International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume – 03, Issue – 04, April 2018, PP – 11-19

Greenhouse Gas Emission Modelling and Its Validation—A Case Study for Okhla Disposal Site

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Abstract*:* A key concern with the increasing waste generation and its improper management is emission of methane from disposal sites. Waste management contributed 14% of the total global methane emissions and about 3.45% of India's total greenhouse gas (GHG)emissions in 2010 with 6,5052.47GgCO_2eq emissions. In 2015, India committed to decrease its emissions intensity per unit gross domestic product by 33–35% below 2005 levelstill 2030.

This study was undertaken with an aim to evaluate the emissions from a non-engineered landfill site and validate the findings with past pilot study.This study is the first-of-its-kind in India providing an impetus for other cities to evaluate their non-engineered sites and validate models for better reporting purposes. The developed model can also help countries evaluate the impacts of their policies and rules in reducing GHG emissions.

A model for evaluating GHG emissions was developed based on IPCC 2006 methodology and site-specific inputs and validated with respect to a past study conducted at Okhla Landfill, Delhi, India. The model predicted site GHG emissions as 275 Gg CO_2eqyr^{-1}in the year 2011 and 285.5 Gg CO_2 eqyr^{-1}in 2017. The developed model on IPCC 2006 methodology was also validated and indicated 16.6% lower predicted value.

The modelling exercise also estimated,a potential of 1,483.5 Gg CO_2 eq GHG emission reduction till 2050 from Okhla disposal site, with an estimated peak emission suppression by 21.79%with intrusion of Swachh Bharat Mission and Solid Waste Management Rules, 2016.

Keywords: Disposal site, Greenhouse gas emission,Modelling,Municipal solid waste, Validation

1.0 Introduction

Waste Quantities

Globally in cities waste generation rates range from 0.5–1.7 kg c^{-1} d^{-1}, with developing country cities having least generation rates (UN-HABITAT, 2010). The average per capita biodegradable fraction of waste in India has been reported as only 52.4% in a survey covering 59 cities (Central Pollution Control Board, 2012). The World Bank projects a 70% global increase in municipal solid waste (MSW) quantities by 2025—with developing countries facing the greatest challenges as their waste is expected to more than double (Bhada-Tata & Hoornweg, 2012).

Urban India generated about 49.35 million tonnes per year (MT y^{-1}) of MSW and collected only 82.12% of this waste. Only 23% of collected wastewas treated and of the total only 17.31 MT y^{-1} was dumped in landfills (Central Pollution Control Board, 2017). India has 1,247 existing dumpsites, 12 dumpsites are reclaimed/capped and only two dumpsites in states of Meghalaya and Telangana are converted to sanitary landfill (Central Pollution Control Board, 2017). With India moving on the path of rapid development, a major increase in the generation of MSW is also being experienced simultaneously increasing the GHG emissions, largely due to uncontrolled emissions from land disposed solid waste and non-recovery of methane from treatment and disposal facilities.

In Delhi, total MSW generated from five municipal areas is 9,620tonnes per day, which is disposed onto four landfill sites namely—Bhalswa, Ghazipur, Okhla, and Narela-Bawana. There are three waste-to-energy (W2E) plants (Okhla:16MW, Ghazipur:12MW,and Bawana:24MW)(Central Pollution Control Board, 2017).It is expected that the generation rate in Delhi will be 0.61 kg $c^{-1}d^{-1}$ and the compost production rate will be 0.342 million tonnes in 2024 (Ahmad, 2012). Figure 1describes the waste generation, treatment, and disposal at South Delhi.

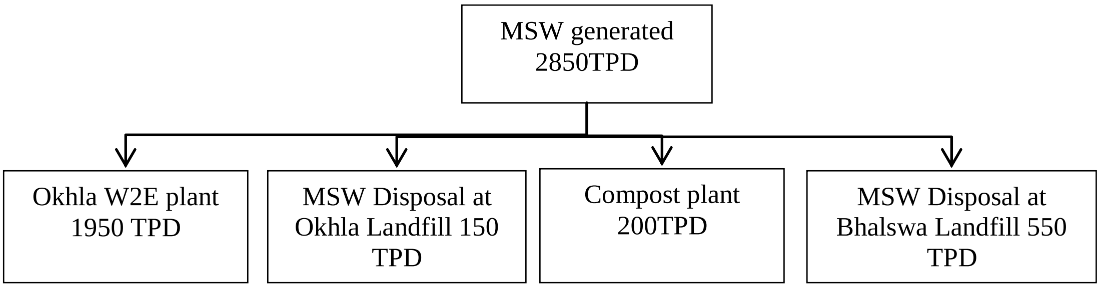

Figure 1: Flow diagram depicting waste generation, treatment, and disposal at South Delhi.

Emissions and commitments

India's Intended Nationally Determined Contributions (INDCs) were announced in 2015 and the country committed to reduce its emissions intensity per unit Gross Domestic Product (GDP) by 33–35% by 2030 compared to 2005 emissions, providing an impetus to undertake this study. The 2007 emissions from India's waste sector were reported as 57,726.81 Gg CO_2 eq increasing at a CAGR of 1.4% from 2000 to 2007(Ministry of Environment and Forest, 2012). MSW management contributed about 14% of the total global methane emissions and about 3.45% of India's total GHG emissions in 2010 with 65,052.47 Gg CO_2eqemissions (Ministry of Environment, Forests and Climate Change, 2015).

Objective of the study

The disposal of MSW varies from city to city and ranges from dumping in low lying areas and outskirts of the city to an engineered sanitary landfill having liners and gas and leachate collection systems (Sahu, 2007)(Kumar, 2008).Immediately after placement of waste in landfill, the organic portion of waste starts decomposing. This anaerobic biodegradation dominates throughout the age of the landfill. The anaerobic phase is important from the perspective of methane generation(George Tchobanoglous, 1977) (Barlaz, 1990).

Landfill gas (LFG) is approximately 50% methane; amount of LFG largely depends on a number of factors, including the type of waste disposal site, the organic content of the waste, and the climate (Hershman, 2009). LFG emission depends on the spatial/physical conditions, such as anaerobic condition, depth from surface, age of dumping, and chemical compositions like carbohydrate and protein contents in the waste. The variables that influence biodegradation of MSW are identified as: (i) the physico-chemical composition of the wastes, viz., organic mass, moisture content, pH, nutrient status, ingress of air, etc.; (ii) the in-situ conditions, such as depth of fill, period of filling, compaction and settlement, soil structure, water table, etc.; and (iii) the atmospheric conditions, such as temperature, pressure, wind speed and direction, rainfall, seasonal changes, etc.(Akolkar A.B. et al, 2008). Due to high proportion of food scraps, and the warm, wet climate, the rate of MSW decomposition in India is faster than in landfills in developed countries. As per a study in Brazil, waste decomposes 4–5 times faster in a tropical wet climate than predicted by traditional first order models using default parameters (Maciel, 2011).

The process of waste biodegradation is exothermic; hence the temperature rises in landfill when the reaction proceeds. A tonne of largely organic waste in a landfill should be able to produce 150–300m^3 of LFGduring its lifetime, with methane constituting 50–60% of the gas by volume (Aswathanarayana, et al., 2010). Although gas production in a landfill can continue for long time, high rates occur for relatively short periods, perhaps upto 10 years after the landfill becomes inactive (Hauser, 2009). National communication (NATCOM) estimated, that in year 2000, 3% of the total GHG emissions from India were contributed by waste sector. About 10,252 Gg CO_2eq were the emissions from solid waste disposal which was 19.5% of total emissions from waste sector (Ministry of Environment and Forest, 2012).

The objectives of present research was to develop Microsoft excel based model and evaluate the GHG emissions from dumpsite using site-specific data and the impacts of policies of government to reduce GHG emissions. Earlier pilot study done on the same Okhla landfill site was reviewed and compared with the model estimates for validation purposes. This study is the first-of-its-kind in India providing an impetus for other developing contries to evaluate their non-engineered sites and validate models for better reporting purposes.

2.0 Materials and Methods

The various models that can be used to estimate LFG recovery from a landfill are: Zero Order Model, Constant Rate Model, SimpleFirst Order Model, Modified First Order Model, First Order Multiphase Model, Second Order Model, Scholl Canyon Model, Triangular Model, Palos Verdes Kinetic Model, Sheldon Arleta Model, GASFILL Model, U.S.EPA LandGEM Model Version 3.02, LFGGEN Model, EPER Germany, EPER

France, IPCC Model 2006, TNO Model, Afvalzorg Model, Colombia Model Version 1.0, CALMIM Model, Phillippines Model Version 1.0, Thailand Model Version 1.0, Ukraine Model Version 1.0, China Model Version 1.0, Mexico Model Version 2.0, Ecuador Model Version 1.0, Central America Model Version 1.0, GasSIM Model, RET Screen LFG Model, EMCON MGM Model, IGNIG Model, Finite Element Model (Vasudevan Rajaram, et al., 2012). We found the IPCC 2006 waste model advantageous over others, as several waste types can be modelled at the same time. The MSW generated in India is heterogeneous and varies based on many socio-economic and environmental factors. IPCC 2006 model offers flexibility to adopt various degradable organic carbon and half-life period of MSW and thus offers tailor-made solutions to its users to quantity GHG emissions from a disposal site. This has been found most applied model in India's NATCOM as well as in 1st Biennial update report(BUR) to United Nations Framework Convention on Climate Change(UNFCCC) but not been validated so far.

Typically, methane emissions from solid waste disposal sites (SWDS) are the largest source of GHG emissions in the waste sector. IPCC adopts relatively simple first order decay (FOD) model as basis for the estimation of methane emissions from landfills. The half-lives for different types of waste vary from few years to several decades based on mean annual temperature and humidity. To achieve acceptable and accurate results, input data for historical disposal of waste, for 3 to 5 half-lives was fed. The key parameters required for running IPCC 2006 model have been described in Table 1. Three tiers to estimate methane emissions from landfills are described as:

a. Tier 1 uses mainly default activity data and default parameters;
b. Tier 2 uses some default parameters, with country-specific activity data on current and historical waste disposal at SWDS; and
c. Tier 3 uses country-specific activity data on current and historical waste disposal at SWDS along with i) nationally developed key parameters, or ii) measurement derived country-specific parameters.

The key input parameters included the half-life, and methane generation potential (Lo), degradable organic carbon (DOC) content in waste and the fraction of DOC which decomposes (DOC_f) (Vasudevan Rajaram,et al., 2012).

Table 1: Parameters to Be Used for Running IPCC 2006 Model for Estimating Emissions

Parameter	**Potential source**
Mean annual rainfall of Delhi in past years	Indian Metrological department (MET)
Annual average temperature of Delhi in past years	MET
Half Life of MSW	IPCC
Average MSW generated, collected, recycled, treated and landfilled in South Delhi District	South Delhi Municipal Corporation (SDMC) / Central Pollution control Board (CPCB) / Delhi Pollution control committee (DPCC)
Composition of MSW	SDMC / CPCB
DOC of food waste, paper, wood and textile	IPCC
Composition of MSW landfilled at Okhla	CPCB / The energy and resources institute
Past Years data on waste landfilled at Okhla	CPCB
Methane percentage in LFG	TERI / MoEFCC / CPCB/ SDMC
Global warming potential of Methane	USEPA (United states environmental protection agency)
Methane Correction Factor	IPCC

The quality of CH_4 emission estimates is directly related to the quality and availability of the waste generation, composition and management data used to derive these estimates. The activity data in the waste sector included the total MSW, total industrial waste, waste composition, and the fraction of solid waste sent to SWDS.

With an aim to find out the impact of Government of India (GoI) initiatives on reducing GHG emissions the existing policies, such as Swachh Bharat Mission (SBM) and Waste Management Rules (WMR), 2016 were reviewed. The SBM has targeted 80% of the urban population to be covered by SWM services byOctober2019 and thereafter 2% per year (Ministry of Urban Development, 2014). Moreover, Rule 15 of new WMR, 2016 states that no urban local body shall be disposing mixed waste after 2 years of these rules in force.

Methane generated from decomposition of organic waste at disposal sites has 28–36 times more global warming potential (GWP) compared to carbon dioxide over 100 years period (USEPA, Understanding Global Warming Potentials, 2016).

2.1 Site Settings

The Okhla disposal site covers an area of 16.2 ha and started in the year 1994. The disposed waste consists of biodegradable waste, non-biodegradable waste, recyclables, silt, construction and demolition waste, and biomedical waste. There is neither LFG collection system nor a leachate collection and treatment system available at Okhla disposal site. In 2011, a study was carried out at the Okhla landfill site by researchers of The Energy and Resources Institute (TERI) and Jamia Millia Islamia (JMI) University with funds of Clean Technology Division of the Ministry of Environment and Forests (MoEF). The LFG extraction and cleaning technology was made operational at the waste disposal site in the month of March 2011 and active monitoring was initiated in the same month itself. The LFG production was reported as 5,138m^3 hr^{-1}, that is, with weight of waste deposited 6,744,316 tonnes till year 2011 and 44.63% methane content the average flow rate of methane can be predicted as about 8.16 $mLkg^{-1}day^{-1}$. This can also be reported as about 20,087,463.14 m^3 CH_4 yr^{-1} in 2011, that is, 13.19 $GgCH_4yr^{-1}$. The mean volume of LFG was found to be about 15m^3hr^{-1} as per the past pilot study at Okhla landfill site (Siddiqui, 2013).

Delhi receives an annual rainfall of about 755.4mm with about 39.7 rainy days (Siddiqui, 2013). The mean daily average temperatures are reported by metrological department as about 25.1 ^oC.The study area neither has a liner system nor a final cover system at the dumpsite. The ground characteristics are silty soil with some clay material. The lower portion of the waste has a bulk density of 0.8–0.9 tonnes m^{-3} and the upper portion of the waste between 0.4–0.5tonnes m^{-3}. The landfill is surrounded by ESI hospital and ESI colony to the North, DTC Workshop/bus depot and open land to the south, storage depot of the railways and railway colony to the east, and the main road (Maa Anandmai Marg) to the west. In addition to the densely populated residential areas towards Eastern and Southern sides of the landfill, container depot of CONCOR and Cement Corporation of India (CCI) also exist on its eastern side.

After every 1–2m layer of waste, a cover of soil and C&D waste is placed with a thickness range of 0.15–0.25 m. Site is divided into 10 pockets. 2–5 ft waste is placed on daily basis in any one of the 10 pockets. The side slopes are very steep (50–60 degrees), and unstable. The existing landfill slopes are unstable and could pose immediate and long-term safety risks. The boundary wall at the easterly side of landfill has been buried by the waste. There is no system at present for leachate collection, recycling, and treatment. Surface water drainage is towards the north. There are no surface water drainage structures at the landfill; therefore rainfall run-off migrates directly to surface water drains. The surface water drains on the roadways west and south of the landfill get clogged in rainy season. The nearest receiving water body is river Yamuna located 2.2 km from the site. Water table depth is 20–40m. Landfill gas (LFG) is neither being recovered nor flared from Okhla dumpsite. Landfill fires were observed either due to migration of LFG at the surface or were created by the rag-pickers.

The MSW is disposed randomly, resulting in increase in height of the disposed MSW and has reached a height of about 40m from the front side and 60m from the back side. It is observed that Okhla landfill is being operated beyond its capacity and is overflowing. Foul smell, flying birds, and wild dogs are a major problem at the landfill. Table 2 highlights the Waste Disposal Data since 1994 till March 28, 2017. All these parameters and site conditions were considered while modelling the GHG emissions from landfill site.

Table 2: Historical data for waste disposal at Okhla landfill site, New Delhi

S. No	Year "x"	MSW Disposed in TPA
1	1994	132203
2	1995	317280
3	1996	218006
4	1997	369065
5	1998	302601
6	1999	201588
7	2000	383911
8	2001	539763
9	2002	422833
10	2003	392513
11	2004	409997

S. No	Year "x"	MSW Disposed in TPA
12	2005	368168
13	2006	421143
14	2007	424093
15	2008	429357
16	2009	427078
17	2010	477616
18	2011	507101
19	2012	209623
20	2013	78080
21	2014	176290
22	2015	147940
23	2016	638829
24	2017	293023

2.2 Model

Methodology adopted is to analyse the amount of GHG emissions from Okhla landfill site using IPCC 2006 Model. Various parameters available from literature have been studied and used as input parameters to the model along with certain parameters from default list.

The steps followed for estimation of GHG emissions from solid waste are as follows(Inter governmental pannel on climate change, 2006):

Step 1:

$$DDOC_m = W \times DOC \times DOC_f \times MCF$$

Where,

$DDOC_m$ Amount of decomposable degradable organic carbon deposited, Gg

W Mass of waste deposited, Gg

DOC Degradable organic carbon in the year of deposition (fraction)

DOC_f Degradable organic carbon that decomposes under anaerobic conditions

MCF Methane correction factor (fraction)

Step 2:

$$DDOC_{mat} = DDOC_{mdt} + (DDOC_{mat-1} \times e^{-k})$$

Where,

$DDOC_{mat}$ $DDOC_m$ accumulated in SWD at end of year t

$DDOC_{mat-1}$ $DDOC_m$ accumulated in SWD at end of year $t-1$

$DDOC_{mdt}$ $DDOC$ deposited into SWDS in year t

t Inventory year

k Reaction constant $\frac{\ln(2)}{t_{1/2}}$ in per year

Step 3:

$$DDOC_{m\ decomp\ t} = DDOC_{mat-1} \times (1 - e^{-k})$$

Where,

$DDOC_{m\ decomp\ t}$ $DDOC$ decomposed into SWD in year t

Step 4:

$$CH_4 generation\ potential(L_o) = DDOC_{m\ decom\ t} \times F \times \frac{16}{12}$$

Where,

F Fraction of CH_4 generated in landfill gas

Step 5:

$$CH_4 generated\ \left({}^{Gg}/_{Yr}\right) = \left[\sum_x L_o - R_t\right] \times (1 - OX_t)$$

Where,

OX_t Oxidized methane in year t

R_t Recovered methane in year t

t Inventory Year

x Waste category/type of material

Excel-based model using IPCC 2006 methodology was developed to evaluate the GHG emissions from Okhla landfill site. Tier 2 level approach was used in estimates with an aim to minimize the uncertainties in the estimates. Alternate scenario with implementation of WMR 2016 and SBM were also run to identify the GHG emission reduction potential over a period of time.

Using the outcomes of GHG emissions from past pilot study at Okhla disposal site, the modelling results were validated. Reasons for variation were established to justify the outputs and help modelers to derive results from Tier 3 level approaches in future.

The present study has also used GWP of methane as 25, to keep the outputs consistent with the NATCOM and BUR.

3.0 Results and Discussion

The earlier study revealed the composition of MSW at Okhla dumpsite as food waste (57.4%), intert (17%), textiles(10.8%), and paper (7.2%)(Siddiqui, 2013). As per IPCC 2006 Methodology, default degradable organic content of food waste, textile, and paper has been identified as 17.35%. Table 3describes the calculations involved in the same.

Table 3: DOC Content of Waste at Okhla Landfill

Type of waste	Waste %^	Dry matter %	DOC w.r to wet waste	Average DOC
Food waste	57.4	40	15	0.0861
Paper/cardboard	7.2	90	40	0.0288
Wood	7.6	85	43	0.03268
Textile	10.8	80	24	0.02592
Rubber/leather	0	84		
Plastic	0	100		
Metal	0	100		
Glass	0	100		
Other	17	90		
Total				0.1735

The default methane generation rate (K) value is estimated to be about 0.065 for bulk waste. Thus half-life of waste at Okhla dumpsite is estimated to be about 10.66 years ($Ln(2)/T_{1/2}= k$).The methane percentage from previous study was analysed statistically to find the confidence level of the result and were found as given in Table 4.

Table 4: Calculations for statistical analysis of methane generation data from Okhla Landfill site

S. No	Parameters	Values
1.	Mean = Σxi/n	44.633645
2.	Mean deviation (1/n)Σ|xi-mean x|	0.053896
3.	Standard deviation [((xi-mean x)^2)/n]^0.5	5.659876
4.	Best estimate of precision of analysis (Sn= ((n/n-1)^0.5)*standard deviation)	5.673146
5.	Best estimate of uncertainty in Data(Un = Sn/(n^0.5))	0.387808306
6.	Thus methane percentage	44.63 ± 0.39
7.	Standard normal variate (Z_i= (xi-meanX)/standard deviation)	1.690 to -2.99188
8.	Integral Gaussian probability p(-2.99)	0.4986

9.	Integral Gaussian probability p(1.69)	0.4545
10.	Thus Confidence level	0.9531or 95.31%

Thus, the analysis depicts that methane generation data has an average value of about 44.63±0.39% with a confidence level of more than 95%.

In thepresent study, IPCC 2006 model predicted the LFG production in year 2011 as 275 Gg CO_2 eq and with 6,744,316 tonnes of waste deposited till 2011. The present emission for 2017 is found to be 285.7Gg CO_2 eq. This scenario considers that waste gets deposited only till March 2017(when the study wasdone), as disposal site has already lost its capacity.The detail modelled estimatesup till 2050 are shown in Figure 2. The model estimated emission of 2011 is lower by about 16.60%, compared to pilot study results for Okhla landfill site due to various reasons; the average half-life of waste in the present conditions of Delhi is about 10.2 years and waste deposited from year 2007 will showcase emissions of methane till year 2017; composition of waste along with moisture content has changed from season to season; DOC will have to be analysed for waste in city. Another change can also be attributed to the fact that Okhla disposal site used to have a leachate circulation system in place which can reduce the half-life of waste to about 1.2 years with indirect rainfall getting higher. These changes need to be recorded and incorporated to cope up the uncertainties in modelling and move from Tier 2 to Tier 3 level for prediction of GHG emissions.

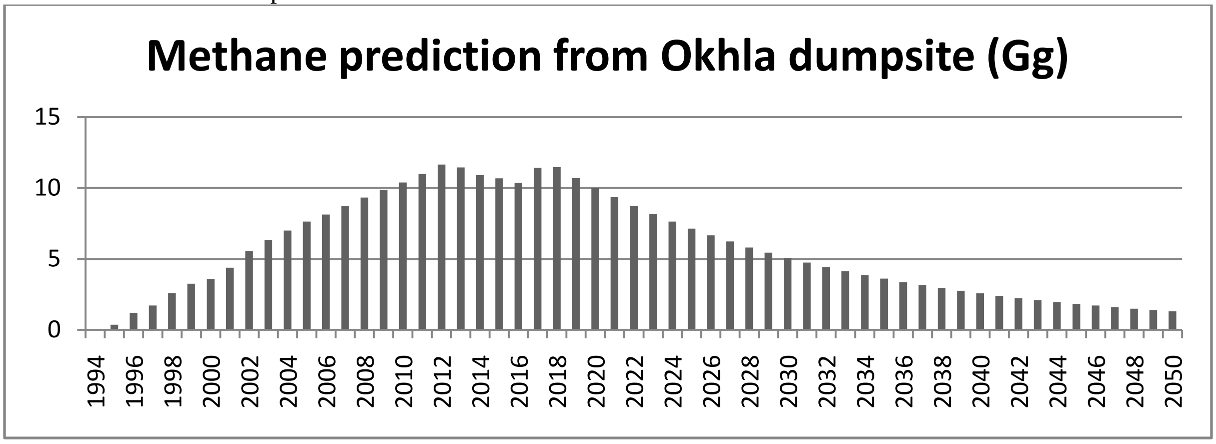

Figure 2: IPCC 2006 predictions for present scenario and waste disposed till March 2017

Other scenario considering waste deposition till end of October 2019 with same compounded annual growth rate(CAGR) of waste getting deposited. This scenario does not consider any intervention of waste-to-energy or waste processing plant. This scenario also considers that the existing SBM and WMR, 2016 is not in force to eliminate organic waste from getting to the landfill. From2006 till 2016, the waste has been seen to increase at a CAGR of 4.18%. Considering the same rate for increase in waste deposition till 2019 the GHG emissions have been estimated.This has particular implications to find out the efforts of SBM in eliminating GHG emissions from landfill. The peak in emissions is estimated just after one year of closure of waste deposition and thereafter the decline in emissions can be forecasted. This is particular feature of GHG emission curve and mainly occurs due to half-life of deposited waste. In 2020, 365.35 Gg CO_2 eq emissions are estimated from Okhla disposal site.

Another scenario was considered with waste deposited in Okhla landfill site till 2019 along with intervention of SBM and WMR 2016 from 2017 onwards. Assuming, all organic waste is diverted from disposal site by 2018 end and 50% organic food waste gets diverted from landfill by the end of 2017,the study evaluated the GHG emissions. DOC was altered with same percent removal of organic food waste from the disposal site. The prediction gave us emissions as 285.07Gg CO_2 eq in 2018 and thereafter a decline in GHG emissions. Figure3 showcases the difference in GHG emissions due to policy intervention, such as WMR, 2016 and SBM. The estimates depict that by 2050 there is a potential for GHG emission reduction of 1,483.5 Gg CO_2eq with GoI intervention from Okhla disposal site.

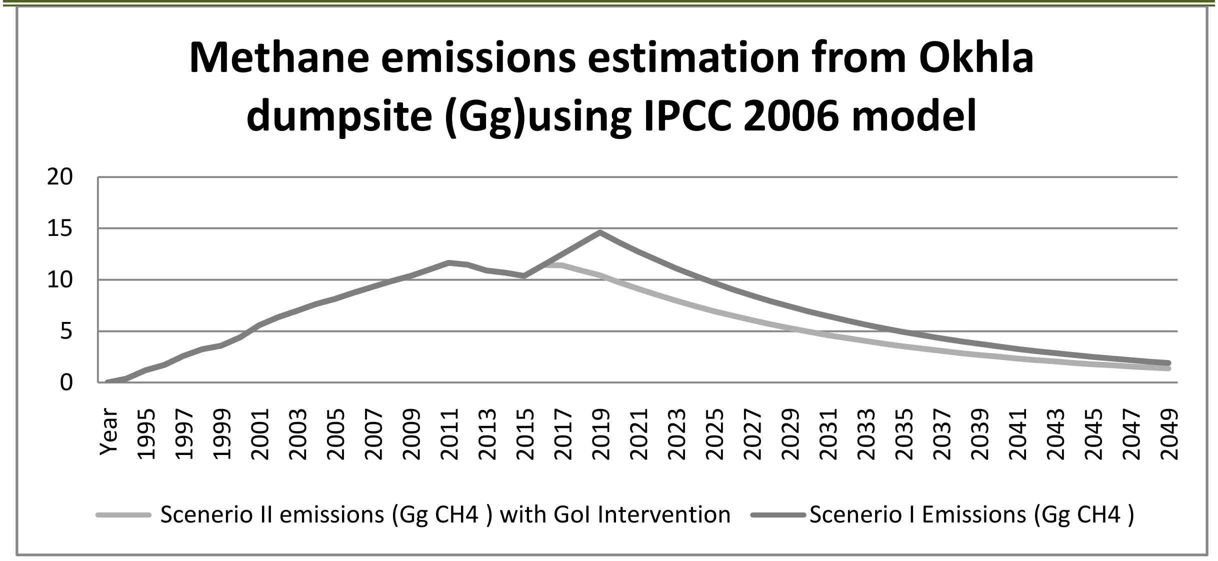

Figure 3: GHG emission estimates with and without GoI intervention

The peak of GHG emission will shift to 2020 and will yet be less by about 21.79%.Thus, GHG emissions can clearly be reduced with diversion of biodegradable organic matter from landfills to other treatment trajectories, such as composting or bio-methanation.

4.0 Conclusions

The negative impacts of uncontrolled LFG are not limited to its climate change impact, as odours, toxic and carcinogenic trace components are also accompanied.

The details of the waste management and present scenario indicated a vast scope still existsin waste characterization at each stage of waste management, along with influence of factors affecting waste generation.

IPCC 2006 model offers flexibility and thus offers tailor-made solutions to its users to quantify emissions from a disposal site. However, the developed model has not been validated so far in Indian conditions. The activities at site, such as recirculation of leachate, average half-life of various componentsof waste, composition of waste along with moisture content, andDOC need to be analysed for coping up the uncertainties in modelling and move from Tier 2 to Tier 3 level for prediction of GHG emissions.

With a purpose to showcase the ways in which this model can be used by various urban local bodies we have developed two alternate scenarios. The estimates depict that by 2050 we have a potential for GHG emission reduction of 1,483.5 Gg CO_2 eq with this intervention. This picture will further be enlarged if we look at the validation results which indicated a 16.6% lower predicted value by IPCC 2006. Hence, this model will help cities to evaluate the GHG emissions and streamline their activities along with priorities to reduce methane emissions and prove to be a valuable asset for further development in the area of waste management.Even, large size dumpsites can be analysed to seekmethane as a renewable energy source.

Acknowledgements

We thank South Delhi Municipal Corporation and Central Pollution Control Board for providing access to site and data. We also thank Dr Faisal Zia Siddiqui, Associate Professor, Aligarh Muslim University, for his comments and suggestions that have significantly added value to this research. We also thank all the authors whose work has been cited in this manuscript.

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