Estimation method for national methane emission from solid waste landfills

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Abstract

In keeping with the global efforts on inventorisation of methane emission, municipal solid waste (MSW) landfills are recognised as one of the major sources of anthropogenic emissions generated from human activities. In India, most of the solid wastes are disposed of by landfilling in low-lying areas located in and around the urban centres resulting in generation of large quantities of biogas containing a sizeable proportion of methane. After a critical review of literature on the methodology for estimation of methane emissions, the default methodology has been used in estimation following the IPCC guidelines 1996. However, as the default methodology assumes that all potential methane is emitted in the year of waste deposition, a triangular model for biogas from landfill has been proposed and the results are compared. The methodology proposed for methane emissions from landfills based on a triangular model is more realistic and can very well be used in estimation on global basis. Methane emissions from MSW landfills for the year AD 1980–1999 have been estimated which could be used in computing national inventories of methane emission.

Keywords: Global warming; Greenhouse gas (GHG); Municipal solid waste (MSW); Biogas; Climate change

1. Introduction

Global warming has become a matter of public concern since last few years. This could be mainly attributed to the trapping of enormous quantities of typical gases (termed as “greenhouse gases”) in the earth’s atmosphere resulting in greenhouse gas (GHG) effect thereby increasing the ambient temperatures.

Methane is regarded as one of the most important GHGs because its global warming potential has been estimated to be more than 20 times of that of carbon dioxide and atmospheric methane concentration has been increasing in the range of 1–2% yr$^{-1}$ (IPCC, 1996).

Waste landfills have been recognised as the large source of anthropogenic methane emission and an important contributor to global warming (IPCC, 1996). Methane emission from landfill is estimated to account for 3–19% of the anthropogenic sources in the world (IPCC, 1996). The estimation has been made from mere calculation using national statistics on waste generation. In many countries, especially the developing economies of the world, the available data on waste generation are not consistent, leading to a large uncertainty in the estimates.

In India, most of the solid wastes are disposed of by landfilling in low-lying areas located in and around the urban centres. The total methane emissions from Indian landfills carried out by National Environmental Engineering Research Institute (NEERI), worked out to be 0.334 Tg yr$^{-1}$ during 1990–1991 (Bhattacharya and Mitra, 1998). The present paper, therefore, makes an attempt to estimate the realistic values of methane emission from municipal solid waste (MSW) landfills, by carrying out extensive investigations both from field and available national statistics.

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2. Activities under National Communication in India

The Ministry of Environment and Forests (MoEF), Government of India (GOI) has initiated a project towards preparation of India’s Initial National Communication (NATCOM) to the United Nations Framework Convention on Climate Change (UNFCCC) funded by the Global Environment Facility (GEF) under its enabling activities programme through the United Nations Development Programme, New Delhi.

The source-specific areas for the estimation of GHG inventories are land use change and forestry, energy and transformation, agriculture and industrial process and against this backdrop, NEERI, Nagpur has been entrusted with the GHG inventory estimation for the waste sector.

3. Estimation of methane emission from landfills on global basis

The estimation of methane gas emission from landfills has been consistently investigated by various researchers across the globe. Mostly, attempts were directed to estimate the landfill gas (LFG) for its extraction and utilisation as a renewable source of energy. These methodologies could be very well explored for their use in the estimation of GHG emissions.

It could be seen that there is a need for reliable and consistent data on MSW for estimation of LFG when solid waste is disposed of in a controlled manner. In India, where such conditions do not prevail, it may be necessary to adopt empirical relationship coupled with scientific logic. The LFG could be better estimated by using the first-order decay (FOD) in two phases. In the first phase, the rate of generation keeps on increasing till the peak is reached; thereafter, it keeps on declining till the material is stabilised.

4. Methodology for inventory estimation

The Revised IPCC (1996) Guidelines for National GHG Inventories outline two methods to estimate methane emissions from solid waste disposal sites: the default method (Tier 1) and the FOD method (Tier 2).

4.1. Default method

Among the available methods, the simplest one for the estimation of methane emissions from landfills is based on mass balance approach, i.e. the default methodology. This method was developed by Bingemer and Crutzen (1987) and is being used in the Revised IPCC (1996) guidelines as the default methodology for estimating methane emissions from solid waste disposal sites. The detailed methodology for estimation of methane emissions from solid waste disposal sites is explained as Appendix A. The equation or formulae to compute degradable organic carbon (DOC) is given in Appendix A, with sample calculation for one or two representative cities.

A number of empirical constants, like methane correction factor, DOC, dissimilated organic fraction converted into LFG, have been considered while developing the default methodology and accordingly the emissions are calculated. Though IPCC has claimed that the default methodology provides reasonable annual estimate of actual emissions and this has been widely used in the situations where detailed data are not available, but it may not provide realistic estimate as it is assumed that all potential methane is released in the year the waste is disposed of.

4.2. Triangular method

The FOD method provides a time-dependent emission profile that reflects the true pattern of the degradation process over time. The FOD method requires data on
current, as well as historic waste quantities, composition and disposal practices for several decades. Since the historical data are not available for Indian conditions and hence this method cannot be used for estimation of methane emissions. Therefore, there is a need to develop a realistic method, which will account for variation in the waste deposition, the degree of stabilisation, the zone for aerobic and anaerobic decomposition and the most importantly the cycle over which LFG is generated from the deposited waste. Therefore, a modified approach is proposed wherein the biogas release is based on FOD in a triangular form as shown in Fig. 1, where the area of the triangle would be equivalent to the gas released over the period from every tonne of solid waste deposited. In the absence of detailed data, this area (volume of gas) is assumed to be equal to the volume computed using the default methodology. It is also assumed that the degradation takes place in two phases. The first phase starts after 1 year of deposition and rate increases, which continues for 6 years. Thereafter second phase starts when the gas generation rate decreases and becomes zero after 15 years. Accordingly, for every year of deposition, the gas generated between years 1980 and 1999 is computed.

The methane emission estimated using the default method is equated to the area of the triangle. The ‘h’ value, i.e. peak value, of methane emission shown in Fig. 1 is calculated knowing the volume of gas and base of triangle. Using the peak value (h), other ordinates are calculated. The same procedure is applied for every year from 1980 to 1999 and the gas emission values for consecutive years are added up to get the volume of methane emission for every year.

5. Activity data

The IPCC guidelines (1996) defined activity data as the data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time. For example, while estimating methane generation from MSW landfills, the population, total MSW reaching landfills, etc. are the activity data.

The activity data in respect of MSW have been collected/generated and finally data on national and state level for all the components have been compiled for estimation of methane emission.

In India, organised solid waste management services are provided in class I (population >1 lakh) and class II (50,000 > population <1,00,000) towns. These systems invariably adopt ultimate disposal of solid waste by landfilling. The population for classes I and II cities is obtained from census 1991 and provisional census 2001 from Census Department. Based on decadal growth rate, compounded annual growth rate for each state is computed and the national level population was calculated between years 1980 and 1999 (NEERI Final Report,
In order to estimate the LFG emission from these dumps, it may be necessary to survey all these towns (which may be around 640). However, it may not be possible to study each and every city in these categories. Hence, a well-defined methodology, i.e. categorisation of cities on the basis of geographical features, i.e. plain, hilly and coastal, and demographical status is adopted. Among the categorised city(s), representative city(s) have been selected and detailed data on solid waste, like quantity and composition, landfilling details, etc. are collected. The identification of representative city for detailed data collection on quantity and composition of MSW and computation of DOC is detailed out in Table 1. The representative cities are indicated in Fig. 2. In addition to the representative city identified, some more city(s) in the regions are visited and data on MSW are collected/generated. The data on MSW from representative city are extrapolated for that population range in which the identified city lies, and finally, national level MSW data are extrapolated.

The data on solid waste quantity and composition in representative city(s) are presented in Table 2. The default value of DOC is 0.15, suggested by IPCC (1996) for a certain period of time for Indian conditions. The DOC values computed for representative cities based on physical composition of MSW does not differ much with the default value. Hence, these values are used for calculation of methane emission. Also a city representing a different category holding the DOC values estimated is used for a particular category and not for the national population.

6. Estimation of methane emission from municipal solid waste landfills in India

The methane emission from solid waste disposal sites for years 1980–1999 in India has been estimated by the default methodology taking the values of emission coefficients, viz. methane correction factor as 0.4,
fraction of DOC in MSW taken as per the calculated values for different population ranges and the demographic and geographical status of the city based on the field studies of identified cities, fraction of DOC which actually degrades as 0.77, fraction of carbon released as methane as 0.5, conversion ratio as 16/12, potential methane generation rate as 0.077 and realised methane generation rate per unit of waste as per the category. The methane emission for different population ranges, viz. 1–2.5 lakhs, 2.5–10 lakhs, above 10 lakhs and 0.5–1 lakh, and different regions, viz. plain, hilly, and coastal on national basis is estimated using the default method and triangular method. After combining the total emission value for different population ranges, the total national level emission for years from 1980 to 1999 has been estimated and presented in Table 3 and Fig. 3.

Fig. 3 indicates the comparison of methane emission value from solid waste landfills estimated using the default and triangular methodology. The values estimated using the default methodology indicate that they increase as compared to the values estimated using the triangular methodology from 1980 to 1999. The assumption made in the default methodology is that the potential methane is emitted in the same years from 1980 to 1999 for which the solid wastes are deposited yearly, which may not be realistic. The values estimated using triangular form give realistic value as it is based on the assumption that the gas generation follows triangular form and the gas keeps on generating for the next 15 years. Every year the methane is generated due to waste deposited in the past 15 years.

7. Conclusion

The methane emission has been estimated for solid waste disposal sites through MSW landfills. The national level methane emission from solid waste disposal sites using the default methodology varies from 263.02 Gg in year 1980 to 502.46 Gg in year 1999 and the methane emissions using triangular pattern of gas generation indicates that the methane emissions vary between 119.01 Gg in 1980 and 400.66 Gg in 1999. However, there are certain limitations in the inventory estimation of methane emission estimated for the years 1980–1999 in India. The inventory estimation has been made mostly on the basis of published documents and a little on the data generated. Mostly, the default values suggested by IPCC have been used in estimation, as guided by IPCC based on the studies made in other situations. For realistic values for Indian condition, detailed study is required to arrive at appropriate factors.

Similarly, in data collection also several constraints have been observed. Most of the municipalities do not maintain the solid waste data due to lack of awareness, small financial budget and low priority.
Table 3
Estimation of methane emission from MSW landfills using the default method and triangular method on national basis for the year 1980–1999

<table>
<thead>
<tr>
<th>Year</th>
<th>Total annual MSW disposed to SWDDSs (Gg MSW)</th>
<th>Net annual methane generation (Gg CH₄) default method</th>
<th>Net annual methane generation (Gg CH₄) triangular method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>8479.68</td>
<td>263.02</td>
<td>119.01</td>
</tr>
<tr>
<td>1981</td>
<td>8765.83</td>
<td>271.92</td>
<td>146.00</td>
</tr>
<tr>
<td>1982</td>
<td>9062.45</td>
<td>281.13</td>
<td>171.00</td>
</tr>
<tr>
<td>1983</td>
<td>9369.95</td>
<td>290.68</td>
<td>194.00</td>
</tr>
<tr>
<td>1984</td>
<td>9688.73</td>
<td>300.57</td>
<td>214.89</td>
</tr>
<tr>
<td>1985</td>
<td>10019.26</td>
<td>310.85</td>
<td>233.62</td>
</tr>
<tr>
<td>1986</td>
<td>10361.99</td>
<td>321.50</td>
<td>250.11</td>
</tr>
<tr>
<td>1987</td>
<td>10717.47</td>
<td>332.54</td>
<td>264.31</td>
</tr>
<tr>
<td>1988</td>
<td>11085.18</td>
<td>343.98</td>
<td>276.13</td>
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<td>1989</td>
<td>11468.63</td>
<td>355.86</td>
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<td>1990</td>
<td>11865.42</td>
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<tr>
<td>1991</td>
<td>12277.12</td>
<td>380.97</td>
<td>305.29</td>
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<tr>
<td>1992</td>
<td>12704.33</td>
<td>394.26</td>
<td>315.76</td>
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<tr>
<td>1993</td>
<td>13147.69</td>
<td>408.03</td>
<td>326.57</td>
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<tr>
<td>1994</td>
<td>13607.91</td>
<td>422.33</td>
<td>337.83</td>
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<tr>
<td>1995</td>
<td>14085.65</td>
<td>437.18</td>
<td>349.48</td>
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<tr>
<td>1996</td>
<td>14581.57</td>
<td>452.57</td>
<td>361.57</td>
</tr>
<tr>
<td>1997</td>
<td>15096.54</td>
<td>468.59</td>
<td>374.12</td>
</tr>
<tr>
<td>1998</td>
<td>15631.29</td>
<td>485.20</td>
<td>387.16</td>
</tr>
<tr>
<td>1999</td>
<td>16187.10</td>
<td>502.46</td>
<td>400.66</td>
</tr>
</tbody>
</table>

Assumptions: Waste reaching to landfill site during 1980–1999 is assumed as 70%. Waste generation rate for all the class I and class II cities based on the studies carried out for the representative cities and studies carried out earlier by NEERI.

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Appendix A

The equation was employed by Bingemer and Crutzen to calculate Methane emissions.

Methane emission (Gg yr⁻¹) = (MSWₜ × MSWF) × MCF × DOC × DOCₜ × F × (16/12 − R) × (1 − OX),

where 1 Gg yr⁻¹ = 1000 tonnes yr⁻¹.

MSWₜ = Total municipal solid waste (MSW) generated (Gg yr⁻¹). Total MSWₜ can be calculated from population (in thousand persons) × annual MSW generation rate (Gg 10⁻³ persons yr⁻¹)

MSWF = Fraction of MSW disposed of at the disposal sites. The percentage of 70% is based on field investigative studies. The remaining 30% is assumed to be lost due to recycling, waste burning at source as well as at disposal site, waste thrown into the drains and waste not reaching the landfills due to inefficient solid waste management system

MCF = Methane correction factor (fraction). The fraction depends upon the method of disposal and depth available at landfills. The IPCC document indicated the value of 0.4 for open dumps < 5 m depth and hence used for computation

DOC = Degradable organic carbon (fraction). DOC content is essential in computing methane generation. It depends on the composition of waste and varies from city to city. Equation to determine DOC values

\[0.4A + 0.17B + 0.15C + 0.3D\]

where

\[A = \text{paper + rags}\]
\[B = \text{leaves + hay + straw}\]
\[C = \text{fruits and vegetables}\]
\[D = \text{wood}\]

Sample calculation

(1) Ramagundam

\[= 0.4 \times 6.17 + 0.17 \times 37.67 + 0.15 \times 52.39 + 0.3 \times 0\]
\[= 1.60\]

(2) Varanasi

\[= 0.4 \times 4.2 + 0.17 \times 30.98 + 0.15 \times 61.32 + 0.3 \times 0\]
\[= 0.164\]

As per the exact calculation there is variation in DOC value of Ramagundam and Varanasi. But for calculation purpose, DOC value computed is only used up to two decimal places

DOCₜ = Fraction DOC dissimilated. It is a portion of DOC that is converted to LFG. The estimates are based on a theoretical model that varies only with the temperature in the anaerobic zone of a landfill site. The model is described as 0.014T + 0.28, where T=temperature in °C (Tabasaran, IPCC document 1996). It is assumed that temperature remains constant at 35°C in the anaerobic zone of the landfill. The value is thus computed as 0.77 and adopted
$F =$ Fraction of methane in LFG (default is 0.5). The fraction of methane in LFG is assumed 0.5 as default value and adopted.

$R =$ Recovered methane (Gg yr$^{-1}$). Recovery of LFG is not adopted in India, hence the value is zero.

$OX =$ Oxidation factor (default is 0). It accounts for the methane that is oxidised in the upper layer of waste mass where oxygen is present. Oxidation may reduce the quantity of methane generated that is ultimately emitted. However, there is no internationally accepted factor and can be assumed as zero.

Fig. 3. Comparison of methane emission from solid waste landfills vs. year using both the default method and triangular method.

References


