Estimating the Methane Emissions and Energy Potential from Trichy and Thanjavur Dumpsite by LandGEM Model

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Research Article

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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. There are various US EPA recommendation model. The Landfill Gas Emissions Model (LandGEM) is one the conventional model and also provides better estimation compared to other method. It is used to the amount of gases produced in the landfills of Trichy (Ariyamangalam) landfill and Thanjavur (Srinivasapuram) landfills have been predicted. 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 16.2 + 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.

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 (ULB’s). 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; 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, carbon dioxide etc., 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 (GHG) (Amirmahani et al., 2020; Cai et al., 2020). 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 warming 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 one and predominantly are 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, first order model, etc., and site appraisement methods (Ramprasad et al., 2019; Amirmahani et al., 2020; Cai et al., 2020). Fallahizadeh et al (2019) describes 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 are 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 North-East 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 gases 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.

In the present study, the two major cities located in the center part of Tamil Nadu viz a viz., Trichy and Thanjavur are selected. The dumpsite receives more than 200–250 tons of waste every day from the various zones within its vicinity. Most importantly, there cities don’t possess any facilities for methane recovery and are open dumps. Due to lack of information about the evaluating methane gas emission from municipal solid waste landfill and its energy potential, the study aimed to estimate the amount of generated gases, such as methane, carbon dioxide and other gases from municipal solid waste in landfills of Thanjavur (Srinivasapuram 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. 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

In the present study, two major districts of Tamil Nadu were considered viz a 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 to 30 cm; the soil type in the landfill site is a 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 temperature of this City is 28.7°C and the normal annual rainfall is 1053mm.

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. As per the Censes, 2011 the population of Tiruchirappalli Municipal Corporation is just more than 8.47 lakhs as per 2011 censes whereas in Thanjavur the population was 24.1 lakhs as per Census 2011, the population growth rate in both the cities were increasing rapidly. 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, 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.

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

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's, 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 were 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 be helps to determine emission rate of methane, carbon dioxide and total landfill gas from the municipal landfill site through the

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.

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

Q_{CH4} = annual methane generation in the year of the calculation (m3/year)

i = 1-year time increment

j = 0.1year time increment

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

k = methane generation rate and taken as 0.050 (year-1)

Lo = potential methane generation capacity and taken as 170 (m^3/Mg)

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

tij = 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)

$$L_0 = MCFxDOCxDOCFx\frac{16}{12}xF \text{--}(2)$$

MCF = methane correction factor (1 = well managed landfill, assumed in this case XXX),

DOC = degradable organic carbon (fraction),

DOCF = fraction DOC dissimilated, and

F = fraction of methane in landfill gas (measurement at landfill has indicated a value of 56% CH_4 in biogas). The site-specific degradable organic carbon (DOC) is calculated based on IPCC (1996) formula,

$$\%DOC(Dryweight) = 0.4C + 0.17B + 0.15C + 0.3D \text{--------------------}(3)$$

A = % paper and textiles,

B = % garden waste, park waste, or other non-food organic putrescible

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D = % wood or straw DOCF can be determined through the lignin content of the volatile solid (VS) (author name, year):

$$DOCF = 0.83 - 0.028LC \text{------------------------------------(4)}$$

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 value of methane generation potential ($L0$) is estimated for Trichy and Thanjavur are 71.23 and 56.37 m^3/ Mg respectively.

Estimation Of Energy Potential

The landfill gas especially methane has higher energy potential and can be recovered as an alternative energy source. The energy generation potential (E_p in kWh per year) from the methane emissions from the Trichy and Thanjavur landfills is estimated by the following equation (Ayodele et al., 2017; Rodrigue et al., 2018),

$$\mathrm{E_p} = \frac{0.9 \times \mathrm{Q_{methane}} \times \mathrm{LHV_{methane}} \times \eta \times \lambda}{3.6} \text{------------------------------(5)}$$

The $Q_{methane}$ is the amount of methane gas emitted in cu. m from the landfills during the particular year, $LHV_{methane}$ is the Lower Heating Value of methane and usually taken as 37.2 MJ per cu. m (Cyril et al., 2018), η is the electrical conversion efficiency for the internal combustion engine and usually taken as 33%, λ is the collection efficiency of methane from landfills and usually taken as 75%, 0.9 is the empirical coefficient and 3.6 is the conversion factor from MJ to kWh.

Results And Discussion

Trichy Dumpsite

The disposed solid waste quantities of Ariyamangalam dump site during the last 10 years are tabulated in the Table 2. The amount of municipal waste produced was approximately estimated 181040 Mg in 2010 which decreased to 112967 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.

Table 2
Input datasheet to software for Ariyamanglam dump yard from the LandGEM model

Year	Waste Accepted		Waste in Place		Year	Waste Accepted		Waste in Place	
	Mg/ year	Short tons / year	Mg/ year	Short tons / year		Mg/ year	Short tons / year	Mg/ year	Short tons / year
2010	181040	199144	0	0	**2015**	164615	181077	892425	981668
2011	180675	198743	181040	199144	**2016**	156950	172645	1057040	1162744
2012	179580	197538	361715	397887	**2017**	141255	155381	1213990	1335389
2013	176660	194326	541295	595425	**2018**	138152	151967	1355245	1490772
2014	174470	191917	717955	789751	**2019**	112967	124264	1493397	1642735

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 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.

Table 3
The amount of landfill gases emitted based on LandGEM model

Year	Total landfill gas	Methane	Carbon dioxide	Year	Total landfill gas	Methane	Carbon dioxide
	(Mg/year)	(Mg/year)	(Mg/year)		(Mg/year)	(Mg/year)	(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	2.223E + 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

Thanjavur, Srinivasapuram Landfill site results

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.

Table 4
The waste acceptances and waste in places of Thanjavur landfill

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	(short tons/year)	(Mg)	(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

Figure 5(a) showed that the methane emissions of Thanjavur (Srinivasapuram) landfill. It also shows that emission of CH_4 start from 2002 and will last into 2140. The highest value of methane generation will happen in the year of 2027 which is approximately 5000000 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. The rate of biodegradable decrease and thereby decreasing the rate of gas emission. Thus, the rate of emission gets to nil.

Figure 5(b) and 5(c) showed 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 13000000 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); Amirmahani et al (2020). To estimate the site-specific degradable organic carbon *(*DOC*)* is calculated using Eq. (3), based on IPCC (1996), degradable organic carbon (fraction) content values for Trichy and Thanjavur were 14.55% and 11.50 % respectively found based on the characteristics of waste. The average volatile lignin content of solid waste Trichy and Thanjavur estimated as 37% and 32% respectively. To calculate DOC_F by using Eq. (4). The DOC_F values for Trichy and Thanjavur were 0.819 and 0.821 respectively, were determined through the lignin content of the volatile solid (VS) as designed by Kreith and Tchobanoglous. By using Eq. (2) and the methane potential was calculated as 71.23 and 56.39 m^3 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 Thanjavir 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 depends on methane generation potential (Rodrigue et al., 2018). The electrical energy in kWh per year was obtained for Trichy and Thanjavur 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.

Conclusion

The present study showed that the municipal solid waste generated in Trichy and Thanjavur showed that on an average it predominantly comprises of organic waste. There is a strong correlation between the methane emission potential from the dumpsite to the degradable organic carbon fraction. The study concludes that more the organic fraction, the methane emissions were also increased as visible in Trichy municipal dumpsite. The degradable organic fraction in Trichy and Thanjavur municipal solid waste characteristics were 14.55% and 11.50% respectively. As the methane gas is considered as one of the major contributors for the global warming and also a source of green energy, it needs to 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 the clean energy production approach and thereby to a healthier environment.

Declarations

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

Conceptualization of the article – Subramanyam Busetty and Ramprasad Chandrasekaran

Methodology – Ramprasad Chandrasekaran and Subramanyam Busetty

Writing the original manuscript and draft preparation - Ramprasad Chandrasekaran

Writing - review and editing (pre-publication stage) – Subramanyam Busetty

Data collection, analysis and validation – Subramanyam Busetty and Ramprasad Chandrasekaran

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Competing Interests

The authors hereby declare that they don’t have any competing interests.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

Figure 1

Location of Ariyamangalam dumping yard, Trichy.

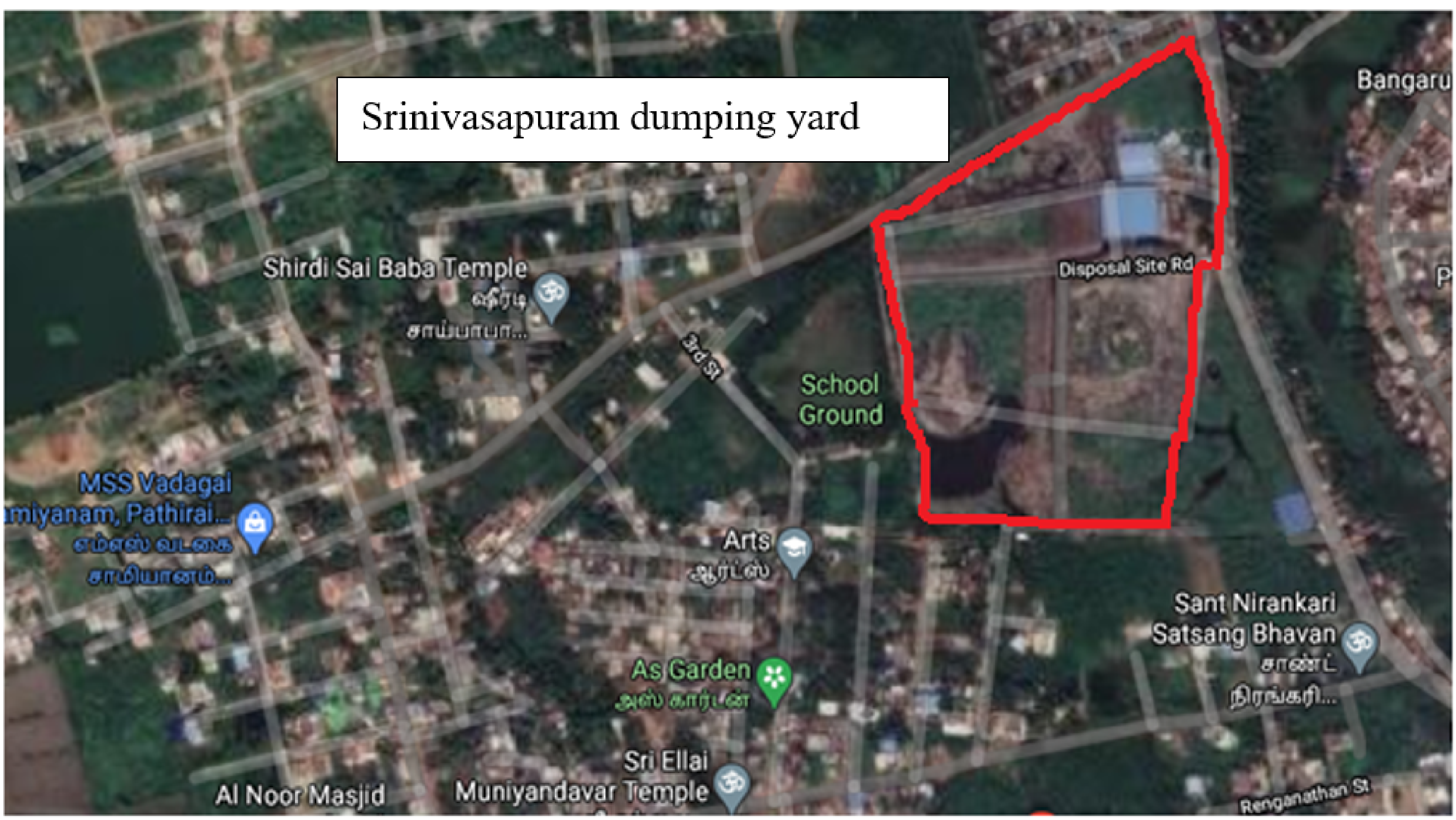

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Figure 2

Location of Srinivasapuram Landfill site, Thanjavur

Figure 3

(a) Accumulation of wastes disposed in open dumping yard, Trichy (b) Lorry carrying the wastes to the open dumping yard, Trichy (c) Accumulation of wastes disposed in open dumping yard, Thanjavur

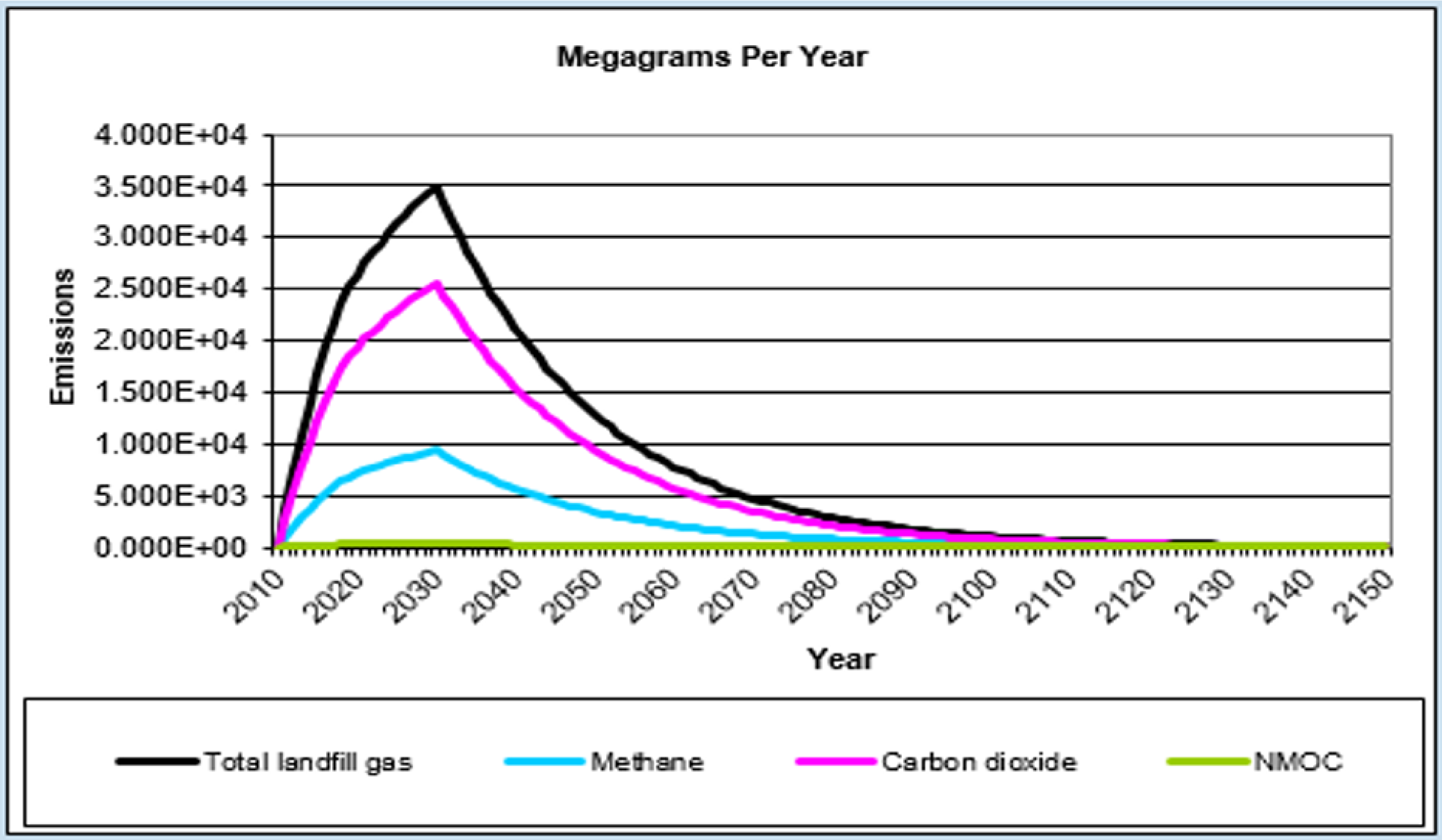

Figure 4

Gas emission from Ariyamanglam dump yard using LandGEM model.

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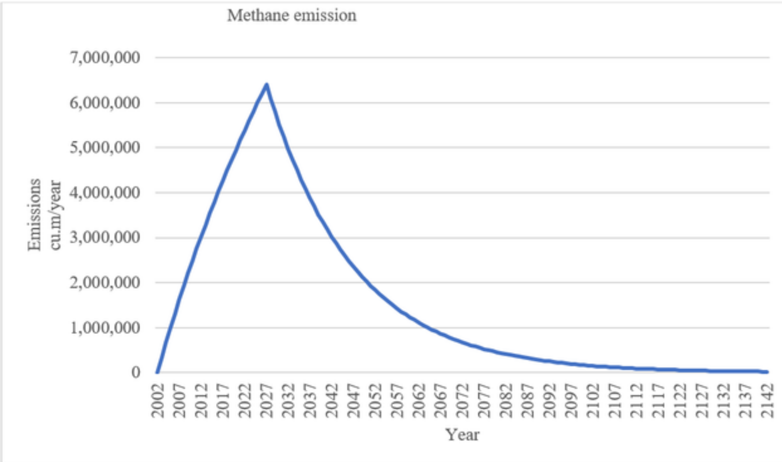
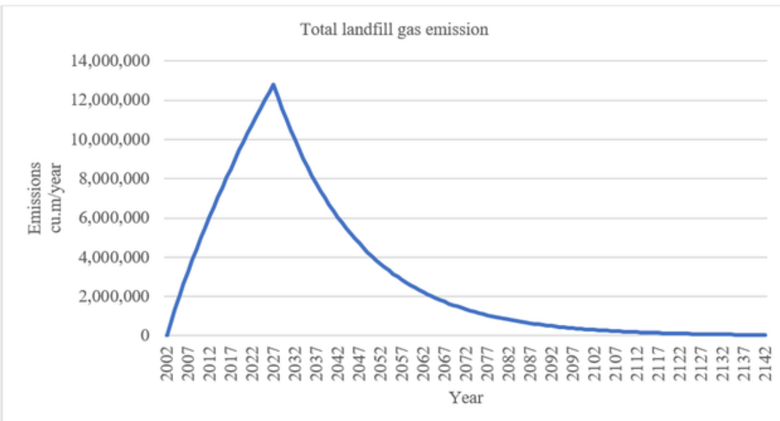
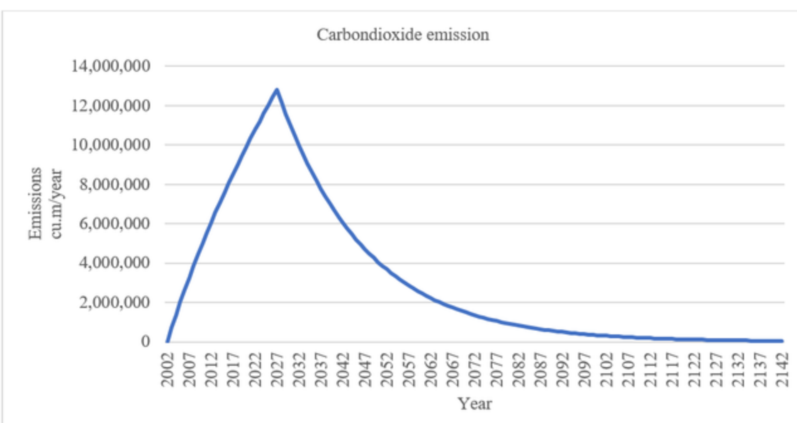


(a)



(b)



(c)

Figure 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

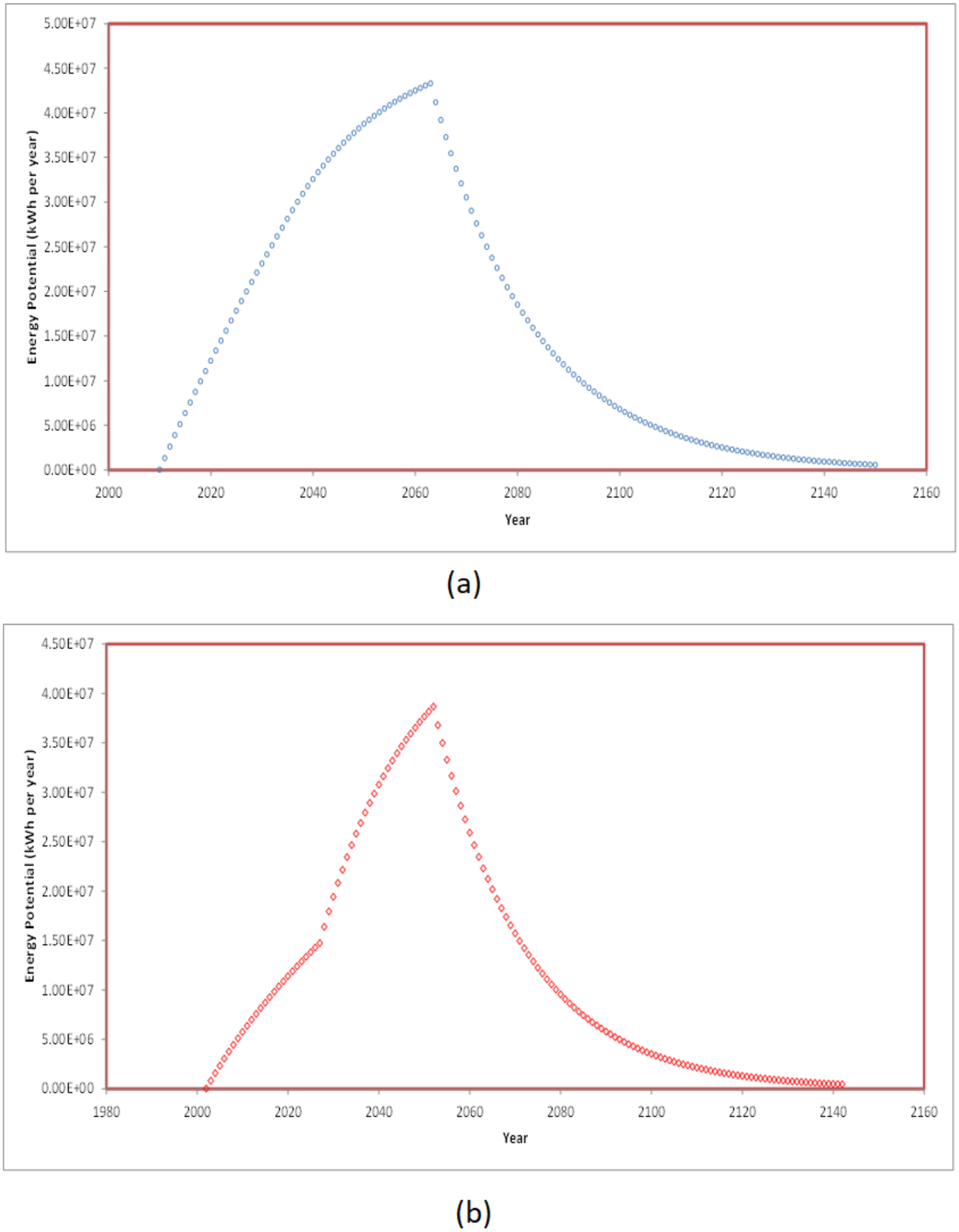


Figure 6

(a) The energy potential from the Trichy MSW landfill site (b) The energy potential from the Thanjavur MSW landfill site

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