Estimation of Land-fill Gas Generation from Municipal Solid Waste in Indian Cities

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Estimation of land-fill gas generation from municipal solid waste in Indian Cities

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Abstract

Estimation of methane emission from the landfills is very much required for fast urbanizing countries. Rapid growth in population and industrialization causes a direct impact on the environment. As methane emission is a key contributor to the greenhouse effects it is necessary to quantify the methane emission from municipal solid waste (MSW), so as to take measures to ease the greenhouse gas emission. In this present study four models have been used to quantify the LFG emission estimation characteristics from MSW in six metropolitan cities covering different parts in India for a period of 30 years (1982 - 2012).

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Keywords: GHG emission; Municipal solid waste; Landfill gases; Indian cities; LFG estimation

1. Introduction

In recent times with rapid urbanization, management of municipal solid waste (MSW) is one of the biggest problems faced by India and other developing countries. According to Census 2011, India with a population of 1.21 billion generates about 100000 tons of municipal solid waste (MSW) per day. Daily per capita waste generation rate vary from 200 to 600 gm in major cities of the country depending on the lifestyle adopted by the people and the nature of the places [1]. Few years back community bins collection was practiced, however after commencement of MSW (Management and Handling) rules 2000, collection, segregation and containerized system adopted in many

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cities. But unfortunately almost 70-90% of MSW is openly dumped, which is the most ordinary and cheapest disposal method for every municipalities of India [2].

The unscientific way of dumping MSW in landfills may lead to hazards like soil pollution, ground water contamination and air pollution due to emission of greenhouse gases. Lack of attention by the government causes huge amount of methane gas exposed into the atmosphere. Methane is one of the major ingredients of greenhouse gases (GHG) which is responsible for global warming. Today methane is the second most greenhouse gas after carbon dioxide. About 30% of methane emitted to the atmosphere is from landfill sources as per Intergovernmental Panel on Climate Change (IPCC) [6]. Today policies have been adopted all over the world to reduce emission of landfill gases (LFG) from MSW.

Quantitative assessment of landfill gases with appropriate methodology is required to reduce the greenhouse gas emission by possible means waste to energy conversion. It is not feasible for a new project to be successful if we do not asses potential of the source. For the application of new technologies it is also necessary to determine the energy generation potential from MSW. Government is adopting new concept to recovery energy from the MSW but in most of the cases, lack of insufficient potential of raw material leads to a failure. Although MSW treatment is a great challenge but it can prove to be a golden opportunity if we can extract energy using certain technologies. The energy recovery from the MSW may repay for energy demand and thus to minimize the use of conventional energy sources. Various inventories are practiced throughout the world for estimation of landfill gases. India is also adopting different methodologies for assessing GHG emissions like stoichiometric method, IPCC 1996 default method, IPCC 2006 first order decay (FOD) method, triangular method (TM), modified triangular method (MTM), in-situ closed flux chamber method [2]. Protocol like First Order model (TNO), Multi-phase model, LandGEM model (US-EPA), EPER Model Germany (UmweltBundesamt), GasSIM, EPER Model France (ADEME) are used by European Union and other developed nation also for estimation LFG emission from landfills [3]. In many countries estimation of LFG using these inventory is a great challenge because of inadequate data availability on MSW management. During the landfill process the municipal waste has to gone through a certain stages like collection, transportation and or segregation leading to variation in quantity and quality of waste during final disposal of waste. In the present paper an attempt has been made to estimate LFG emissions from landfills of some selected tier I cities in India considering various factors in Indian condition.

2. Methodology

Four different models (1) First Order model (TNO), (2) Multi-phase model (Afvalzorg), (3) LandGEM model (US-EPA) and (4) EPER Model Germany (UmweltBundesamt) have been used to carry out the present work. All the data implemented here were secondary data collected from different sources. Tier one cities of India were selected for quantification of LFG emission for a period of 30 years from 1982 to 2012. Populations of the respective cities have been obtained from Census 2011. Here it is considered that total MSW generated in the city are directly proportional to the population of the city and with no collection recovery efficiency. In the existing work, we have considered per capita MSW generation in Indian cities increased with a rate of 1.2 % every year [4]. Total volatile solid (VS) and organic carbon content of the typical MSW in urban India have been considered as 13.27% and 12.06% respectively in wet weight basis throughout the investigation. All the generated waste in throughout the city is landfilled in the respective dumping sites.

2.1. Overview of selected cities

To carry out the present work tier I cities of India are taken for estimation of LFG emission. Six cities (tier I) namely Bangalore, Chennai, Delhi, Hyderabad, Kolkata and Mumbai have been selected for this study. As per government of India tier I refer to the city having population of one lakh and above. Tier I cities are selected here because these cities are highly affected with the overwhelming increase in MSW with the increase in population and industrialization. Cities with area, population, and waste generation rates are shown in Table 1. The generated wastes of the city are usually landfilled within the city. Table 2 shows the landfill sites of the respective cities. Also the physical characteristics of MSW of these cities are shown in Table 3.

Table 1. Cities with waste generation rates.

Name of the city	Area (km²)	Population (Census 2011)	Waste Generation Rate (Kg/capita/day)
Bangalore	741	9,588,910	0.484
Chennai	1,189	4,681,087	0.657
Delhi	1,484	16,753,235	0.475
Hyderabad	650	4,010,238	0.382
Kolkata	185	4,486,679	0.383
Mumbai	603	3,145,966	0.436

Source: [5]

Table 2. Cities with their dumping sites.

Name of the City	Disposal sites
Bangalore	Mandur, Mavallipura, Anaanapura, Cheemsandra, Kannahalli, S.Bingipura
Chennai	Kodungaiyur, Perungudi
Delhi	Ghazipur, Okhla, Bhalswa
Hyderabad	Jawaharnagar
Kolkata	Dhapa, Garden Reach
Mumbai	Deonar, Mulund, Gorai, Kanjur

Table 3. Physical characteristics (% in wet weight basis) of waste in different tier I cities in India.

City	Paper	Textile	Leather	Plastic	Metals	Glass	Ash, fine earth and others	Compostable matter
Bangalore	8.00	5.00	–	6.00	3.00	6.00	27.00	45.00
Chennai	10.00	5.00	5.00	3.00	–	–	33.00	44.00
Delhi	6.60	4.00	0.60	1.50	2.50	1.20	51.50	31.78
Hyderabad	7.00	1.70	–	1.30	–	–	50.00	40.00
Kolkata	10.00	3.00	1.00	8.00	–	3.00	35.00	40.00
Mumbai	10.00	3.60	0.20	2.00	–	0.20	44.00	40.00

Source [7]

2.2. Inventory for emission quantification

In the present work, four different emission models are used namely First order model (TNO), Multi-phase model (Afvalzorg), LandGEM model (US-EPA) and EPER Model Germany (UmweltBundesamt). These models are practiced in many countries for LFG emission estimation. The parameters used in these models are described briefly in literature [3].

2.2.1. First order model (TNO)

This model was developed by Oonk and Boom in the year 1995[8]. Here the amount of waste generated was assumed to be decayed exponentially with time. The mathematically expression of the first order model is given below.

$$\propto_t = \varsigma * 1.87 * A * C_0 * k_1 * e^{-k_1 * t} \quad (1)$$

Where,
$\propto_t$ = landfill gas production at a given time [m^3 LFG . y^{-1}]
ς = dissimilation factor, 0.58
1.87 = conversion factor [m^3 LFG . $kgC^{-1}_{degraded}$]
A = amount of waste in place [Mg]
C_0 = amount of organic carbon in waste [kgC . Mg Waste $^{-1}$]
k_1 = degradation rate constant, 0.094 [y^{-1}]

t = time elapsed since depositing [y]

2.2.2. Multi-phase model (Afvalzorg)

In the first order multi-phase model different fraction of waste are taken into account. All types of waste contain typical fraction of slow, moderate and fast degradable. Here three waste fractions are taken and for that LFG productions are calculated separately the model was developed by Agricultural University of Wageningen in the year 1996. Mathematical model is shown in equation 2.

$$\propto_t = \varsigma * \sum_{i=1}^{3} c * A * C_0 * k_{1,i} * e^{-k_{1,i} * t} \quad (2)$$

Where,
$\propto_t$ = landfill gas production at a given time [m^3 LFG . y^{-1}]
ς = dissimilation factor, 0.58
i = waste fraction with degradation rate $k_{1,i}$[kg_i . kg_{waste}^{-1}]
c = conversion factor [m^3 LFG. $kgC_{degraded}^{-1}$]
A = amount of waste in place [Mg]
C_0 = amount of organic carbon in waste [kgC . Mg Waste $^{-1}$]
$k_{1,i}$ = degradation rate constant of fraction i [y^{-1}]
t = time elapsed since depositing [y]

Here the values of k were reported as 0.1, 0.03 and 0.009 per year for fast decaying (e.g. food and garden waste), medium decaying (e.g. paper, wood, textiles) and slow decaying organic waste (e.g. leather, rubber) respectively.

2.2.3. LandGEM model (US-EPA)

LandGEM model was developed by and made available by United Nation Environmental Protection Agency (US-EPA). It is also a first order decay model where it determines the mass of methane generated using the methane generation capacity and the mass of waste deposited and it shown in equation 3.

$$Q_{CH_4} = \sum_{i=1}^{n} k * L_0 * M_i * (e^{-k * t_i}) \quad (3)$$

Where,
Q_{CH_4} = methane emission rate [m^3 CH_4 . y^{-1}]
k = methane generation constant [y^{-1}]
L_0 = methane generation potential [m^3 CH_4 . Mg Waste $^{-1}$]
M_i = mass of waste in ith section [Mg]
t_i = age of the ith increment or section [y]

Data source used for this model like methane generation constant, methane generation potential and average annual precipitation of different cities are shown in table 4.

Table 4 CH_4 generation potential, average annual precipitation rate and CH_4 generation rate constant of waste in different metro cities of India.

City	L_0 (m^3 CH_4 .Mg Waste $^{-1}$)	Average annual precipitation (mm/year)	k ($year^{-1}$)
Bangalore	46.07	877.8	0.04
Chennai	47.66	1549.9	0.06
Delhi	33.72	755.4	0.03
Hyderabad	40.49	821.7	0.04
Kolkata	44.23	1765.1	0.07
Mumbai	44.3	2334.6	0.08

Source [9]

2.2.4. EPER Model Germany (UmweltBundesamt)

This is a Germany based zero order model and can be mathematically describes as

$$Me \ = M * \ BDC * BDC_f * F * D * C \quad (4)$$

Where,
Me = amount of diffuse methane emission [Mg CH_4. y^{-1}]
M = annual amount of landfilled waste [Mg waste . y^{-1}]
BDC = proportion of biodegradable carbon [MgC .Mg Waste $^{-1}$]
BDC_f = proportion of biodegradable C converted 0.5 [–]
F = calculation factor of carbon converted into CH_4, 1.33 [Mg CH_4. MgC^{-1}]
D = collection efficiency:
active degassing 0.4 [–]
no recovery 0.9 [–]
active LFG recovery and cover 0.1 [–]
C = methane concentration 50 [%]

For the present case study it has been considered that the total waste generated in the city was landfilled and not recovered for other use. So here we took 0.9 as collection efficiency for all the metro cities.

3. Results and Discussion

Landfill gas generation rate (10^6 m^3/y) in six tier I cities in India, given in Fig. 1, have been estimated using the four different mathematical models discussed earlier.

From Fig. 1 it has been observed that, the LFG estimation according to the Multi-phase model is minimum for all the cities, while the EPER model Germany estimates the maximum emission which is almost 300-500% of the minimum estimation. The First order model estimation is about 200% of the minimum estimation. According to first order model, the entire amount of waste has been taken into consideration for calculation while only slow, medium and fast degradable portions of wastes are considered in Multi-phase model excluding the non-biodegradable or inert materials. Large fluctuations in LFG emissions have been estimated with the German EPER model. In this study, the zero order model was used i.e., the methane production of an amount of waste landfilled in a particular year is released in that same year.

The estimations according to the first two models (First Order and Multi-phase) have followed the same pattern i.e. the LFG emission increases first with increase in population as well as generated MSW for a certain period of time, then the gas emission declines with increasing MSW (Fig. 1). This is because landfill sites have a certain period of life time for which it has to be reconstructed again. While in the other two models (LandGEM and EPER Germany), LFG emission increases throughout the entire period (1982-2012) with increasing amount of MSW. Therefore, it can be concluded that the mathematical models diverge from each other with increasing time. For all the cities same patterns of LFG emissions have been observed throughout the entire period of study.

4. Conclusions

The study concluded that all the above LFG emission inventories used in the present work show that large amount LFG emitted to the atmosphere from all the Indian metro cities. With rapid industrialization in metropolitan all cities causes a direct impact in its MSW generation. There is a huge potential for energy generation from methane in Indian cities. By proper management of municipal solid waste we can reduce the health hazards and convert the waste to useful energy. Collection, transportation and segregation of MSW are needed if we want to utilize this LFG directly for heating purpose or indirectly for electricity generation, otherwise the greenhouse gas emissions will increase day by day.

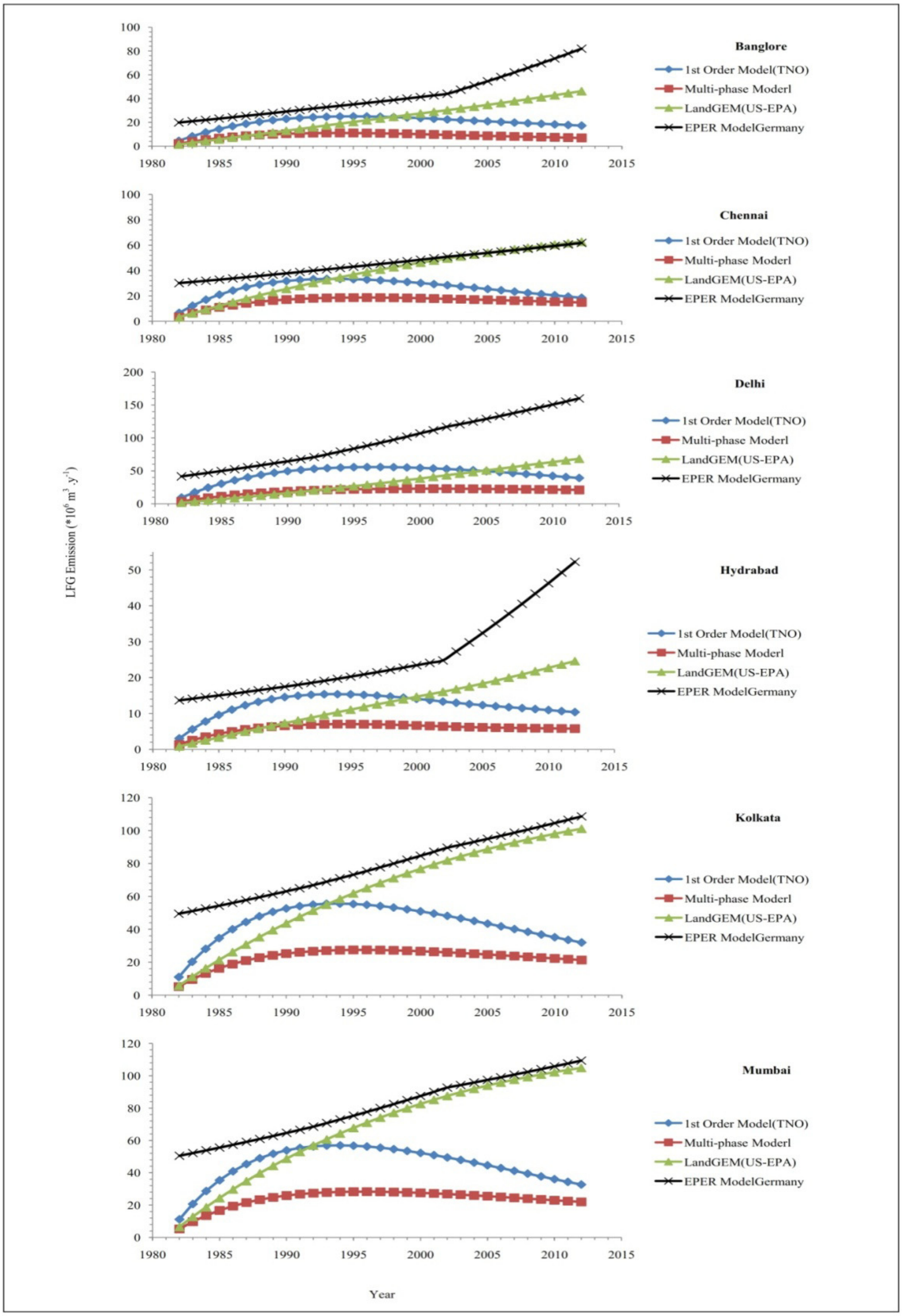

Fig. 1. Estimated LFG emission from six different city from 1982-2012.

The present work deals with the comparability and transparency of the four mathematical models. There is no such intention to validate or check the accuracy of the stated methodologies. The main purpose of the present work is to assess the LFG emission of Indian metro cities. The inventory estimation is made mostly on the basis of the published data from respective sources. More extensive research is needed for Indian condition to attain the factors used in all the models. There are many constraints for collection of data source mostly on municipalities regarding MSW management. It is because due to lack of awareness among the people and because of less priority given for MSW management, which leads to insufficient financial budget allocation for the municipalities.

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