

Quantitative Analysis of Methane Gas Emission from Municipal Solid Waste in Jabalpur

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Abstract - In past few decades increased emissions of greenhouse gases have adversely affected global climatic conditions. The municipal solid waste (MSW) generated by households is considered the third largest anthropogenic source of methane CH₄ emissions. The current study derived total MSW CH₄ emission estimates using the IPCC default method (DM). The estimated CH₄ emission was higher for the DM than the other methods, and was comparable to estimates from other studies therefor DM was used. This study observed that the net annual emission of CH₄ from landfills in India increased from 404 Gg in 1999–2000 to 990 Gg and 1084 Gg in 2011 and 2015, respectively. We also found that CH₄ emissions were highly correlated with the gross state domestic product (GSDP) of states and the gross domestic product (GDP) of the country, which is an indicator of human well-being. Study pertaining to MSWM for Indian cities has been carried out to evaluate the current status and identify the major problems. The MSW management policy of India needs to be reviewed in a current policy context, as the management and efficient utilization of MSW technologies might help increase the use of CH₄ as an energy source and thereby improve its sustainable and cost-effective management.

Introduction

Methane CH₄ is regarded as one of the most important GHG because of its global warming potential, which is 28 times higher than that of CO₂ over 100 years. The increase in greenhouse gas (GHG) emissions has altered the global temperature pattern and created a threat against human health and the environment. Methane emitted from landfills is one of the most important contributors to GHGs. Over the last few centuries, the concentration of CH₄ in the atmosphere has increased rapidly. In a span of 260 years, from 1750 to 2010, the concentration of GHG CH₄ in the environment has increased from 700 ppb to 1808 ppb. The rate of increase observed during the last few decades is 1–2% per year. Along with natural sources, i.e., wetlands, termites, and oceans, which account for 36% of the total CH₄, anthropogenic activities, including the production and burning of fossil fuels, livestock farming, landfills and agriculture, contribute 64% of the total amount of global CH₄ emissions. Rapid population growth and development activities have increased the potential CH₄ emission level, and it has been estimated that the concentration of GHG CH₄ is expected to increase from 6.88 Gt CO₂-eq, the value recorded in 2010, to 8.59 Gt CO₂-eq by 2020. The decomposition of municipal solid waste (MSW), i.e., wastes generated from households and residential settings, is considered the third major anthropogenic source of CH₄, and it contributes approximately 11% of the total anthropogenic CH₄ emissions.

Asian countries are the largest producers of MSW due to their high population densities. The generation of MSW in Asia is predicted to increase up to 1.8 million tons/day by 2025 from the current value of 1 million tons/day. India, with its huge population and GDP growth rate of 6.7%, is witnessing rapid urbanization and lifestyle changes. The per capita generation rate of MSW in India ranges from 0.2 to 0.5 kg/day. Presently, approximately 90 million tons of solid waste is generated by the country, which is eight times higher than the amount of solid waste that was generated in 1947. Metropolitan cities have the largest contribution to the generation of waste compared to smaller and less developed cities. At present, India produces 16 Mg CO₂ equivalent of CH₄ per year, and the annual value is expected to reach 20 Mg CO₂ equivalent by 2020. It is also estimated that CH₄ contributes 29% of the total GHG emissions from the country, which is higher than the global average of 15%. Studies suggest that the MSW generated in India mostly consists of a large fraction of organic wastes (40–60%), 3–6% paper waste, and 30–40% ash and fine earth material waste, with smaller fractions of plastics, glass and metal wastes (all <1%). The moisture content of the wastes is 47%, with an average calorific value of 6.8–9.8 MJ/kg and a C/N ratio of 800–1000 Kcal/kg.

Once MSW is disposed into landfills, it undergoes aerobic decomposition, which produces a very small amount of CH₄. Afterwards, the anaerobic condition prevails, and due to methanogen activities, the MSW emits CH₄ for years, even if the landfill is closed. The technologies used to generate energy from MSW that are prevalent in India, are incineration and biochemical conversion. In India, only 70–75% of the MSW gets collected, and only 20–25% of it is treated. The technologies involved in MSW management include composting/vermicomposting, recycling and landfilling. So far, only 553 compost and vermi-compost plants, 56 bio-methanation plants, 22 refuse derived fuel (RDF) plants and 13 waste-to-energy conversion plants are installed in the country (CPCB). Many of these schemes have experienced failure due to

several issues related to the segregation of waste, low calorific values of the waste, and challenges in the operation and maintenance of the plants (CPCB).

In India, due to inadequate data availability, a large amount of uncertainty related to MSW management and emissions has been observed, which makes it difficult to estimate the accurate value for the landfill GHG emission potential. The International Panel on Climate Change has established a method for the estimation of GHGs emitted from landfills that has been widely used by researchers.

Studies have been conducted by using different methods, i.e., the stoichiometric method, default method (DM), first order decay method (FOD), modified triangular method (MTM), in situ closed chamber methods and the landfill gas emission method (Land GEM). India is the largest producer of MSW, and landfills are third largest contributors to the total CH₄ emission value of the country. The CH₄ emitted from landfills can be utilized as a potential source of renewable energy. With the above background, this study aimed to estimate the potential emissions of CH₄ from landfills at the national scale, which would support sustainable management practices in a quickly evolving economy.

Trends in Methane Emissions from Landfills and Populations

Migration from rural areas to the urban areas has increased the generation of MSW. According to the census of India, during the period from 2001 to 2011, the population of the country increased by 181 million, which is 17.6% of the total population, and within the 2001–2011 period, the urban population increased by 31.8%. This increase in the urban population has resulted in a huge generation of MSW and has also changed the characteristics of the wastes due to changes in the economic status and living standards of the

Methane Emission, Population Growth and Economic Development

We found that the CH₄ emissions were highly correlated with economic development and population growth. Economic development drives the population to move to cities where basic infrastructure and amenities are available. This diversion of the population subsequently leads to changes in the overall lifestyle and living standards and thereby increases the per capita generation of MSW. We found that the higher the population density, the more MSW was generated. Similarly, for the regions, higher GDPs indicated higher human activity levels and consequently higher MSW generation rates. The generation of MSW is often linked with per-capita income and development. The generation of MSW is considered high in developed countries compared to developing countries. Our findings show a high correlation between the MSW methane emission level and the GSDP, which is an indicator of social well-being, of the states. Along with their development level, the lifestyles of the communities also change accordingly, which further enhances the generation of MSW.

CH₄ from Landfills: A Potential Source of Energy

India, one of the fastest growing economies, is still improving its existing technological capability to generate power sources and energy from MSW. Most of the gases emitted from landfills have the potential to be utilized as biogas, which is a source of clean/green energy. Landfills directly emit GHGs into the environment, which affects the global temperature and puts the environment at risk. The open dumping of wastes leads to significant reductions in nutrients, i.e., nitrate, potassium and phosphorus; reduces the ability to recycle and reuse waste; and increases the risk of groundwater pollution by leaching. Controlled or engineered landfills with a proper covering and collection system can enable the sustainable disposal of solid wastes and their use as an energy source. According to one estimate, only 20–25% of landfill gases can be recovered, while the rest of the gases escape into the atmosphere. If properly designed landfills are established, 30–60% of the gases can be utilized from these controlled landfills. These recovered landfill gases can be used as a direct source of energy and for power generation or can be upgraded into vehicle fuel.

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Status and Challenges for MSW Management in Jabalpur Comparing to Whole Country Scenario

The emission of CH₄ is directly related to the amount of waste generated from the households or the society in a region. In India, there is a huge amount of climatic, cultural and demographic variability based on the different food habits of its communities. According to the 2011 census, the urban population in India increased from 285 million in 2001 to 377 million in 2011, and approximately 70% of this population resides in 366 cities of the country. In the present study, we observed that over the last fifteen years, the total MSW has increased by three times compared to the amount that was generated in 1999–2000, i.e., from 52125 MT/day in 1999–2000 to 127485 MT/day in 2010 and 139566 MT/day in 2015. Landfills are one of the most cost effective, simplest, and oldest techniques for MSW management, but they require land area near cities but away from habitation clusters and other places of socio-economic or environmental importance. Most of the existing landfills in megacities such as Delhi are oversaturated and are serving beyond their maximum carrying capacity. When a landfill operating above its capacity in Delhi collapsed on 1st September 2017, a 50 m high mound of waste killed several people. According to one estimate, the total urban waste generated in India will increase to 107 thousand tons/year in 2031 and will reach up to 160.9 thousand tons/year in 2041. The proper disposal of this waste will require an area of 1400 sq.km, i.e., an area equivalent to the area of Hyderabad, Mumbai and Chennai.

MSW contains large amounts of biodegradable wastes and wastes with high calorific values that can be utilized for vermicomposting/compost preparation and energy generation, respectively. The Indian government revised the 2001 law related to MSW after 15 years and produced a new MSW law in 2016 under the Environmental (Protection) Act of 1986 for the proper management and utilization of MSW. This law is intended to make the community aware of ways to reduce waste generation and to involve locals in the proper management of waste and innovations of technology for recycling and energy recovery purposes. The huge amount of waste generated in the country has a potential use as renewable energy, as landfill gases have high a calorific value, and can consequently minimize the impacts of greenhouse gas emissions on the climate.

Conclusion

In the last few decades, the overall growth of the population, urbanization level and economy of India has increased the amount of municipal solid waste generated in the country and so of Jabalpur also. The disposal of these wastes into landfills results in the emission of gases with a high global warming potential such as CH₄, CO₂, and NO_x. The results of this study indicate that a gradual increase in the CH₄ emissions has occurred over the last 7 years (2011–2018). Landfill gases have the potential to be utilized as sources of green energy, and if properly planned and engineered landfills are constructed at suitable sites, these gases can be recovered and utilized as a sustainable source of renewable energy.

METHOD

Data acquisition and determination of waste characteristics

This study was conducted to determine the generation and composition of waste in various parts of the country. It has been observed that the composition of waste depends on various factors, including the food habits and socio-cultural practices of a community, the climate and the community income. The source composition of MSW approximately consisted of a fraction of **organic matter** varying from **40 to 60%**, followed by fractions of **earth and ash materials (30–40%)**, **paper (3–6%)** and **plastic, glass and metals (1% each)**. It was reported that the composition of municipal waste was **30–70% rapidly biodegradable organic matter**, **0.6–31% paper and cardboard**, and **1–16% plastic materials**. In this study, we assume that **70% of the MSW reaches a landfill**. The collection efficiency is poor due to a number of reasons (e.g., poorly designed bins, open dumps, collection vehicles, and the frequency of waste collection). The average **collection efficiency** for MSW is approximately 70%. The MSW generation data for 2011 and 2018 (approximated) were collected from the Central Pollution Control Board (CPCB) and Jabalpur Municipal Corporation (JMC). The population data was taken from the Census 2011.

Calculation of CH₄ emissions from landfills

Among the available methods for the estimation of CH₄ emissions from landfills, the simplest one was provided by Bingemer and Crutzen (1987) and revised by the IPCC in 1996. It is a mass balance approach that provides the actual emissions from the landfill, and it is widely used when detailed data are not available. The CH₄ emissions from MSW were calculated using following formula:-

$$\text{CH}_4 \text{ (Gg/yr)} = (\text{MSW}_T \times \text{MSW}_F) \times \text{MCF} \times \text{DOC} \times \text{DOCF} \times F \times ((16/12) - R) \times (1 - \text{OX})$$

where 1 Gg/yr = 1000 tons/yr.

In equation 1, MSW_T = total amount of solid waste generated (Gg/yr),

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MSW_F = the fraction of MSW that reaches the landfill sites (considered 70% for the current study, as the rest of the MSW was considered lost by recycling, reuse or other processes),

MCF = Methane correction factor

DOC = Degradable organic carbon, which can be calculated using the following equation:

$$\text{DOC} = 0.4A + 0.17B + 0.15C + 0.3D$$

where A = paper, cardboard and rags, B = leaves, straw and others, C = fruit and vegetable wastes and D = wood

DOCF = the value of the dissimilated fill gas, which was considered 0.77 (at a temperature of 35 °C),

F = fraction of methane gas, which was considered 0.5.

R = recovered methane gas, which was considered 0 for this study, as recovery techniques for landfill gases have not been adopted in most of India.

OX = oxidation factor, which was also considered 0 (as the default value) and accounted for the methane gas that was oxidized in the upper layer of the waste in the presence of oxygen.

The IPCC has identified two types of uncertainties in the model, but the model generates reasonable estimates for regions where the data on waste generation are limited.

The uncertainty in the model is as follows: First, the methodology assumes that a constant amount of waste is added each year and that the CH_4 generation is the same in each year. Thus, temporal increments at the landfills are not considered, which may cause the methane emission value to be overestimated. The amount of waste disposed is a highly sensitive parameter in the default methodology.

Result

Temporal CH_4 Emission Estimate with the DM (default method)

The CH_4 emission values calculated using the DM. Using the DM the estimated the net annual methane generated in Jabalpur to be 13.83 Gg, in the year 2018. DOC value is taken to be 0.16, based on the fractions depicted in the CPCB, 2013.

MAP SHOWING KATHONDA LANDFILL SITE

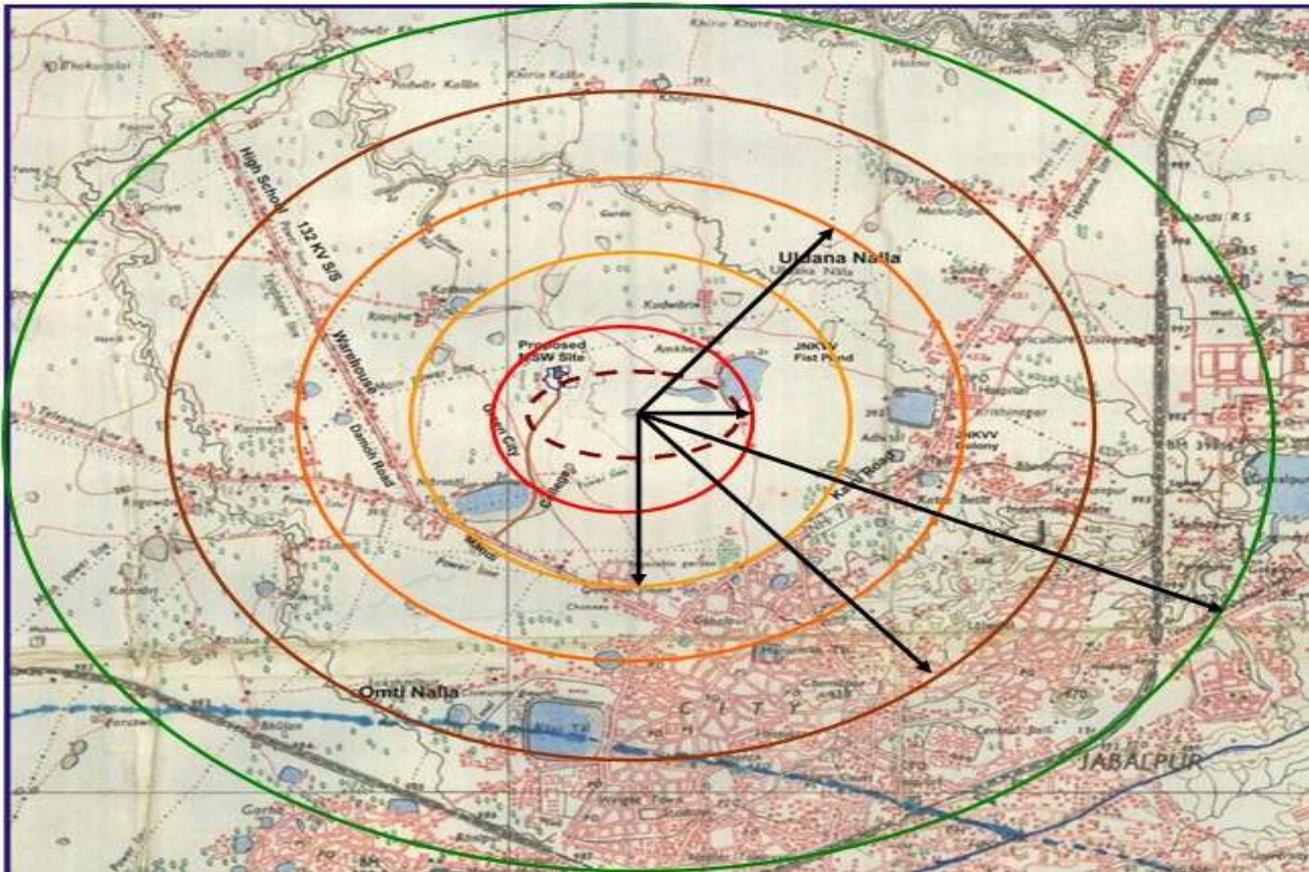


Table showing Ward-wise Population and Municipal Solid Waste Generation

S. No	Ward No.	Population	MSW generation (Kg)	S. No	Ward No.	Population	MSW generation (Kg)
1	Ward No. - 1	12,306	5316.19	42	Ward No. - 42	13,501	5832.43
2	Ward No. - 2	11,834	5112.29	43	Ward No. - 43	15,961	6895.15
3	Ward No. - 3	12,907	5575.82	44	Ward No. - 44	11,716	5061.31
4	Ward No. - 4	9,158	3956.26	45	Ward No. - 45	14,851	6415.63
5	Ward No. - 5	11,112	4800.38	46	Ward No. - 46	11,322	4891.10
6	Ward No. - 6	13,093	5656.18	47	Ward No. - 47	12,035	5199.12
7	Ward No. - 7	10,966	4737.31	48	Ward No. - 48	20,562	8882.78
8	Ward No. - 8	8,683	3751.06	49	Ward No. - 49	15,434	6667.49
9	Ward No. - 9	8,039	3472.85	50	Ward No. - 50	10,026	4331.23
10	Ward No. - 10	12,073	5215.54	51	Ward No. - 51	9,129	3943.73
11	Ward No. - 11	26,114	11281.25	52	Ward No. - 52	12,782	5521.82
12	Ward No. - 12	21,910	9465.12	53	Ward No. - 53	14,301	6178.03
13	Ward No. - 13	14,585	6300.72	54	Ward No. - 54	18,375	7938.00
14	Ward No. - 14	10,059	4345.49	55	Ward No. - 55	25,946	11208.67
15	Ward No. - 15	8,816	3808.51	56	Ward No. - 56	15,075	6512.40
16	Ward No. - 16	8,890	3840.48	57	Ward No. - 57	16,000	6912.00
17	Ward No. - 17	10,922	4718.30	58	Ward No. - 58	17,707	7649.42
18	Ward No. - 18	11,874	5129.57	59	Ward No. - 59	19,525	8434.80
19	Ward No. - 19	11,920	5149.44	60	Ward No. - 60	13,795	5959.44
20	Ward No. - 20	8,600	3715.20	61	Ward No. - 61	16,258	7023.46
21	Ward No. - 21	7,671	3313.87	62	Ward No. - 62	20,074	8671.97

22	Ward No. - 22	8,802	3802.46	63	Ward No. - 63	17,444	7535.81
23	Ward No. - 23	11,404	4926.53	64	Ward No. - 64	27,693	11963.38
24	Ward No. - 24	30,453	13155.70	65	Ward No. - 65	9,661	4173.55
25	Ward No. - 25	17,642	7621.34	66	Ward No. - 66	23,384	10101.89
26	Ward No. - 26	12,674	5475.17	67	Ward No. - 67	15,216	6573.31
27	Ward No. - 27	13,567	5860.94	68	Ward No. - 68	20,718	8950.18
28	Ward No. - 28	16,436	7100.35	69	Ward No. - 69	14,368	6206.98
29	Ward No. - 29	11,472	4955.90	70	Ward No. - 70	12,537	5415.98
30	Ward No. - 30	11,558	4993.06	71	Ward No. - 71	3,928	1696.90
31	Ward No. - 31	12,404	5358.53	72	Ward No. - 72	3,749	1619.57
32	Ward No. - 32	13,181	5694.19	73	Ward No. - 73	2,283	986.26
33	Ward No. - 33	12,971	5603.47	74	Ward No. - 74	1,333	575.86
34	Ward No. - 34	14,725	6361.20	75	Ward No. - 75	583	251.86
35	Ward No. - 35	29,814	12879.65	76	Ward No. - 76	1,891	816.91
36	Ward No. - 36	14,486	6257.95	77	Ward No. - 77	2,099	906.77
37	Ward No. - 37	26,537	11463.98	78	Ward No. - 78	5,463	2360.02
38	Ward No. - 38	22,265	9618.48	79	Ward No. - 79	4,823	2083.54
39	Ward No. - 39	14,532	6277.82				
40	Ward No. - 40	19,087	8245.58	Population As percensus Year 2011 -1,081,677 MSW=467284.46Kg			
41	Ward No. - 41	24,587	10621.58	Now At present approximate Population is 1525640 & waste generation is more than 659 tons			

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