Estimating the methane emissions and energy potential from Trichy and Thanjavur dumpsite by LandGEM model

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Abstract
One major factor, contributing to the emission of greenhouse gas in the environment, is generation of hazardous gases in municipal landfills. Due to these potential negative impacts, it is obligatory to estimate the amount and type of landfill gasses to design and build a gas collecting system. Landfill gas emissions are governed by the type of waste, its biodegradability, its methane emission potential, the degree of separation, and other miscellaneous factors. LandGEM model was used to predict the amount of gases produced in the landfills of Trichy (Ariyamangalam) and Thanjavur (Srinivasapuram). According to the results, the largest amount of landfill gas emissions would be in 1993 for Trichy (Ariyamangalam) landfill and in 2027 for Thanjavur (Srinivasapuram) landfill. The total amount of produced gas, methane, and carbon dioxide would be 16.2E+10, 8.2E+10, and 16.2E+10 cubic meters per year in 1993 for Trichy and 13E+6, 5E+6 and 13E+6 cubic meters per year in 2027 for Thanjavur.

Keywords Energy potential · Greenhouse gases · Trichy · Thanjavur · LandGEM model · Municipal solid waste · Methane

Introduction
In the last few decades, the urban population in India is increasing many folds with a 91 million in the last decade, an increase of 31.8% (Das et al. 2012; Mandal et al. 2019). The growth in the population and change of lifestyle has resulted in enormous quantity solid waste generation and disposal in the developing country. As the municipal solid waste (MSW) generation cum dumping is accumulating as well mounting in the landfills, the waste management practices are not having significance in the country as well as not implemented up to the mark in many Urban Local Bodies (ULBs). The solid waste comprises of degradable components such as food wastes and vegetable wastes; non-biodegradable components such as plastics, glass, and metals; partial biodegradable fractions such as paper, wood, and leather; and other inert waste materials. The municipal solid wastes are generated from different sources like residential, commercial places, institutional areas, agricultural areas, and municipal locations. The management approach involves the following operations like collection, segregation, storage, transportation, treatment/processing, and disposal of solid waste in cities and rural areas. The municipal solid waste generated in the country varies from 0.1 kg per capita per day to 0.5 kg per capita per day, depending upon the location, accomplishments, and lifestyle of the residents (Gollapalli and Kota 2018). The most popular and easy way of disposing the generated solid waste is dumping in the areas of least concern or at the outskirts of the city. It was estimated that around 75% of the generated MSW are dumped unscientifically in the open grounds (Mehta et al. 2018). In line with dumping of solid waste, they generate inevitable by products such as landfill gases and leachates due to the meteorological conditions, waste microbial disintegration or degradation, landfilling operations, and refuse properties (Ramprasad et al. 2019).

Landfill gases (LFG) are noxious gases like methane, nitrous oxide, and carbon dioxide, which are produced from the chemical and biological disintegration and degradation of the buried solid wastes. The primary constituents of the LFG are the carbon dioxide (40–50%) and methane (50–60%), which are also considered as greenhouse gases.
The landfill gases such as methane are produced due to the anaerobic biodegradation of the organic wastes dumped in the site. The methane is one of the most vital landfill gases generated with a global warning potential of 21 times greater than the carbon dioxide (Jonova et al. 2018). In proper engineered landfills, there will be compaction done for the wastes on daily basis, and soil cover will be provided regularly, as well as gas recovery pipes also will be installed; hence, there will be lesser release of such noxious gases into atmosphere (Huang et al. 2019; Wong et al. 2019). In India, many of the landfills are not engineered and predominantly are on open grounds without any proper management options (Ramprasad and Gopalakrishnan 2013). There are several studies carried out in the estimation of landfill gas emissions from the municipal solid waste dumpsites especially through modeling approach. The proper operation and maintenance of the landfill sites are governed by a good design, proper prediction, and modeling of methane generation rate. The contributions of the greenhouse gases from the Indian landfills are very significant that helps to evaluate the carbon sink in the country. In order to substantiate the above scenario, measuring or modeling the amount of methane as well as other landfill gas emissions are very vital and significant.

The methane emissions can be estimated by various methods as already been researched by many authors; they have adopted field experiments; mathematical modeling like LandGEM, IPCC model, and first-order model; and site appraisement methods (Ramprasad et al. 2019; Amirmahani et al. 2020; Cai et al. 2020). Fallahizadeh et al. (2019) describe the methodology of LandGEM model and its components. Gollapalli and Kota (2018) compared the experimental values with three models such as LandGEM model, CAA, and inventory default model values, and it clearly states that methane emission that is predicted is more than the observed values. The IPCC model which uses site-specific waste composition gives 1.4 times greater than the observed emissions for a landfill in Northeast India. Qu et al. (2019) used the IPCC-SD model to estimate the methane emissions from the municipal solid waste landfills and derive an optimal path for its reduction. Kaushal and Sharma (2016) showed that methane emission was superiorly predicted by IPCC default model compared to LandGEM and FOD methods and the variations in GHG emissions from open dumps and landfills are more significant. In view of the above literature, it is found that the estimation of methane and other landfill gas emissions from the MSW open dumps over the Indian region is very scanty. In the recent decades, many researchers are focused on the plans and methods to combat against climate change and global warming; in this view, the estimation of methane emissions and its energy potential has become vital.

The present study aimed to estimate the amount of generated landfill gases, such as methane, carbon dioxide, and other gases from municipal solid waste in landfills of Thanjavur (Srinivaspuram landfill) and Trichy (Ariyamangalam landfill) by using a LandGEM simulation model and estimating the CH4 quantities that would be generated from a proposed landfills and could be transferred into different forms of energy such as electric power, fuels. As there are many research evidence available to substantiate the use of LandGEM model to estimate the landfill gases, the novelty of present study is to estimate the methane emissions and evaluate the energy potential in two major cities of South India. The cities Trichy and Thanjavur come under the Smart City Plan of Government of India and help to follow the Clean Development Mechanisms and achieve the SDG’s millennium development goals. This study also helps in designing methane collection system and proper mitigation measures that aim at minimizing GHG emissions into the atmosphere.

Materials and methods

Study area

The present study investigated the amount of methane and other landfill gas emissions using LandGEM model and estimated the energy potential empirically for two major districts of Tamil Nadu, viz., Trichy and Thanjavur. Tiruchirappalli Municipal Corporation, Trichy, Tamil Nadu, India, is one of the important tourists and holy place in South Tamil Nadu. Tiruchirappalli Municipal Corporation is divided into four zones, viz., Srirangam, Ariyamangalam, Abishekapuram, and Ponmalai; they were divided into 65 wards for administrative purposes. Ariyamangalam dump site covers a spread up area of nearly 47.70 Ha and was located at a distance of 12 km from the city center and in Trichy-Thanjavur Road with the inception during 1967. The dumping site is positioned at 10.48’N and 78.43’ E (Fig. 1). The dumping yard is elevated to a height of + 75.88 m above the mean sea level. The trench method of waste burial is adopted in the Trichy landfill site. The dumped waste is covered with a layer of soil at regular intervals to a depth of 15–30 cm; the soil type in the landfill site is sandy clay.

The Thanjavur municipal corporation is having a dumping site with a total spread up area of 20.23 acres for the solid waste management activities and it’s located at 10°47' N and 79°7’ E (Fig. 2). The city generates a 124MT of garbage every day out of which 116MT waste was being collected by Municipal Corporation. In this city, there are 14 zones within which 51 wards are located. The average
Fig. 1 Location of Ariyamangalam dumping yard, Trichy

Fig. 2 Location of Srinivasapuram Landfill site, Thanjavur
temperature of this city is 28.7 °C and the normal annual rainfall is 1053 mm. The dumpsite receives more than 200–250 tons of waste every day from the various zones within its vicinity. Most importantly, there cities do not possess any facilities for methane recovery and are open dumps. Due to a lack of information about evaluating methane gas emissions from municipal solid waste landfills and their energy potential.

Collection of data

The information’s related to the two selected dumpsites (Trichy and Thanjavur) like amount of waste generated, fraction of waste disposed, population growth over years, and disposal strategies adopted were obtained from the Municipal Corporation office. Additionally, the data required by the LandGEM software like methane production capacity, constant methane value and % of content by volume were entered the default values as prescribed by the United States Environment Protection Agencies (USEPA), and finally methane emission value is calculated. According to the 2011 census, Tiruchirappalli Municipal Corporation has a population of slightly over 8.47 lakhs, whereas Thanjavur has a population of 24.1 lakhs, indicating that both cities' population growth rates are fast expanding. The compressive waste management plan that includes the methane emissions and potential for energy source for the Trichy and Thanjavur was computed for a ground period of 60 years, and the waste composition was tabulated in Table 1. Appropriately to estimate the amount of methane emissions by LandGEM software, the most vital component is the weight of waste produced during plan period, and LandGEM determines the methane mass produced by using the mass of waste deposited and the methane generation capacity.

Present condition of the dumping yard

Solid Waste Management in Tiruchirappalli and Thanjavur Cities are entirely collected and managed by the corporation. The corporation has allowed the dumping of Trichy solid waste at the Ariyamangalam composite yard since 1967, and Thanjavur solid waste at Srinivasapuram since 2002 without foreseeing the problems that the accumulated solid waste can pose to a growing city. The generated waste is directly buried into the dumping yard without a proper compaction and segregation. With an estimated 12 lakh tons of garbage accumulated down the years and more than 400 tons added to it every day, the garbage dump literally presents a massive problem to the local residents and civic body as well. Additionally, the dumped wastes are not properly covered, and bottom is not lined, leading to spread of contamination. The generated leachate contaminates the ground water, and the absence of cover generates noxious gases. The dumpsites are freely accessible by the scavengers and rag pickers for collecting the recoverable/recyclables and some valuables in an unhealthy and unhygienic manner. Subsequently, there are many food-starving animals like cattle, pigs, buffaloes, and dogs scavenging for food waste in the dumpsite (Fig. 3(a)-(c)). Due to the above circumstances, the spread of diseases like cholera, hepatitis, dysentery, and other water-borne diseases was reported in the surrounding regions.

Description of the LandGEM model

A landfill gas emissions model (LandGEM) model was developed by the US environmental protection agency. It is an automated estimation tool with a Microsoft Excel interface that can help to determine emission rate of methane, carbon dioxide, and total landfill gas from the municipal landfill site through the first-order equation. Some real field data need to provide such as landfill open year, landfill closure year, design capacity of the landfill, and amount of being dumped every year to the corresponding landfills. The decay rate (k) and the methane potential capacities of the landfill waste (Lo) are the two vital factors that govern the amount of methane emissions. Additionally, the prediction of landfill gas emissions also depends on waste biodegradability factor, microbial usage rates, volatile solids concentrations, availability of micro- and macro-nutrients, pH of the waste, moisture and temperature of waste, and waste composition of the specific location.

| Table 1 Physical composition of Municipal Solid Wastes in Trichy and Thanjavur |
|-----------------------------|-----------------------------|
| Parameters                  | Trichy Waste Composition in % | Thanjavur Waste Composition in % |
| Biodegradable (Food wastes, garden wastes, etc.) | 75.0 | 55.55 |
| Glass                       | 1.5 | 0.01 |
| Rags                        | 5.0 | 0.41 |
| Paper                       | 1.0 | 5.59 |
| Plastic                     | 1.0 | 5.79 |
| Leather and Rubber          | 0.5 | 0.07 |
| Metals and other domestic hazardous | 1.0 | 0.06 |
| Inert                       | 15.0 | 32.52 |
| Total                       | 100.0 | 100.00 |

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\[ Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kLo \left( \frac{M_i}{10} \right) e^{-kt_{ij}} \]  

1. Annual methane generation in the year of the calculation (m³/year).
2. i: 1-year time increment. 
3. j: 0.1 year time increment.
4. n: (year of the calculation) – (initial year of waste acceptance).
5. k: Methane generation rate and taken as 0.050 (year⁻¹).
6. Lo: Potential methane generation capacity and taken as 170 (m³/Mg).
7. Mi: The mass of waste accepted in the year (Mg).
8. t_{ij}: The age of the jth sector of waste mass Mi accepted in the ith year.

To determine the site-specific value of (Lo) the following equation is applied (Osra et al. 2021).
\[ L_0 = MCF \times DOC \times DOCF \times \frac{16}{12} \times F \]  

(2)

- **MCF**: Methane correction factor (1 = well managed landfill, assumed in this case 0.75).
- **DOC**: Degradable organic carbon (fraction).
- **DOCF**: Fraction DOC dissimilated.
- **F**: Fraction of methane in landfill gas (measurement at landfill has indicated a value of 56% CH4 in biogas). The site-specific degradable organic carbon (DOC) is calculated based on IPCC (1996) formula

\[ \%\ DOC\ (Dry\ weight) = 0.4C + 0.17B + 0.15C + 0.3D \]

(3)

A - % paper and textiles.
B - % garden waste, park waste, or other non-food organic putrescible.
C - % food waste.
D - % wood or straw

**DOCF** can be determined through the lignin content of the volatile solid (VS) (author name, year):

\[ DOCF = 0.83 - 0.028 LC \]

(4)

0.83 = empirical constant; 0.028 = empirical constant; and LC = lignin content of the VS expressed as a percent of dry weight from leachate sample. From the above expressions, the values of methane generation potential \((L_0)\) estimated for Trichy and Thanjavur are 71.23 and 56.37 m3/Mg, respectively.

**Results and discussion**

**Trichy dumpsite**

The disposed solid waste quantities of Ariyamangalam dumpsite during the last 10 years are tabulated in the Table 2. The amount of municipal waste produced was approximately estimated 18,1040 Mg in 2010 which decreased to 11,2967 Mg in 2019. These digits show that there has been decrease in quantity of municipal waste due to fires every year. Also, there is another reason that the government was trying to convert the present landfill area into treatment plant, other complexes for shops and others. Methane emission estimates based on LandGEM is the practical method in nature which vary according to landfill management and waste composition were considered developing this method. The level of food culture and tastes in Trichy is such that a significant part of waste mainly is food waste. From Table 1, we can see that major composition of waste comprises of food waste and inert’s in waste stream. The emission of methane gas is maximum waste and also takes more time to produce it but decreases in production in later stages.

The default values which were used by the US environmental agency were used in the current scenario. The constant value terms used for the model are listed in table. Table 3 shows the annual methane production from disposed site. The methane production in 2011 was 1.004E+03 Mg/year and it rapidly increased to 9.152E+03 Mg/year in 2029. Figure 4 shows the trend of total gas, methane, and

![Table 2 Input datasheet to software for Ariyamangalam dump yard from the LandGEM model](image-url)
carbon dioxide emission in different years of the project at the dump site. Certain constants are used in the calculation for estimation of methane gas which are tabulated in table.

**Thanjavur, Srinivasapuram, landfill site result**

These are the results of waste accepted and waste in place for Thanjavur landfill site obtained from LandGEM model. The waste accepted is the amount of waste dumped in the landfill before compaction and waste in place is the amount of total waste after compaction are shown in Table 4.

Figure 5(a) showed that the methane emissions of Thanjavur (Srinivasapuram) landfill. It also shows that emission of CH₄ starts from 2002 and will last into 2140. The highest value of methane generation will happen in the year of 2027 which is approximately 5,000,000 cubic meters. The model showed that approximately 90% of the gas would be produced in first 80 years from the opening. The maximum amount of methane will be produced after the closure year of the landfill. Due to the increase in population, it leads to an increase in the total waste that is dumped in landfills and reflects the sudden increase in methane emissions in the year 2011. The model estimated that gas emission will reach its peak in 27 years after the start of LFG generation. After reaching the peak, emission value begins to decrease. As the rate of biodegradation decreases, so does the rate of gas release. As a result, the rate of emission drops to zero.

Figures 5(b) and (c) show the graph of total landfill gas and carbon dioxide emissions of landfill, respectively. A year of 2027 record shows the peak value of total landfill gas and carbon dioxide production of approximately 13,000,000 cubic meters. After reaching a peak, it begins to fall due to the exhaust gas on the landfill. The obtained results are in good agreement with Rodrigue et al. (2018), Ramprasad et al. (2019), Fallahizadeh et al. (2019), and Amirmahani et al. (2020). According to IPCC (Houghton 1996)(Eq. 3),

| Year | Total landfill gas (Mg/year) | Methane (Mg/year) | Carbon dioxide (Mg/year) | Year | Total landfill gas (Mg/year) | Methane (Mg/year) | Carbon dioxide (Mg/year) |
|------|-------------------------------|-------------------|--------------------------|------|-------------------------------|-------------------|--------------------------|
| 2010 | 0                             | 0                 | 0                        | 2020 | 2.640E+04                     | 7.053E+03         | 1.935E+04                |
| 2011 | 3.758E+03                     | 1.004E+03         | 2.754E+03                | 2021 | 2.746E+04                     | 7.335E+03         | 2.013E+04                |
| 2012 | 7.326E+03                     | 1.957E+03         | 5.369E+03                | 2022 | 2.847E+04                     | 7.604E+03         | 2.086E+04                |
| 2013 | 1.070E+04                     | 2.857E+03         | 7.839E+03                | 2023 | 2.942E+04                     | 7.860E+03         | 2.156E+04                |
| 2014 | 1.384E+04                     | 3.697E+03         | 1.014E+04                | 2024 | 3.033E+04                     | 8.103E+03         | 2.233E+04                |
| 2015 | 1.679E+04                     | 4.485E+03         | 1.230E+04                | 2025 | 3.120E+04                     | 8.334E+03         | 2.287E+04                |
| 2016 | 1.939E+04                     | 5.179E+03         | 1.421E+04                | 2026 | 3.202E+04                     | 8.554E+03         | 2.347E+04                |
| 2017 | 2.170E+04                     | 5.796E+03         | 1.590E+04                | 2027 | 3.281E+04                     | 8.763E+03         | 2.404E+04                |
| 2018 | 2.357E+04                     | 6.297E+03         | 1.728E+04                | 2028 | 3.355E+04                     | 8.962E+03         | 2.459E+04                |
| 2019 | 2.529E+04                     | 6.756E+03         | 1.854E+04                | 2029 | 3.426E+04                     | 9.152E+03         | 2.511E+04                |
The degradable organic carbon (fraction) content values for Trichy and Thanjavur based on waste characteristics were 14.55 percent and 11.50 percent, respectively. The average volatile lignin contents of solid waste in Trichy and Thanjavur are estimated as 37% and 32% respectively. To calculate DOCF by using Eq. (4), the DOCF values for Trichy and Thanjavur were 0.819 and 0.821, respectively, which were determined through the lignin content of the volatile solid (VS) as designed by Kreith and Tchobanoglous. By using Eq. (2), the methane potential was calculated as 71.23 and 56.39 m3 of methane per ton of waste. The default recommended value is 170 kg of methane per ton of waste.

**Energy potential from MSW of the Trichy and Thanjavur landfills**

The methane emission predicted by the LandGEM model for the Trichy and Thanjavur landfills as shown in the previous section was used to estimate the energy potential. The assessment is based on the rate constant (k) value and the potential methane generation capacity (Lo). The landfill gas to energy technology depends largely on the methane content generated from the landfills, and subsequently it can be viewed as energy potential estimation depending on methane generation potential (Rodrigue et al. 2018). The electrical energy in kWh per year was obtained for Trichy and Thanjavir landfills and was shown in Fig. 6(a) and (b) The quantity of electrical energy produced by Trichy landfill site during the year 2020 was 1.22E7 kWh per year and peaked in the year 2063, with 4.33E7 kWh per year. Similarly, the Thanjavur dumpsite showed energy potential of 1.14E7 kWh per year during the year 2020 and peaked (3.87E7 kWh per year) during the year 2052. According to the Council on Energy, Environment, and Water report for the year 2020, the average household consumption in a day was 5.7 kWh. Assuming a city with 10–20 lakh houses could have been provided with a continuous supply of green power from the landfills. The above phenomena indicate that harnessing energy from the landfill gases especially Methane can reduce the emission of greenhouse gases as well as provide alternative energy source for the country diminishing coal mines.

### Table 4

| Year | Waste Accepted (Mg/year) | Waste Accepted (short tons/year) | Waste-In-Place (Mg) | Waste-In-Place (short tons) |
|------|--------------------------|----------------------------------|---------------------|--------------------------|
| 2002 | 41,720                   | 45,892                           | 0                   | 0                        |
| 2003 | 42,377                   | 46,615                           | 41,720              | 45,892                   |
| 2004 | 43,151                   | 47,466                           | 84,097              | 92,507                   |
| 2005 | 43,691                   | 48,060                           | 1,27,248            | 1,39,973                 |
| 2006 | 44,348                   | 48,783                           | 1,70,939            | 1,88,033                 |
| 2007 | 45,169                   | 49,686                           | 2,15,287            | 2,36,816                 |
| 2008 | 45,951                   | 50,546                           | 2,60,456            | 2,86,502                 |
| 2009 | 46,483                   | 51,131                           | 3,06,407            | 3,37,048                 |
| 2010 | 47,304                   | 52,034                           | 3,52,890            | 3,88,179                 |
| 2011 | 48,125                   | 52,938                           | 4,00,194            | 4,40,213                 |
| 2012 | 48,916                   | 53,808                           | 4,48,319            | 4,93,151                 |
| 2013 | 49,604                   | 54,564                           | 4,97,235            | 5,46,959                 |
| 2014 | 50,425                   | 55,468                           | 5,46,839            | 6,01,523                 |
| 2015 | 51,246                   | 56,371                           | 5,97,264            | 6,56,990                 |
| 2016 | 52,210                   | 57,431                           | 6,48,510            | 7,13,361                 |
| 2017 | 52,889                   | 58,178                           | 7,00,720            | 7,70,792                 |
| 2018 | 53,710                   | 59,081                           | 7,53,609            | 8,28,970                 |
| 2019 | 54,531                   | 59,984                           | 8,07,319            | 8,88,051                 |
| 2020 | 55,504                   | 61,054                           | 8,61,850            | 9,48,035                 |
| 2021 | 56,270                   | 61,897                           | 9,17,354            | 10,09,089                |
| 2022 | 57,036                   | 62,740                           | 9,73,624            | 10,70,986                |
| 2023 | 57,802                   | 63,582                           | 10,30,660           | 11,33,726                |
| 2024 | 58,568                   | 64,425                           | 10,88,462           | 11,97,308                |
| 2025 | 59,334                   | 65,267                           | 11,47,030           | 12,61,733                |
| 2026 | 60,100                   | 66,110                           | 12,06,364           | 13,27,000                |

### Conclusion

The present study showed that the municipal solid waste generated in Trichy and Thanjavur on average predominantly comprises of organic waste. There is a strong correlation between the methane emission potential from the dumpsite to the degradable organic carbon fraction. According to the findings, when the organic fraction grew, methane emissions increased as well, as shown at the Trichy municipal dumpsite. In Trichy and Thanjavur, the degradable organic component was 14.55 percent and 11.50 percent, respectively. Because methane gas is both a big contributor to global warming and a source of renewable energy, it must be sequestered. The total peak amount of methane emission from the Trichy and Thanjavur dumpsite are 1.87E7 cu. m per year and 1.67E7 cu. m per year, respectively. The methane gases that will be recovered from the dumpsite with a potential of 170 kg of methane per ton of waste can be converted into energy. The peak energy potential form Trichy and Thanjavur dumpsite were 4.33E7 kWh per year and 3.87E7 kWh per year, respectively. The concentration of methane generated from the landfills can be converted to energy production, but research needs to do for the techno-economic evaluation. Therefore, the integrated solid waste management scheme for the Trichy and Thanjavur is recommended with an approach to harness the methane energy. This approach can alleviate the over dependency on fossil fuel especially coal for the energy production as well as pave way for
Fig. 5 (a) The graph of methane gas emission model—Thanjavur landfill; (b) The graph of total landfill gas emission model—Thanjavur landfill; (c) The graph of carbon dioxide emission model—Thanjavur landfill.
Fig. 6 (a) The energy potential from the Trichy MSW landfill site; (b) The energy potential from the Thanjavur MSW landfill site
the clean energy production approach and thereby to a healthier environment.

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Declarations

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