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# Methane emission from municipal solid waste dumpsites: A case study of Chennai city in India

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**Abstract.** The indiscriminate growth in global population poses a threat to the world in handling and disposal of Municipal solid waste. Rapid urban growth increases the production, consumption and generation of Municipal solid waste which leads to a drastic change in the environment. The methane produced from the Municipal Solid waste accounts for up to 11% global anthropogenic emissions, which is a major cause for global warming. This study reports the methane emission estimation using IPCC default, TNO, LandGEM, EPER and close flux chamber from open dump yards at Perungudi and Kodungaiyur in Chennai, India. The result reveals that the methane emission using close flux chamber was in the range of 8.8 Gg/yr-11.3 Gg/yr and 6.1Gg/yr to 9.1 Gg/yr at Kodungaiyur and Perungudi dump yard respectively. The per capita waste generation was estimated based on waste generation and population. The waste generation potential was projected using linear regression model for the period 2017-2050. The trend of $CH_4$ emission in the actual field measurement were increased every year, similarly the emission trend also increased in IPCC default method (mass balance approach), EPER Germany (zero order decay model) where as TNO and Land GEM (first order decay model) were decreased. The present study reveals that Kodungaiyur dump yard is more vulnerable to methane emission compared to Perungudi dump yard and has more potential in waste to energy conversion mechanisms than compare to Perungudi dump yard.

**Keywords**: methane emission; IPCC; flux chamber; municipal solid waste; urbanization

## 1. Introduction

Rapid population growth coupled with unplanned urbanization has led to several basic infrastructure problems such as municipal solid wastes, drinking water supply, storm water and sewerage management etc. Due to changing lifestyle, land use patterns, demographic growth of cities in addition to the increased rate of per capita Municipal solid waste generation causes more complexity (Goel 2008). In developing like India, almost 70 to 90% wastes are landfilled in open dumpyards, which without segregation of degradable, non-degradable and partially degradable waste. Furthermore, the collection of MSW is improperly managed, the uncontrolled disposal of

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waste leads to the groundwater contamination through leachate, increasing of water borne diseases and also the indiscriminate burning of waste at dumpyard leads to serious health impacts to the surrounding population (Singh *et al.* 2017). The high density of residential, industries households, floating population in Delhi, Mumbai, Kolkata and Chennai are the top producer of MSW in India (Sharholy *et al.* 2008).

Carbon dioxide ($CO_2$), Methane ($CH_4$) and Nitrous oxide ($N_2O$) are the major greenhouse gases (GHGs) which are emitted from industries, solid waste dump sites, burning of agricultural waste and fossil fuel usage. The dumpyards generate about 60% $CH_4$ and 40% $CO_2$ with other trace gases during anaerobic decomposition of wastes. About 50% of carbon emissions from dumpyards are transformed into methane. The biomass burning, paddy cultivation, fossil fuel use, domestic ruminants and waste decomposition are the major anthropogenic source of methane emission (Du *et al.* 2017). The next to agriculture and enteric fermentation, methane is emitted from the MSW landfills.

The world is emitting about 36.7 Tg/year of methane from MSW landfills (Themelis and Ulloa, 2007). According to the Global Methane Initiative (GMI), the global anthropogenic methane emission was 6.88 Gt $CO_2$- eq in 2010 and in 2020 the methane emission is expected to reach about 8.59 Gt $CO_2$-eq (Annual Report 2018) (Zuberi and Ali 2015). Most of the studies deal with the observed status of methane emission in dumpyards (Mor *et al.* 2006) (Rawat and Ramanathan, 2011) (Kumar *et al.* 2004) and they have not been addressed the future emission scenario of the methane with growing population. Hence, the aim of this study is to quantify the methane emission by actual field measurement, empirical estimation model and validation of the actual and model emission data.

## 2. Materials and methods

### *2.1 Study area*

Chennai is the fourth largest metropolitan cities in India, the city is located at a latitude of 13°07’N and longitude of 80°16’E with an area of 426 sq.km. In the 2012, 10 zones of Chennai city was reformed to 15 zones. The population in Chennai city has increased by 46% from in 1971 (26.42 lakhs) to 2011 (46.46 lakhs) and with the floating population of 2.25 lakhs (Census of India, 2011). The solid waste generated in Chennai city reaches up to 7000 tonnes/day. The generated waste is collected and deposited in two open dumpyards of Chennai, Kodungaiyur in the North, covering the Zone I to V and Perungudi in the South are covering Zone VI to XV (Fig. 1).

Perungudi dumpyard has been started operating in the year 1987, which is situated in Eco sensitive place, nearer to Pallikaranai marshland with an area of 99 ha. The Perungudi dumpyard is nearer to school zone, hospital, institution, etc., and also it pollutes the surface water and ground water through leachate. The Kodungaiyur dumpyard was started in the year 1981, and it is situated in heavy settlement area. The area coverage of dumpyards is 107.2 ha. The serious issues in Kodungaiyur dumpyards are surroundings through frequent burning of waste causes health impact and ground water pollution. Table1 reveals the salient features of Kodungaiyur and Perungudi dumpyard.

### *2.2 Close flux chamber estimation method*

CH4 gas were collected in close flux gas chamber in all four seasons viz., winter, summer,

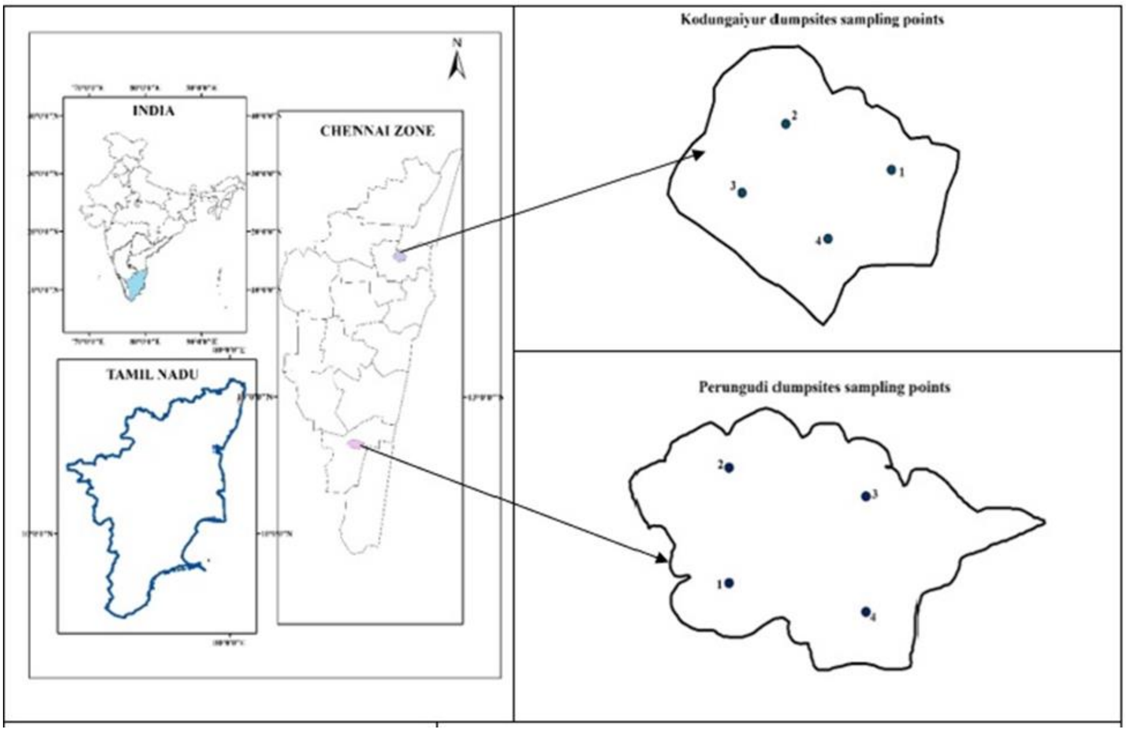



Fig. 1 MSW dump yard in Chennai City

Table 1 Details of dumpyards in Chennai Zone

| Details | Perungudi | Kodungaiyur |
|---|---|---|
| Location | South of Chennai | North of Chennai |
| Geographical Location | 12º 57’13.5” N & 80°14’5.8” E | 13°07’37.6” N & 80°16’48” E |
| Year of Start | 1987 | 1981 |
| Site type | Open dumping (active) | Open dumping (active) |
| Age of site | 29 years | 35 years |

south west monsoon and north east monsoon both at Perungudi and Kodungaiyur dumpyards. The four sampling points were identified are shown in the Fig. 1. Gas samples were collected at three different depths (3.0 ft, 6.0 ft and 9.0ft) and an interval of 1 h, 3 h and 5 h using 50 ml syringes. The collected $CH_4$ gas was transferred to the standardized leak proof 5.9 ml vacutainer (soda glass vial flat bottom, 819W). The gas (Cai *et al.* 2014, Thompson *et al.* 2009, Sunil *et al.* 2004) samples were analyzed by gas chromatograph with flame ionization detector, equipped with a methanizer (GC; SRI, USA, Model 8610 C). The rate of gas emission in the flux chamber was estimated using the Eq. (1),

$$CH_4\ (mg^{-1}m^{-2}h^{-1}) = V/A\ (dc/dt) \tag{1}$$

where, V is the volume of the flux chamber ($m^3$) and A is the area of the flux chamber ($m^2$) and (dc/dt) is the concentration of gas inside the chamber (mgh-1) is the rate of concentration of the component gas inside the chamber (Hegde *et al.* 2003) (Akolkar *et al.* 2008).

Table 2 Empirical models to compare the methane emission in dump yards

| S. No | Models | Equation | Description and Assumption |
|---|---|---|---|
| 1 | IPCC Default method | $Q_{CH4}$ = ($MSW_T$*$MSW_F$*MCF* DOC*$DOC_f$ *(16/12-R)*(1-OX) | Mass balance approach, depends on estimating degradable organic carbon (DOC) content to calculate the methane emission, **Assumption** DOC = 0.4A +0.17B + 0.15C +0.30D, Where A= paper, B=leaves+ hay straw, C=fruits+ vegetables and D= wood, DOCf= Fraction DOC dissimilated (0.014T+0.28), 35℃ in the anaerobic zone of the landfill, F= Fraction of methane in LFG (default is 0.5), R= Recovered methane (Gg yr-1), Recovery of Landfill was not adopted in India, hence the value is zero, OX = 0 |
| 2 | German EPER method | $Q_{CH4}$ = M*DOC*$DOC_f$*F*D | The EPER model used in Germany, it is a zero-order model. **Assumption** DOC, $DOC_f$ and F are assumed as IPCC default method D is the collection efficiency factor |
| 3 | First order model (TNO) | $Q_{CH4}$=$DOC_f$*1.87*M*DOC*k*e-kt | The first order model TNO, amount of waste was assumed to decay exponentially in time **Assumption** $DOC_f$ and DOC are assumed as IPCC default method M is the waste generation in dumpyards, 1.87 is the conversion factor (m3 LFG.kg C-1 degrades), K is the decay rate (0.06) |
| 4 | LANDGEM version 3.02 models | $Q_{CH4}= \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}}$ | Landfill gas emission model (LANDGEM) is the spreadsheet interface, used for either site-specific data to estimate methane emission or default parameters if no site-specific data are available **Assumption** k = methane generation rate (year-1) 0.05 Lo = potential methane generation capacity ($m^3$/Mg) |

where $Q_{CH4}$ = annual methane generation in the year of the calculation ($m^3$/year), $MSW_T$ = Total municipal solid waste (MSW) generated (Gg $yr^{-1}$), $MSW_F$ = Fraction of MSW disposed of at the disposal sites, MCF = Methane correction factor (fraction), fraction depends upon the method of disposal and depth available at landfills, DOC (Degradable Organic Carbon), $DOC_f$= Fraction DOC dissimilated, F= Fraction of methane in LFG,R= Recovered methane (Gg yr-1), OX= Oxidation factor, k = the decay rate (yr-1), t is the time of waste disposal, i = 1year time increment, n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1year time increment, k = methane generation rate (year-1), Lo = potential methane generation capacity ($m^3$/Mg), Mi= Mass of waste accepted in the ith year (Mg),tij = age of the jth section of waste mass Mi accepted in the $i^{th}$ year (decimal years, e.g.,3.2 years)

### *2.3 Empirical estimation method of methane emission*

The municipal solid waste generation data were collected from Greater Chennai Corporation for the period from 2000 to 2016. The waste generation data were used in first order decay (TNO model and LandGEM) model, mass balance approach (IPCC default Method) and Zero order decay model (EPER Germany) model for estimating the methane emission in two open dumpyards of Chennai City. The comparison of the methane estimation in different methods is given in the Table 2.

## 3. Results and discussion

### *3.1 Population growth and waste generation in Chennai city*

The Chennai city population data were collected from the census department (Census of India 2011), it has shown that the population of Chennai city has increased exponentially. The municipal solid waste generation data were obtained from Greater Chennai Corporation for the period of 2000 to 2016. Based on the waste generation data and population, the per capita waste generation was estimated, which is shown in Fig. 2. The projected population were fitted with exponential regression model and the projected waste generation were fitted with linear regression model and used for the time series analysis from 1981 to 1999 and 2017 to 2050.

The projected population growth shows that it will reach the stationary phase at the end of 2050, but at the same time waste generation trend assumed to be increased linearly (Fig. 2). The per capita generation of MSW in Chennai city has been increased about 70% from 334 g to 1137 g/day for the period of 1981 to 2016 and it has been projected and increase by 48% (1683g/day). The waste composition of Chennai city data was collected from Greater Chennai Corporation, waste classified as 54% of degradable waste and 46% of non-degradable waste, which is shown in Fig. 3(a) and 3(b). The degradable waste comprised of Food waste (15%), paper waste (12%), timber (13%) and Green waste (60%).

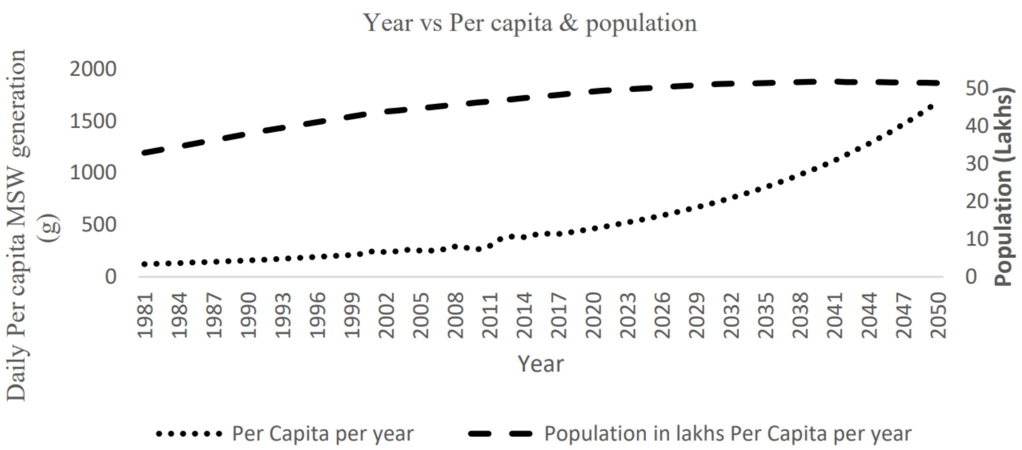
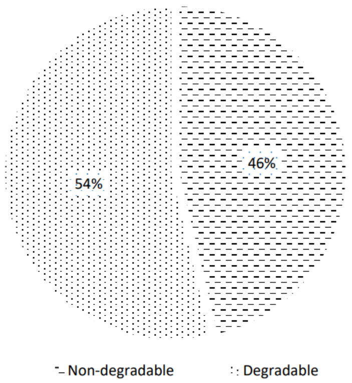
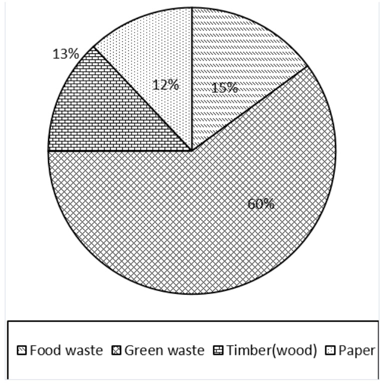



Fig. 2 Population trend and per capita waste generation




(a) Waste classification




(b) Composition of degradable waste

Fig. 3 Composition of MSW in Chennai City

Table 3 Season wise methane flux rate (mg/m$^2$/h) in Chennai dumpyards

| **Kodungaiyur ($CH_4$ mg/m$^2$/h)** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | South west Monsoon | | | | North East Monsoon | | | | Winter | | | | Summer | | | |
| Feet | L- 1 | L-2 | L-3 | L-4 | L- 1 | L-2 | L-3 | L-4 | L- 1 | L-2 | L-3 | L-4 | L- 1 | L-2 | L-3 | L-4 |
| 3 | 1040 | 1029 | 1264 | 1103 | 1059 | 970 | 1481 | 1131 | 1383 | 1228 | 1022 | 1389 | 1321 | 1291 | 1230 | 1282 |
| 6 | 958 | 1067 | 1177 | 1042 | 992 | 891 | 1261 | 1050 | 1219 | 1252 | 970 | 1395 | 1245 | 1253 | 1217 | 1222 |
| 9 | 1011 | 1041 | 1243 | 1049 | 992 | 951 | 1145 | 852 | 1280 | 1160 | 1022 | 1435 | 1368 | 1363 | 1347 | 1326 |
| **Perungudi ($CH_4$ mg/m$^2$/h)** | | | | | | | | | | | | | | | | |
| | South west Monsoon | | | | North East Monsoon | | | | Winter | | | | Summer | | | |
| 3 | 1174 | 950 | 971 | 955 | 919 | 889 | 984 | 1025 | 1280 | 1316 | 1357 | 1203 | 1186 | 1145 | 1092 | 1048 |
| 6 | 1044 | 844 | 912 | 877 | 842 | 811 | 812 | 971 | 1226 | 1220 | 1213 | 1082 | 1032 | 1073 | 959 | 976 |
| 9 | 978 | 765 | 870 | 756 | 735 | 761 | 750 | 889 | 1093 | 1114 | 1131 | 1029 | 983 | 1027 | 925 | 890 |

*L-Location of dumpsites

### *3.2 Quantification of methane emission by using closed flux chamber*

The season wise methane flux rate in Kodungaiyur and Perungudi dumpyards of Chennai city are given in Table 3. The depth of dumpyard is directly proportional to the waste collected in the year. Hence it has been assumed that 2-4 ft increase in landfill height per year and methane sampling year were fixed at 2012-2014 based on the landfill height. At Kodungaiyur dumpyard, $CH_4$ flux rate in summer was ranged from 1216 to 1367 mg/m$^2$/h with an average of 1288 mg/m$^2$/h, winter was ranged from 851.8 to 1480.7 mg/m$^2$/h with an average of 1229 mg/m$^2$/h, southwest monsoon ranged from 958 to 1264 mg/m$^2$/h with an average of 1085 mg/m$^2$/h and north east monsoon were varied between 891 and 1461 mg/m$^2$/h with an average of 1065 mg/m$^2$/h. Perungudi, $CH_4$ flux in summer was varied between 1028 and 1358 mg/m$^2$/h with an average of 1188 mg/m$^2$/h, winter was ranged from 890 to 1186 mg/m$^2$/h with an average of 1028 mg/m$^2$/h, southwest monsoon was ranged from 765 to 1174 mg/m$^2$/h with an average of 925 mg/m$^2$/h and North east monsoon was varied between 735 and 1025 mg/m$^2$/h with an average of 866 mg/m$^2$/h (Jha *et al.* 2008, Rawat and Ramanathan 2011, Mor *et al.* 2006).

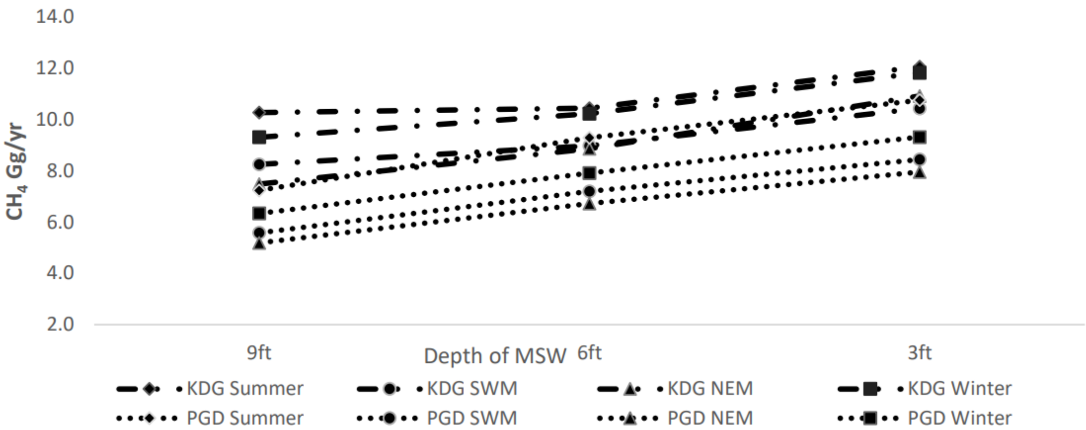
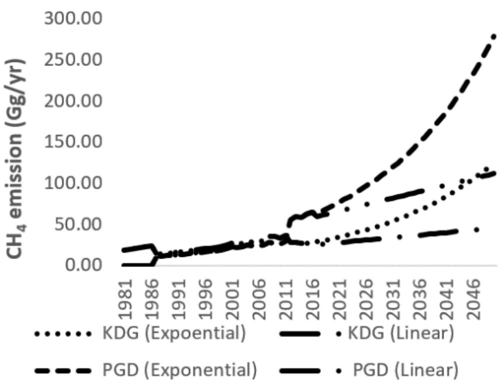
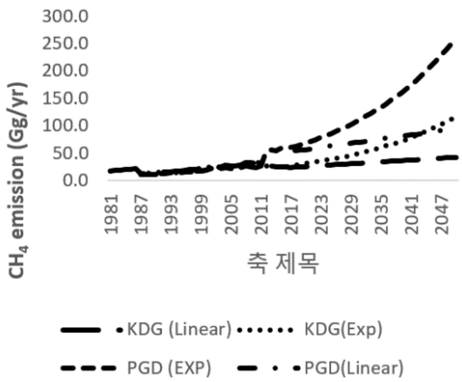



Fig. 4 $CH_4$ emission in Perungudi and Kodungaiyur dumpyards of Chennai using close flux chamber

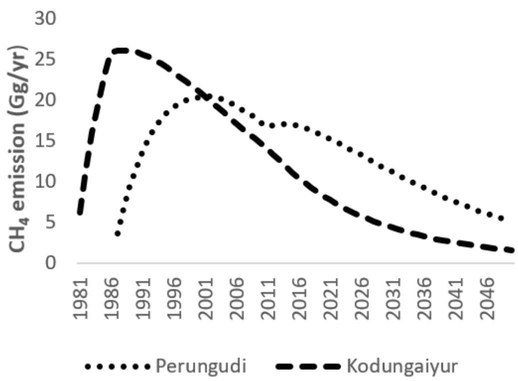



(a) IPCC default method

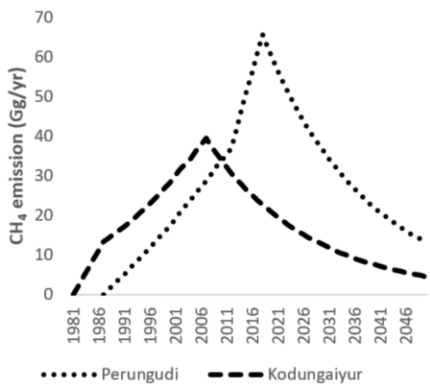



(b) EPER model

Fig. 5 Time series of CH4 emission in mass balance approach and Zero order decay model




(a) TNO model




(b) LandGEM model

Fig. 6 Time series of CH4 emission in first order decay model

The $CH_4$ emission in Kodungaiyur was 11.3 Gg/yr from 3 ft height (2014), 9.6 Gg/yr from 6 ft height (2013) and 8.8 Gg/yr from 9 ft height (2012). At Kodungaiyur, highest $CH_4$ emission of

10.9 Gg/yr was recorded during summer, 10.4 Gg/yr in winter, 9.1 Gg/yr in south west monsoon. The $CH_4$ emission in Perungudi dumpyards were varied from 9.1 Gg/yr in 3ft, 7.8 Gg/yr in 6 ft and 6.1 Gg/yr in 9 ft (Fig. 4). At Perungudi, highest $CH_4$ emission of 9.1 Gg/yr during summer, 7.9 Gg/yr in winter, 7.1 Gg/yr in south west monsoon and 6.6 Gg/yr in northeast monsoon. Kodungaiyur dumpyard emits a higher of $CH_4$ than Perungudi dumpyard of Chennai city. This could be due to the differences in the dumpyard nature, waste characterization and population density difference between north and south of Chennai City. The season wise trend shows that during summer, the emission is higher when compared to winter and monsoon seasons. The rate of $CH_4$ emission were high during summer (March to May) season due to the several favouring conditions such as high temperature (29℃ to 42℃), low rainfall (average 45-50 mm) and availability of high organic content which influence the methanogenesis process (Mallick 2009).

### *3.3 Quantification of methane emission through mass balance approach and Zero/ First order decay*

The composition of waste was used to calculate the degradable organic carbon (DOC). The degradable organic carbon, total waste generation and methane correction fraction were considered during methane emission quantification at Kodungaiyur and Perungudi dumpyards. The default method of IPCC, shows that the $CH_4$ emission in Kodungaiyur was increased by about 45% (13.4 Gg/yr to 36.2 Gg/yr for the period of 1981 to 2017, the projected emission shows that it will be increased by about 61% for the period of 2017 to 2050 (Fig. 5(a)). In Perungudi, the emission was increased by about 80% for the observed period and the projected emission shows that it will be increased by about 90% for the period from 2017 to 2050. Whereas in Zero order decay model (EPER Germany) given in Fig. 5(b), $CH_4$ emission in Kodungaiyur and Perungudi dumpyards were increased by about 84% (12.5 to 42.5 Gg/yr) for 1981 to 2050 and 95% (10.2 to 94.5 Gg/yr) for 1987 to 2050 respectively (Karthikeyan *et al.* 2012). If the trend in the future $CH_4$ emission is exponential rather than linear in the dumpyards. The $CH_4$ emission based on IPCC default method would have increased by about 88% (25.8 to 124.88 Gg/yr) and 79% (60 to 266 Gg/yr) in Kodungaiyur and Perungudi dumpyard respectively. Whereas based on EPER Germany, $CH_4$ emission would have increased by about 79% (12 to 117 Gg/yr) and 95% (10 to 260 Gg/yr) in Kodungaiyur and Perungudi dumpyard respectively.

In First order Decay model (TNO model) given in Fig. 6(a), stated that methane emission in Perungudi dumpyard increased during 1987 to 2003 by about 81.5% and decreasing trend during 2004 to 2050 (39%). The $CH_4$ emission in Kodungaiyur showed that the increasing trend in 1981 to 1990 (85%), and decreased by about 94% for the period from 1991 to 2050 (Rawat and Ramanathan 2011). Landfill Gas Emissions Model (LandGEM) estimates the $CH_4$ emission was increased by about 10% in Kodungaiyur for the period of 1981 to 2008 (Fig. 6(b)). The $CH_4$ emission in Perungudi was increased by about 19% during 1987 to 2019. The peak emission of $CH_4$ in Kodungaiyur and Perungudi was recorded at 2008 (37.5 Gg/yr) and 2018 (65.7 Gg/year). The LandGEM model predicted the methane emission in Perungudi dumpyard, it would be decreased by 70% for the period of 2020 to 2050 and Kodungaiyur methane emission would decrease by about 93% for the period of 2009 to 2050.

### *3.4 Validation of zero/first order decay model and mass balance approach with field measurement*

The trend of $CH_4$ emission in the actual field measurement were increased every year, similarly

Table 4 Methane emission from MSW dump yards of Chennai using the empirical models and field measurements

| Year | TNO model (Gg/yr) | IPCC default method (Gg/yr) | LandGEM model (Gg/yr) | EPER German model (Gg/yr) | Field measurement (Gg/yr) |
|---|---|---|---|---|---|
| 2012 | 22.9 | 80.3 | 36.2 | 78.2 | 14.9 |
| 2013 | 22.2 | 85.3 | 37.9 | 81.3 | 17.4 |
| 2014 | 21.5 | 84.2 | 39.5 | 79.3 | 20.4 |

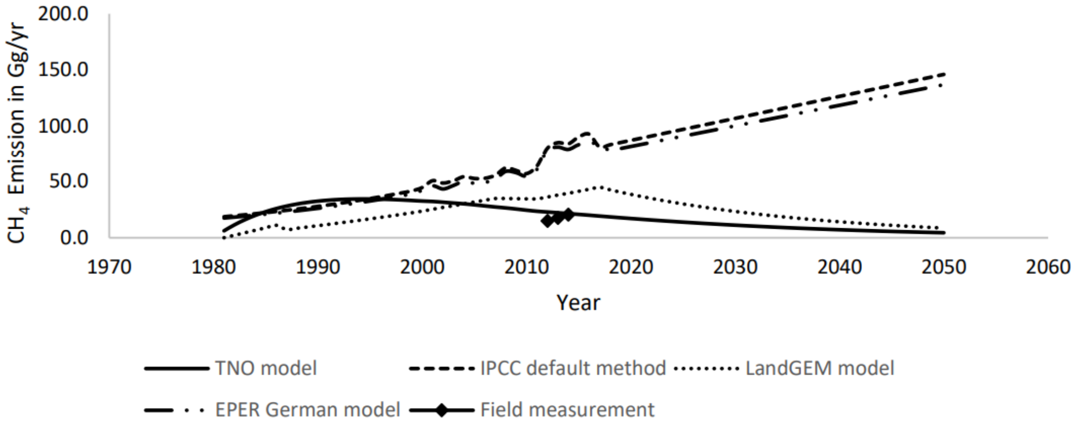



Fig. 7 Comparison of CH4 emission in first order decay model, Zero order decay, mass balance approach and Field measurement (Flux chamber)

the emission trend also increased in IPCC default method (mass balance approach), EPER Germany (zero order decay model) where as TNO and Land GEM (first order decay model) were decreased. The $CH_4$emission in mass balance approach (IPCC default method) does not consider the substrate degradation and in zero order decay models (EPER Germany method) it's independent of substrate degradation and hence $CH_4$ emission are increasing every year, whereas first order decay model (LandGEM and TNO) are dependent on the substrate degradation and hence the $CH_4$ emission are decreasing based on the active period (Fig. 7). The emission ranged between 14.9 Gg/yr and 20.4 Gg/yr for the period of 2012-2014 from the actual field measurement. Based on the per capita, the model estimates that the $CH_4$ emission by assuming the constant in composition of waste, degradable organic carbon, methane correction factor, oxidation factor, but the actual scenario for the Chennai may be different in handling the waste. The models does not consider the variability factor for the efficiency in collection, conversion and recycling of waste.

The $CH_4$ emission values of Zero/first order decay model, LandGEM model has been increased at the rate of 36.2 to 39.4 Gg/yr is nearer to field measurement values of $CH_4$ emission which is increase at the rate of 14.9 to 20.4 Gg/yr. IPCC default method complies with Indian condition as its reflect the per capita waste generation, it will not give the variation in solid waste disposal dumpyard and process of degradation is constant for every year (Kumar *et al.* 2004) (Table 4). While comparing the past and future projection of $CH_4$ emission between the Kodungaiyur and Perungudi dumpyard, Kodungaiyur emits more amount of $CH_4$ emission which receives MSW from six zones (previously five zones) and also densely populated and thus $CH_4$ emission is higher when compared to Perungudi. Moreover, the other impact due to water, air pollution is also higher in Kodungaiyur with less adaptive capacity.

## 4. Conclusions

The validation of field measurement with the empirical models, the trend of $CH_4$ emission in field measurement are similar to trend of IPCC and EPER showed an increasing and for the TNO and LandGEM showed a decreasing trend. The unmanaged waste generation in Chennai City leads to pressure on the dumpyards and it gives the serious implication in the environmental and climate impacts. As per the Solid Waste Management Rules prescribed by the Ministry of Environment, Forest and Climate Change (MoEFCC), the proper closure period of the Kodungaiyur and Perungudi should be on 2006 and 2012 respectively. This study envisaged the importance of the MSW treatment and waste recovery as the lifespan of both the dump sites are exceeding the capacity. The Greater Chennai Corporation has planned to set up a waste recovery plant which includes processing, collection and remediation to alter these dumpyard in Minjur (North) and Kuthambakkam (South). Since the global warming potential for methane is higher and its equivalence for 20 years will be 1120 Gg of $CO_2$ and 100 years will be 420 Gg of $CO_2$. Implementing of waste segregation at the collection level will help in waste and methane recovery, thereby the emission of greenhouse gas could be mitigated in the future.

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