic organic compounds, and carbon monoxide, are considered potential global warming agents because they are classified as greenhouse gases. According to the research, the annual k value is 0.070m^3 and the Lo value is 66 cubic meters. m/ton obtained from the biomethane capacity test reaches the highest value on the 30th day in this study. Methane emissions from Mittaganahalli waste disposal site between 2019 and 2060 are shown in Figure 6. Landfill gas emissions, methane emissions show a steady increase until 2024 and then begin to decrease. Methane emissions are zero in 2019 and will reach 1,542 × 10^7 cubic meters per year in 2023. Authors: (Kumar et al. (2014), Ramprasad et al.

(2022) and Chandra et al. (2023)) state that there are methane emissions. The values estimated by the LandGEM model vary depending on the location of the waste and the composition of the waste.

- The energy production potential of methane emissions was determined using the Yedla S (Kumar et al. (2014)) method, and MSW can produce 1724.2 TJ of methane energy per year. Equivalent energy production will be close to 54 megawatts that households can use. The results obtained are consistent with the previous study of Kumar et al. (2014), Ramprasad et al. (2022) and Chandra et al. (2023). According to a study by the Council on Energy, Environment and Water (CEEW), Indian households used an average of 5.7 kWh of electricity per day during April-May 2020. Assuming a city/village equivalent to 1500 households, it would need 3.12×10^6 kWh per year. Therefore, it is clear from the above that the use of energy produced from municipal waste can reduce methane emissions and can also be used as local energy.

- The probability assessment of the two scenarios is shown in Table 9. Scenario 1 is the least storage option and can be considered to have higher global warming potential (GWP) and photochemical ozone production potential (POCP) than other options. path. The acidification potential of Scenario 2 is greater than that of the open landfill. This is due to the release of ammonia from the compost unit. The wastes generated in Scenario 1 are released directly into the environment without treatment. This is the effect that can be considered in this case. Scenario 2 is better than Scenario 1, but all of the methane produced is released into the atmosphere. For example, the GWP of 10% methane oxidation in soil is 14,260 kg CO2e. The above results are consistent with those of Babu et al. (2014). Municipal waste treatment plants with waste materials for recycling, composting and fuel recovery reduce environmental impact and are also sustainable and economical (Babu et al. (2014), BP sharma et al. (2016)) are a good choice in the future.

4. CONCLUSIONS

Landfill is one of the disposal methods of municipal waste in many countries. One of the environmental problems arising from landfills (waste gas) can be effectively solved by using waste gas throughout its life. In this study, the methane production rate (k) and capacity (L_0) of the waste were estimated. Natural gas emissions were estimated using LandGEM v3.02. Research shows that the total gas emissions from landfills are $3{,}083\times10^7$ cubic meters/year and methane emissions are $1{,}542\times10^7$ cubic meters/year. We conclude that methane emissions from landfills can be harmful to the environment and air quality. The magnitude of energy recovery will reduce methane emissions and help protect health. Scenarios can be organized according to the impact on the environment by deciding on scenario 1>scenario 2. The traditional disposal option has proven to be the better option of the two. On the other hand, research predicts that choosing traditional landfills instead of open landfills can reduce the potential for global warming. Therefore, a waste management system that includes waste materials and energy recovery is not only a good choice for the environment, but also a sustainable, robust and useful choice.

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