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Greenhouse gas estimation from municipal solid waste dump site in Roorkee (Uttrakhand), India

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ABSTRACT

In recent times, India is facing problem of poor disposal of municipal solid waste (MSW) at dumpsites and landfills. Inappropriate disposal and unmanaged landfills or open dumping of waste leads to the release of toxic gases like methane (CH_4) in atmosphere which causes air pollution and also pollutes ground water through leachate. In view of the poor management of MSW in open dump coupled with associated climate change issues, it has become inevitably important to measure the potential of greenhouse gas (GHG) emission from dump sites. The paper reports the results of GHG emission potential of Saliyar open dump site in Roorkee (Uttrakhand) using four methods, viz: IPCC default method (DM), first order decay method (FOD), EPER Germany model and modified triangular method (MTM). The average GHG emissions from these four methods for 29 years in Roorkee were estimated as 2.0, 0.69, 1.9 and 0.19 Gg/yr, respectively. Summarized literature on GHG estimation methods is also provided with their results and significance. Details of physical analysis of MSW are provided where the analysis results are used as parameters for estimation of GHG. The results of the study suggests that out of four methods, FOD is more site specific and was found to give the most reliable emission results from MSW open dumpsite provided basic parameters of the model are determined precisely.

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INTRODUCTION

One of the major factors causing threat on environment is the emission of toxic greenhouse gas (GHG) from solid waste disposal dumps and landfill sites. Exponential increase in population and meteoric economic development has led to accelerated increase in the generation of municipal solid waste (MSW).

India being the fastest growing country with the second largest population in the world has had unprecedented increase in MSW generation. Central Pollution Control Board (CPCB) and Indian Institute of Technology Roorkee (IITR) have reported that about 40 to 50 million tons of solid waste is being generated annually and may increase to 270 million tons by 2047; thus the country is not able to cope with this huge quantity of waste generated and is facing one of the biggest issues of disposing it safely in order to solve environmental and public health problems. India is one of the largest emitter of CH_4 from landfills. It approximately generates GHGs corresponding to 16 Megagram carbon dioxide equivalent (Mg CO_2e) annually and it is expected to produce almost 20 Mg CO_2e annually by 2020 (Sharholy et al., 2008). Major gases released from landfills/dump sites are CO_2, CH_4, and N_2O, out of which CH_4 is viewed as one of the

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most important GHG because of its 25 times higher global warming potential, compared to CO_2 over 100 years.

Many investigators have estimated GHG emission from landfills and open dumpsites using different methods. Chalvatzaki and Lazaridis (2010) used Triangular, Stoichiometric and LandGEM model for Akrotiri landfill site, Greece. It was reported that each model is different from others based on their scientific approach for estimation of CH_4 emission. Kaushal and Sharma (2016) estimated CH_4 from landfill of Kanpur, India using LandGEM model version 3.02, IPCC default method and FOD method, study concluded that FOD are more reliable and LandGEM 3.02 also gave reliable emission from open dumpsites. Hoklis and Sharp (2014) estimated GHG gas using IPCC (DM) and proposed waste management strategy of recycling the degradable waste and compost organic waste at landfill site which reduces GHG emission and volume of waste. Lee et al. (2017) has evaluated emission from MSW landfill of USA using Life Cycle Analysis method and reported that non-collected CH_4 as the highest contributor of GHG emission on CO_2e basis. Sunarto et al. (2017) has developed a Dynamic model for GHG emission to analyze and predict CH_4 generation from recycling and dumping activity. Manuja et al. (2018) has used FOD method for the estimation of CH_4 emissions from waste water and three landfills of India thus paving the way to capture and utilize CH_4 from effluents and landfills to help in solving the issue of liquid and solid waste management. Gollapalli and Kota (2018) chamber method estimates CH_4 and CO_2 emission from the landfills of Guwahati, North-east of India. Ngwabie et al. (2018) used static flux chambers to determine average emission and calculated the coefficient of determination as 0.8 to evaluate the flux.

The literature reveals that considerable work has been reported on the GHG estimation from landfills/MSW dumpsites using various methods but little work is available on CH_4 estimation on open dumpsites of class III cities like Roorkee. Therefore the present paper is devoted to estimate GHG emission from Saliyar open dumpsite of Roorkee city of Haridwar district, Uttrakhand, India, using four methods and suggest most reliable method to estimate GHG from such open dumpsites. Four GHG estimation methods have been selected based on its suitability for open dumpsites as per literature and the results have been compared among themselves and with literature work. The results of the analysis of sample collection have been used to determine the different constants used in various methods for GHG emission.

MATERIALS AND METHODS

Site description

Saliyar is the only single and active open site for MSW disposal of Roorkee city since 1988 and is located near village Ibhrahimpur in Haridwar district having moderate subtropical to humid climate with three distinct seasons, viz: summer followed by rainy and winter seasons. Temperature begins to rise from March (29.10°C) and reaches to its maximum in May (44°C). During the winter season in the month of November to February the temperature ranges between 10.50 and 6.10°C. Roorkee has population of 238,422 of which 129,802 are males and 108,620 are females (census, 2011). All the management of waste of Roorkee city is handled by Roorkee Nagar Nigam which has the responsibility of collecting, transporting and disposing of the solid waste. The city is presently generating about 104 Metric tons (MT) of municipal waste per day. The waste is dumped uncontrollably without any proper management. Currently there is no provision of segregation of municipal waste at source but after disposal of this waste at the main dumpsite, municipality has engaged many rag pickers to segregate dry waste and manage the waste by reusing or recycling. Rest of the garbage is directly piled up in the site with periodical treatment or application of chemical to reduce the foul smell. Saliyar dumpsite is located about 7 kms away from the city and receives 3224 MT/ month of solid waste from the city. Table 1 shows some salient features of the dumpsite and Figure 1 shares the location of Saliyar dumpsite.

Population estimation

The population data is collected from municipal office from 2011 to 2015 and the projection of population up to 2040 has been done using arithmetic method. Table 2 gives waste generation rate which is considered to calculate total waste generation/day (Thaiyalnayaki and Jayanthi, 2016) and Table 3 gives year wise waste generation of Roorkee city.

Sample collection and analysis

Five samples each of 2 kg were collected from five different points of dumpsite. Individual samples were weighted and analyzed on received basis (RB) and dry basis (DB). Each sample was segregated and the composition is given in Table 4, average moisture content is obtained as 40.66%. National Environmental Engineering Research Institute (NEERI) and CPCB India reported that MSW composition for class III cities comprises of 35-65% compostable, 11-24% recyclables, 30-40% inert materials and less than 1% of glass, metal and rubber (Joshi and Ahmed, 2016).

GHG Estimation Methods

A number of methodologies are available for the

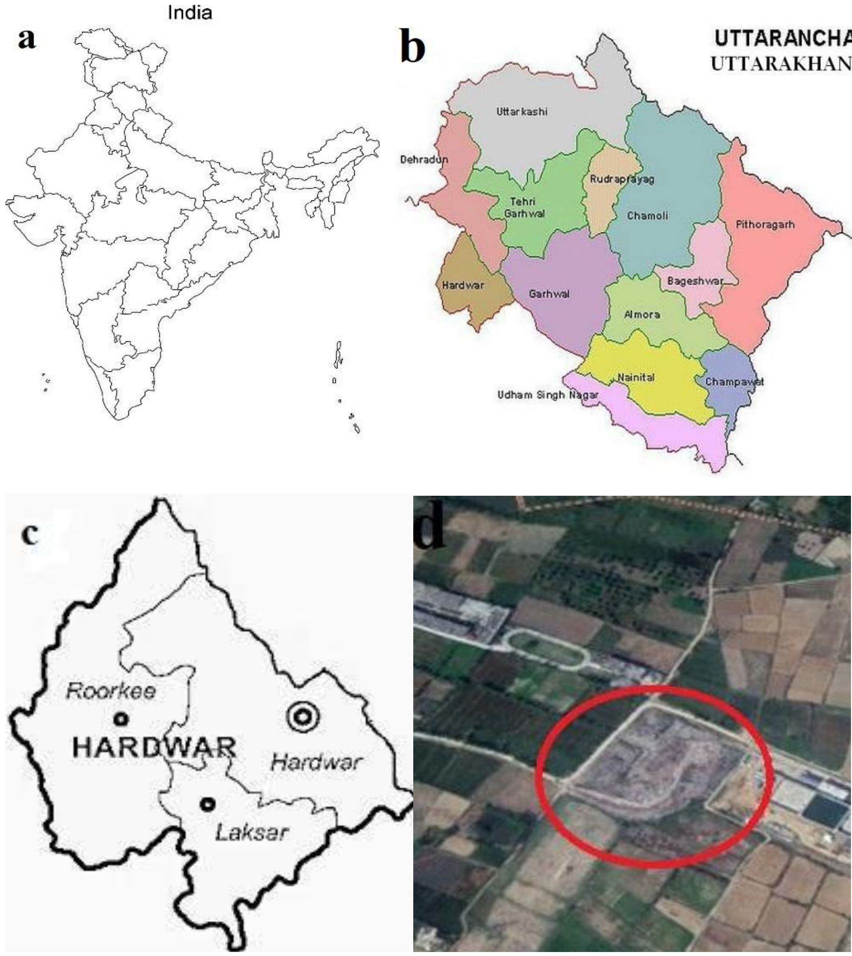

Figure 1. a, India map; **b**, State map; **c**, District map; **d**, google earth view of Saliyar dump site.

Table 1. Salient feature of Saliyar, Roorkee.

Features	Details
Latitude	29.8866 °N
Longitude	77.8739 °E
Year of start	1988
Year of closer	Around 2040
Area (km^2)	0.12
Average depth (m)	6
Depression below the ground level (m)	2-3
Annual precipitation (mm)	1170
Average temperature (°C)	23.7
Dumping quantity	80% of waste is disposed to the site
Site type	Shallow
Waste height above the ground (m)	9 (max)
Waste management facility	Monthly shuffling, spraying and compacting
LFG collection provision/ facility	No LFG recover and no composting facilities
Type of waste dumped	Households, organic wastes and Construction waste

Source: Site observation and documented data from Roorkee Nagar Nigam, Roorkee, India (2011).

Table 2. Per capita waste generation.

S/N	Population size	Waste generation* (Kg/capita/day)	Wastegeneration** (Kg/capita/day)
1	>2000000	0.43	0.55
2	1000000-2000000	0.39	0.46
3	500000-1000000	0.38	0.48
4	100000-500000	0.39	0.46
5	<100000	0.36	-

Source: CPCB (2000b)*, Calculated from R.K. Annepu (2012)**.

Table 3. Population and waste generation.

Year	Population	Waste generation (Gg/year)	Year	Population	Waste generation (Gg/year)
2011	182762	33.38	2026	243228	44.42
2012	186308	34.02	2027	247945	45.28
2013	189922	34.68	2028	252757	46.16
2014	193606	35.36	2029	257661	47.05
2015	197363	36.04	2030	262659	47.97
2016	201191	36.74	2031	267755	48.90
2017	205094	37.45	2032	272949	49.85
2018	209073	38.18	2033	278244	50.81
2019	212619	38.83	2034	283642	51.80
2020	216744	39.58	2035	289145	52.80
2021	220948	40.35	2036	294754	53.83
2022	225235	41.13	2037	300473	54.87
2023	229604	41.93	2038	306302	55.94
2024	234059	42.74	2039	312244	57.02
2025	238600	43.57	2040	318302	58.13

Table 4. Composition of MSW from Saliyar dumpsite.

S/N	Bio degradable						Non-biodegradable							
	Paper %		Organic matter %		Textiles %		Glass %		Metal %		Plastics %		Inert material %	
	RB	DB	RB	DB	RB	DB	RB	DB	RB	DB	RB	DB	RB	DB
1	26.07	16.67	36.80	20.43	0	0	4.70	4.67	2.33	2.06	0	0	28.20	15.33
2	8.00	4.67	34.40	18.47	13.67	9.73	NA	NA	NA	NA	18.57	12.60	25.36	12.33
3	10.87	7.00	46.12	24.00	27.46	13.27	3.33	3.30	1.4	1.1	9.53	6.00	1.29	1.00
4	9.73	3.90	32.33	12.32	13.53	7.27	15.07	14.0	1.73	1.70	7.27	5.5	20.33	10.23
5	7.93	4.34	54.27	30.10	14.0	9.0	NA	NA	1.66	1.46	7.13	5.8	15.0	9.43

RB, Received basis; DB, dried basis; organic matter includes kitchen waste, garden waste etc. The above Table has been used to determine DOC which is further used for GHG estimation.

estimation of GHG emission from disposal sites from which four methods namely IPCC (DM), FOD Method, MTM and EPER Germany method have been used to estimate the emission from Saliyar open dumpsite, Roorkee. Each method is briefly described below.

International panel of climate change (IPCC) default method (DM)

This method was developed by Bingemer and Crutzen (1987) and IPCC in 2006 for the estimation of the GHG emission from the landfill sites (IPCC, 2006). The total CH_4 from the waste for any particular year is estimated by using Equation 1.

QCH_4 emissions (Gg/year) = [MSWT*MSWF*MCF*DOC*DOCf*F*(l 6/12-R)*(l- OX)] (1)

Where, QCH_4, annual CH_4 generation (Gg/yr); MSWT, total MSW generated (Gg/yr); MSWF, fraction of MSW disposed to solid waste disposal sites (generally 80%); MCF, methane correction factor (1-0.4, default value: 0.6); DOC, degradable organic carbon; DOCf, fraction of DOC dissimilated; F, fraction of CH_4 in landfill gas (50%); R, recovered CH_4 Gg/yr (default value taken as 0); OX, oxidation factor (IPCC default value of OX is 0).

First order decay method

The FOD method has been recommended by IPCC in 2006. It presumes that the entire sites in the landfill is not decomposed instantly but slowly with the action of microorganisms and consist of step wise calculation for CH_4 generation (IPCC, 2006). The total CH_4 from waste is determined by Equation 2.

$CH_4generated_T$= $DDOCmdecom_T$* F * (16/12)(2)

Where, $CH_4generated_T$, Annual CH_4 generation (Gg/yr); DDOCm, quantity of decomposable degradable organic carbon deposited (Gg); DDOCmdecompT, DDOCm decomposed in year T (Gg); F, fraction of CH_4 generated in the landfill; 16/12, molecular weight CH_4/C (ratio).

EPER Germany method

This model is zero order model and GHG is calculated using Equation 3:

Me = M*BDC*BDCf*F*D*C (3)

Where, Me, Amount of diffused methane emission [Mg CH4.y^{-1}]; M, the annual amount of landfilled waste [Mg waste.y^{-1}]; BDC, proportion of biodegradable carbon (0.15) [MgC.Mg $waste^{-1}$]; BDC_f, proportion of biodegradable carbon converted (0.5) [-]; F, calculation factor of carbon converted into CH_4 1.33 [Mg CH_4.Mgc^{-1}]; D is collection efficiency (No recovery 0.9, [-]); C, CH_4 concentration 50 [%] (Rajaram et al., 2012).

Modified triangular method (MTM)

This method is used when the detailed waste generation data is not available. It assumes that volume of CH_4 emission is same as that of default method and degradation occurs in two phases. Phase I starts after one year of deposition and rate of gas generation increases till 6^{th} year then second phase starts with decrease in gas generation to zero by the end of 16^{th} year. The ‘h’ value which is peak value, of methane emission in Figure 2 is calculated knowing the volume of gas and base of the triangle. Other ordinates of triangle are calculated by using peak value (h) (Chakraborty et al., 2011).Table 5 gives some salient features of the methods.

Assumptions and calculations

Table 6 reports all assumptions made and parameters used to estimate GHG emissions. Parameters such as Fraction (F) of CH_4 are found most common among methods. Degradable organic carbon (DOC) is mainly determined from analysis of waste composition. Rests of the parameters are site specific and default values.

RESULTS AND DISCUSSION

Four estimation methods which are mostly used have been applied for calculating GHG emission from Saliyar dumpsite of Roorkee city. Estimation is mainly focused on CH_4 emission where all the parameters given in Table 6 are used for calculation. Using respective parameters in the equation discussed above, CH_4 emission resulted to 2.0, 1.9, 0.69 and 0.19 Gg/yr by IPCC (DM), EPER Germany, FOD and MTM respectively.

Figures 3a and c shows that the results of IPCC (DM) and EPER Germany give similar pattern of CH_4 potential by end of 2040 with average CH_4 emission of 2.0 and 1.9 Gg/yr. The results show that CH_4 generation is directly proportional to amount of waste disposed at site assuming that the CH_4 production from a certain amount of waste disposed at dumpsite is released in that same year(Kaushal and Sharma, 2016). IPCC and EPER Germany method gives over estimated GHG in line with gas generation for landfills of India (Das et al., 2016). Figure 3b shows results of FOD method, GHG emission values are observed with average emission of 0.69 Gg/yr. The irregularities in graph explains that when the waste is disposed in a year, GHG is initially high but tend to decrease at the end of that year then again increase in initial of next year. After complete disposal of waste and closure of dump site, GHG emission will exponentially decrease (Kaushal and Sharma, 2016). MTM shows average methane emission of 0.19 Gg/yr in Figure 3d, it can be suggested to estimate GHG emission when there is no data such as historical waste generation data, composition of waste or disposal record. The results

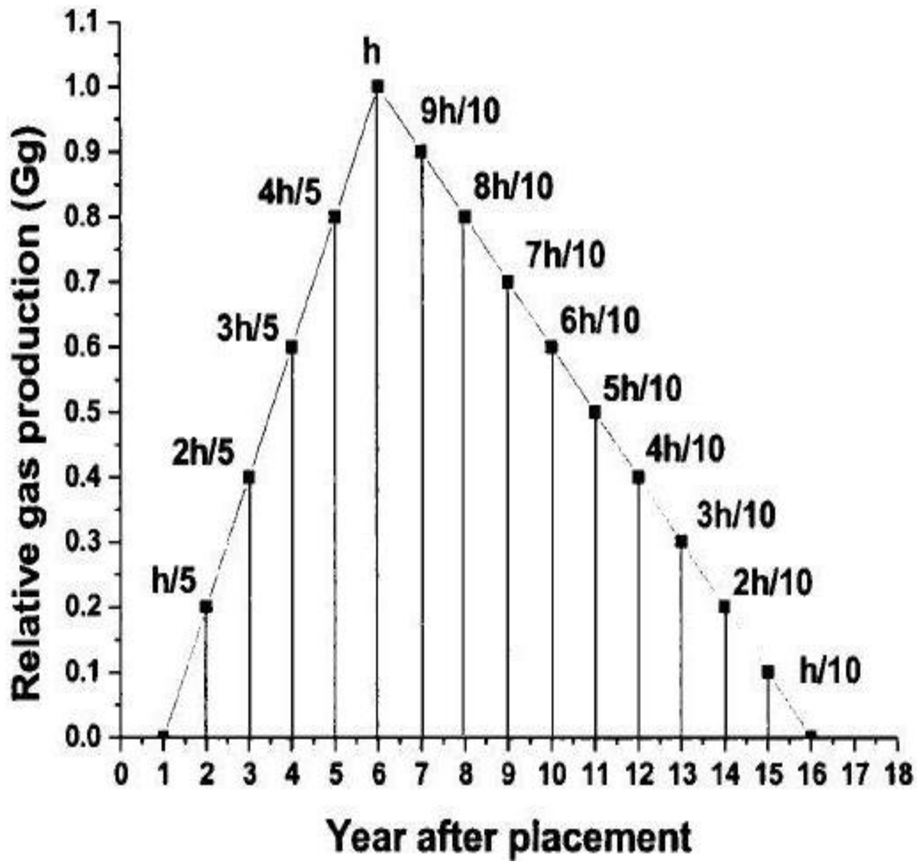

Figure 2. Triangle form for gas formation.

Table 5. Salient features of methodologies.

Features	IPCC (DM)	FOD	MTM	EPER
Input parameter	Waste quantity generated (Gg/yr). Total waste reaching at dumpsite (Gg/yr). Waste characteristics constant as per IPCC	Historical data of total waste generated and disposal at dumpsite. (Gg/yr). Waste characteristics constants	Methane generated by IPCC default method	Annual amount of waste dumped at site
Model equation	QCH_4 = {MSWT*MSWF*MCF*DOC*DOCf *F*(l 6/12-R)*(l- OX)}	$CH_4generated_T$= $DDOCmdecom_T$* F * (16/12)	-	Me =M*BDC*BDC_f*F*D*C
Kinetics reaction of decomposition	Based on zero order model	Based on First Order Model	-	Based on zero order model
Lucidity	Simple mass balance equation	Consist of step wise equation for GHG estimation. Requires Historical waste quantities, composition and disposal practices	Considers CH_4 of IPCC (DM) for GHG estimation and uses triangular form for gas formation (Figure 2)	Similar concept like IPCC (DM)
Output	CH_4 emission (Gg/yr)	CH_4 emission (Gg/yr)	CH_4 emission m^3/yr	CH_4 emission Gg/yr
Reference	(IPCC, 2006) (Kaushal and Sharma, 2016)	(IPCC, 2006) (Kumar and Sharma, 2014)	(Chakraborty et al., 2011)	(Rajaram et al., 2012)

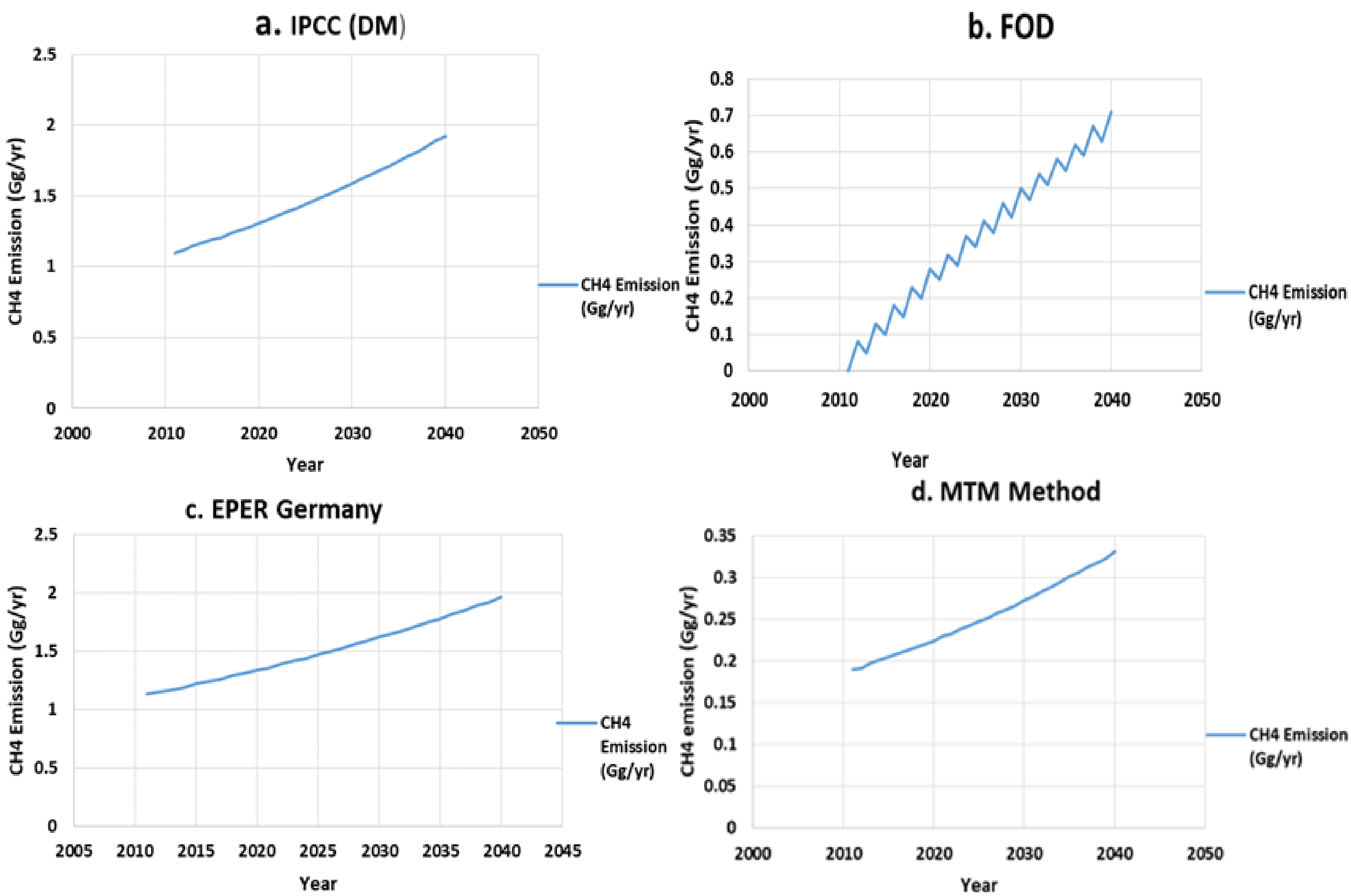

Figure 3. CH_4 emission from Saliyar open dump for 29 years in Gg/yr using; a, IPCC DM; b, FOD; c, EPER Germany; d, MTM method.

Table 6. Assumptions used for estimation of CH_4 emission from Saliyar dumpsite.

S/N	Model parameter	IPCC (DM)	FOD	EPER Germany	Basis
1	Fraction of CH_4 in LFG (F)	0.5[a]	0.5[a]	0.5[a]	Ranges 0.4 – 0.5, based on waste composition and site condition (IPCC)
2	Methane correction factor MCF	0.4[a]	0.4[a]	1.33[d]	Depends on disposal site category and its management (IPCC)
3	The CH_4 generation rate constant (K)	-	0.037[b]	-	Depends on average precipitation in mm of the area (IPCC)
4	DOC/BDC (decomposable organic carbon)	0.23[a,c]	0.25[b]	0.15[d]	Based on composition of waste (IPCC)
5	DOC_f/ BDC_f	0.62[a]	0.62[b]	0.5[d]	Depends on average temperature of area. (EPA LandGEM 3.02 guide, 2005)
6	CH_4 recovery	0[a]	-	-	Considered as 0 for unmanaged dumpsite (IPCC)
7	Oxidation factor (OX)	0[a]	-	-	Considered as 0 for unmanaged dumpsite (IPCC)
8	Collection efficiency	-	-	0.9[d]	-

a, (IPCC 2006); b, site specific value (calculated data); c, (Kaushal and Sharma, 2016) and (Kumar and Sharma, 2014); d, (EPA, U.S 2005).

obtained in this study suggest FOD method as most suitable method for dumpsite because its specific data such as K, DOC, DOCf, climatic condition of site was taken based on field measurement whereas other methods like IPCC, MTM and EPER Germany use assumed default values.

Conclusion

In the present study, attempt has been made to estimate GHG emission potential of Saliyar using four different estimation methods and comparative assessment has been done to determine suitable method for GHG estimation from open dump sites. CH_4 emission estimated for 2011 to 2040 by IPCC (DM), EPER Germany, FOD, LandGEM and MTM methods result as 2.0, 1.9, 0.69 and 0.19 Gg/yr, respectively. It can be concluded from the analysis of results that FOD method is most suitable method for the quantification of the GHG emission from Saliyar open dumpsite because detailed data of waste quantity and waste composition have been taken as parameters and captures site specific circumstances compared to rest of methods thus reducing uncertainties in results.

Roorkee is a small city and its MSW mainly consist of organic matter. With proper management of waste in small scale, further based on analysis of MSW samples, the waste is found suitable for disposing it off biologically. So using suitable technology, the waste can be converted into biogas that can be used as energy source. The decomposed waste which is rich in Phosphorous, Potassium and Nitrogen values can be used as manure in agricultural sector. The potential threat of GHG emission will increase unless landfill or dumping site is properly managed.

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