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Analysis of Methane Gas Emission by LandGEM Model from Open Dump Landfill in Khulna of Bangladesh

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ABSTRACT: Landfills are the potential sources of methane emissions all over the world. Methane emission is directly linked to global warming. This study aims to predict methane emissions from an open dump landfill in Khulna of Bangladesh. The LandGEM model is used in this study to quantify methane emissions. It was made by the USEPA in 2005 and used extensively in quantifying landfill methane emissions from the decomposition of municipal solid wastes. Landfill open year, closure year, waste acceptance rate, meteorological data, and waste composition are used as the input of the model. The findings of this research demonstrate that the rate of methane emissions in 2023 will be 4.16x103 Mg/year, which is the highest, and since then the emission drops. Also, the seasonal variation of methane emission demonstrates that the emission is highest in monsoon times (5.9×10^3 Mg/year in 2023) when the precipitation is higher and lowest in winter times (1.3×10^3 Mg/year in 2023) when both the precipitation and temperature are lowest.

Keywords: Methane, LandGEM, Landfill gas, Municipal solid waste.

1. INTRODUCTION

The mass of discarded homogenous and heterogenous materials in an urban area is known as municipal solid waste (MSW). It contains a highly heterogeneous variety of waste products from homes, businesses, industries, institutions, and other sources (Rafew & Rafizul, 2021). Currently, the global production of Municipal Solid Waste (MSW) is 2.1 billion tons annually and is projected to increase to 3.4 billion tons by 2050 (Kaza et al., 2018). Bangladesh's annual waste production rate grew from 1.1 million tons in 1970 to 5.2 million tons in 2015 (Shams et al., 2017). Municipal solid waste (MSW) production rises with the improvement of socioeconomic conditions (Fallahizadeh et al., 2019a). Also, a large amount of solid waste is produced as a result of technological advancement and population growth (Hosseini et al., 2018a). Being the most densely populated country in the world, urban areas in Bangladesh are generating an increasing quantity of MSW waste and facing immense pressure in handling those. Khulna, the third largest city in the country, generates 450-520 tons of MSW daily (Rafi et al., 2020). The Khulna City Corporation (KCC) manages and clears this enormous amount of MSW. MSW mostly consists of biodegradable materials that decompose anaerobically in landfills to produce landfill gas (LFG), which is composed of around 60% methane (CH_4) and 40% carbon dioxide (CO_2) along with trace amounts of other gases and non-methane organic compounds (Chakraborty et al., 2011). Methane accounts for 16% (by volume) of all yearly anthropogenic greenhouse gas emissions, making it a significant source of concern for global warming (Jeong et al., 2019). Environmental factors, climatic conditions, microbial decay, refuse characteristics, and landfilling procedures, result in the production of gas and leachate in the landfill site (Fallahizadeh et al., 2019a).

Most municipal solid waste (MSW) in Bangladesh is organic (68–81%) and decomposes anaerobically which produces a significant portion of methane (Shams et al., 2017). To estimate methane emission from landfill, multiple established technique is available including field experiments. In this study, the USEPA LandGEM model is used to estimate and predict methane emissions from the Rajbandh open dump site in Khulna city. LandGEM is the most common model used to simulate LFG emission due to its simplicity and immunity to atmospheric instability (Hosseini et al., 2018b). Also, the seasonal variation of methane emission is quantified.

2. METHODOLOGY

The Rajbandh open dump site is incorporated in this study to estimate and predict methane gas emissions. The following articles include the composition of the deposited MSW, details of the LandGEM model, and the description of relevant parameters, as well as necessary equations.

2.1 Site description

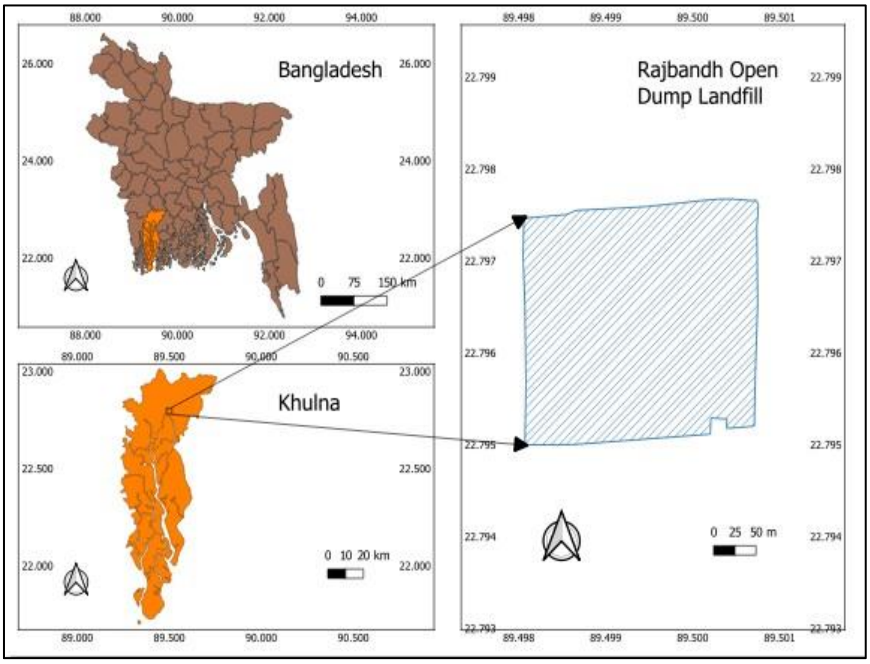

Figure 1: Open MSW dump site located in Rajbandh, Khulna, Bangladesh (QGIS, 2023)

Khulna City Corporation manages municipal solid wastes (MSW) in Khulna city. All generated wastes of Khulna city are transported to the Rajbandh landfill site (La: 22° 47' 47.87'' N and Lo: 89° 29' 57.68'' E), an open dump site located approximately 8 km outside of the city. The total land area of the open dump site is about 20 acres. It is the only operating dump site in the city. Khulna city corporation (KCC) disposes of waste from the entire city in this landfill. As Rajbandh is an open dump landfill, no engineered landfill facility is available here. A gas collection system, composting plant, or leachate treatment facility is not available here. Also, proper earth boundaries or fencing is not available. Waste spreading and compaction are the only management facility available here (Setu et al., 2023). Khulna city's weather is tropical, with average annual precipitation is 1747mm and temperatures ranging between 21°C and 29°C. Most of the rainfall happens in monsoon times.

2.2 Composition of waste

Waste characterization was done in the Rajbandh landfill to determine the percent weight of different waste fractions. The quarter method was used to do the waste composition. A total of 200kg of waste was taken as a sample. Total waste was divided into four quarters. In each quarter 50 kg of waste was taken and then mixed freely so that every quarter becomes homogenous. Then waste composition was done in one quarter and the results are shown in Table 1.

Table 1: MSW composition in Rajbandh open dump landfill

Waste fraction	Percentage by Weight
Food waste	80.17
Paper and Textile Waste	3.84
Wood waste	0.86
Garden waste	0.51

Here in Table 1, only fractions of waste percentage are shown which would be used to find out the degradable organic carbon (DOC). Results show significant percentage of food waste, almost 80%. Similar findings from earlier research on the MSW composition in Khulna were observed, with a ratio of 78.9% food and vegetable waste (Ahsan et al., 2015; Alamgir et al., 2007) which is very near the value found in this study. Also, the waste composition data showed that most of the waste found in the Rajbandh open dump is organic. However, a landfill in Dhaka, Bangladesh showed 67.65% of food waste (Toha & Rahman, 2023).

2.3 Description of the LandGEM model

According to the user manual of LandGEM version 3.03 software, LandGEM is an automated program for calculating MSW landfill emissions of methane and other greenhouse and landfill gases (Alexander et al., 2005). It was made by the USEPA in 2005 and used extensively in quantifying landfill methane emissions from the decomposition of organic wastes. The first-order decay (FOD) equation is used in this software (Fallahizadeh et al., 2019b). The FOD equation is shown in Equation (1).

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} K L_{o} \left(\frac{M_i}{10}\right) e^{-kt_{ij}} \dots\dots\dots\dots\dots\dots (1)$$

Q_{CH_4} = Annual methane generation in the year of the calculation (m^3/year)

i= Time increment (1 year)

n= The number of years since the waste was first accepted

k= Methane generation rate (yr^{-1})

j= Time increment (0.1 years)

L_o=Potential methane capacity (m^3 CH_4/ Mg waste)

M_i= The mass of MSW landfilled in the i^{th} year (Mg)

t_{ij}= Age of the j^{th} section of waste mass M_i accepted in the i^{th} year (decimal years)

In this study, the data of waste acceptance rate in the landfill site was collected between 2000 and 2022. Data was collected from Khulna City Corporation and also from the study of (Rafew & Rafizul, 2021). The assumption in LandGEM software is that methane makes up 50% of the total gas released and CO_2 makes up the other 50%.

2.4 Methane production rate constant

The methane production rate constant (k) value represents the biodegradation half-life in $year^{-1}$ for waste that is landfilled which basically controls the methane generation rate at the landfill (Park et al., 2018). Even though it is known that the organic component of each waste product degrades at a variable rate, the majority of models adopt a single overall value for k (Thompson et al., 2009). LandGEM model provides default values for methane production rate constant. However, in this study, the site-specific value of k is developed. According to (Garg et al., 2006), the most crucial factor in determining the k value is precipitation. As such, using precipitation rates, the k value for bulk waste could be calculated. In this study, the k value is determined using Equation (2).

$$k = (3.2\times10^{-5} \times \text{annual precipitation in mm}) + 0.01 \quad (2)$$

The annual precipitation data is obtained from the Bangladesh Agricultural Research Council (Climate Information Management System, n.d.) website. The annual mean precipitation in Khulna from the data of 1950-2019 is found 1747.8 mm. The methane generation rate, k is found 0.0659 $year^{-1}$ using Equation (2).

2.5 Methane production potential capacity

The methane production potential capacity (Lo) is the amount of CH_4 that can be produced from the unit mass of waste under optimal circumstances (Krause et al., 2016). The site-specific value of Lo is calculated using Equations (3) and (4). The value is found 67.95 m^3/Mg.

$$DDOCm = DOC \times DOC_f \times MCF \quad (3)$$

$$Lo = \frac{DDOCm \times F \times \frac{16}{12}}{0.714} \quad (4)$$

$DDOC_m$= Mass of decomposable degradable organic carbon
DOC = Degradable organic carbon. It is measured according to Equation (5).

$$DOC = 0.40A + 0.17B + 0.15C + 0.30D \quad (5)$$

Here, A = Paper and textile Waste = 3.84%;
B = Garden waste = 0.51%;
C = Food waste = 80.17%;
D = Wood waste =0.86%

DOC_f = Fraction of DOC that decomposes anaerobically. Here, the value of DOC_f is found 0.654 according to Equation (6), where T represents the mean temperature in °C.

$$DOC_f = 0.014 \times T + 0.28 \quad (6)$$

MCF = Methane correction factor. The MCF value in this study is 0.80 as Rajbandh has waste heaps that are higher than 5 meters (IPCC, 2006).
F = Fraction of methane by volume in landfill gas. It should be 0.5 in this study (IPCC, 2006).

In addition to the site-specific value, the default values of k and Lo of the LandGEM software are also employed in this investigation to identify methane emissions. The default values used in this study are Clean Air Act Conventional (Lo=170 m^3/Mg, k=0.05 $year^{-1}$), Clean Air Act Arid Area (Lo=170m^3/Mg, k=0.02 $year^{-1}$), and Inventory Conventional (Lo=100 m^3/Mg, k=0.04 $year^{-1}$). Additionally, Table 2 shows the value of all different parameters used in this model.

Table 2: Different input parameters used in LandGEM model

Parameter	Symbol	Value	Remark
Annual mean Precipitation (mm)		1747.8	Site specific calculation
Methane production rate constant ($year^{-1}$)	k	0.0659	Site specific calculation
Degradable organic carbon	DOC	0.1391	Site specific calculation
Fraction of DOC that decomposes anaerobically	DOC_f	0.654	Site specific calculation
Methane correction factor	MCF	0.80	IPCC 2006 guideline

Mean annual temperature (°C).	T	26.73	Site specific calculation
Fraction of methane by volume	F	0.5	IPCC 2006 guideline
Methane production potential capacity (m^3/Mg)	Lo	67.95	Site specific calculation

2.6 Determination of LandGEM parameters for different seasons

In this study, methane emissions were estimated in three different seasons. In Bangladesh, the three seasons that have the biggest influence are summer, winter, and monsoon. March to June is regarded as the summer season, November to February as the winter season, and July to October as the monsoon season. To identify the k value at different seasons, Equation (2) is used where season-wise mean precipitation data is used. The Bangladesh Agricultural Research Council's website (Climate Information Management System, n.d.) is used to collect rainfall data from 2000-2020, which is then used to produce a season-by-season monthly mean and then a yearly mean. The mean monthly rainfall found in summer, winter, and monsoon seasons is 147.16 mm, 17.63 mm, and 296.27 mm respectively. Later it is converted into season-wise yearly mean. Using these as the input in Equation (2), the k value in summer, winter, and monsoon seasons is found 0.066 $year^{-1}$, 0.016 $year^{-1}$, and 0.124 $year^{-1}$. Also, the methane production potential capacity (Lo) is calculated with seasonal variations. As DOC_f changes with temperature variation, different values of DOC_f are calculated in summer, winter, and monsoon seasons. The mean temperature of summer, winter, and monsoon is found 29.3°C, 21.9°C, and 28.9°C respectively. Using different values of mean temperature in Equation (6), Lo value in summer, winter, and monsoon seasons is found 71.58, 60.98, and 71.16 m^3/Mg, respectively. Table 3 shows the input parameters in LandGEM at different seasons.

Table 3: Input parameters in LandGEM at different seasons

Seasons	k ($year^{-1}$)	Lo (m^3/Mg)
Summer	0.066	71.58
Winter	0.016	60.98
Monsoon	0.124	71.16

3. Results and Discussion

This part of the study contains the results of methane emission estimation from the LandGEM software in various parametric conditions. Also, the results of seasonal variation of methane emission are shown.

3.1 Methane emission estimation results

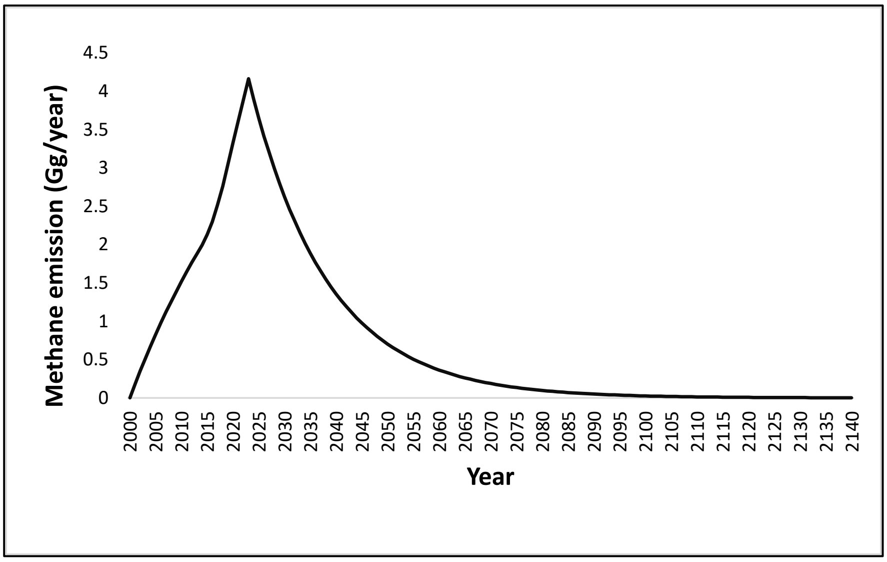

Figure 3: Methane emissions of Rajbandh open dump site estimated by LandGEM model 3.03

The estimation of methane from the Rajbandh open dump site using LandGEM 3.03 is shown in Figure 3. Different simulations have been conducted in this study. These simulations are: Clean Air Act Conventional (Lo = 170 m^3/Mg and k = 0.05 $year^{-1}$), Clean Air Act Arid Area (Lo = 170 m^3/Mg and k = 0.02 $year^{-1}$), Inventory Conventional (Lo = 100 m^3/Mg and k = 0.04 $year^{-1}$), and site-specific value (Lo = 68 m^3/Mg and k = 0.066 $year^{-1}$). Comparative methane emissions from different simulations are shown in Figure 4. From Figure 3, it is shown that methane was not emitted in the year 2000. After that methane emission quickly rises and peaks in the year 2023. The peak value is $4.16x10^3$ Mg/year. From the peak, the methane emission continuously decreases. Figure 4 shows the comparative assessment of methane emissions on different default values and site-specific values of LandGEM 3.03. The peak value of methane emission in CAA Conventional is $8.8x10^3$ Mg/year, in CAA Arid Area is $4.41x10^3$ Mg/year, and in Inventory Conventional is $4.45x10^3$ Mg/year. All the peak value is found in the year 2023. After that methane emission decreases over the year. Among these four types of simulations maximum peak emission is observed in CAA Conventional but its decrease rate is much higher comparing other simulations. Also, the emission of other pollutants like CO_2, NMOC, total landfill gas is shown in Figure 5. The peak value of total landfill gas, methane, CO_2, NMOC are $1.56x10^4$ Mg/year, $4.16x10^3$ Mg/year, $1.14x10^4$ Mg/year and $1.79x10^2$ Mg/year respectively.

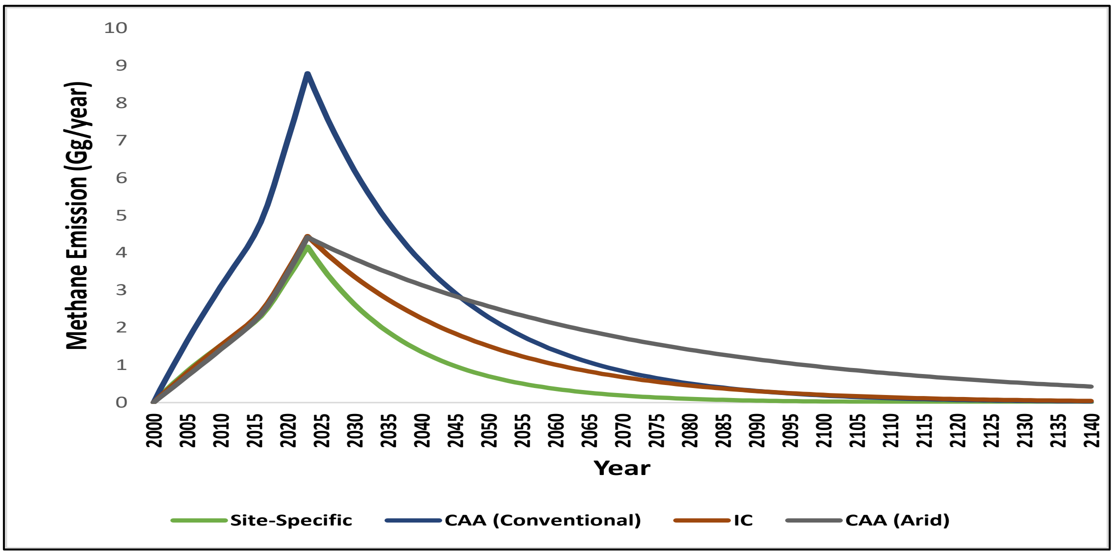

Figure 4: Comparative assessment of different default values and site-specific value of LandGEM 3.03

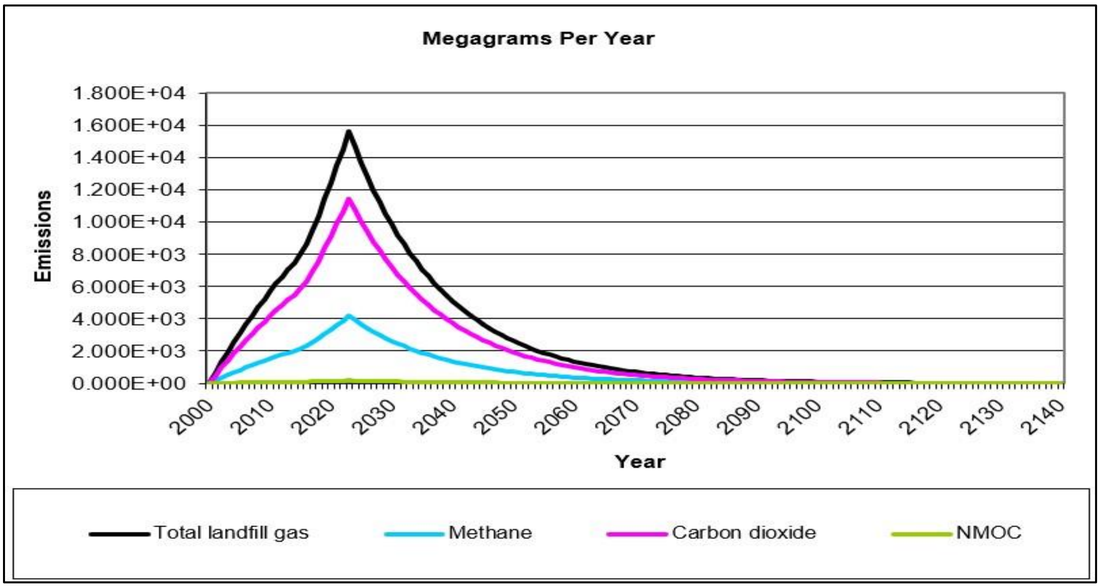

Figure 5: Different gas pollutants emission from LandGEM 3.03

3.2 Seasonal variation of methane emission

Gas emissions are evaluated in different seasons to better understand the effect of temperature and precipitation on gas production. The value of k and Lo is estimated for different seasons. The LandGEM software estimates methane emission using the seasonal values of k and Lo as inputs. The seasonal fluctuations in methane emission are depicted in Figure 6. It demonstrates that the monsoon season, when precipitation is significantly more than in other seasons, has the highest rate of gas emission, peaking at 5.9×10^3 Mg/year. In the summer, when temperatures are greater than in other seasons, the emission rate peaks at 4.3×10^3 Mg/year, while in the winter when both temperatures and precipitation are significantly lower, it peaks at 1.3×10^3 Mg/year.

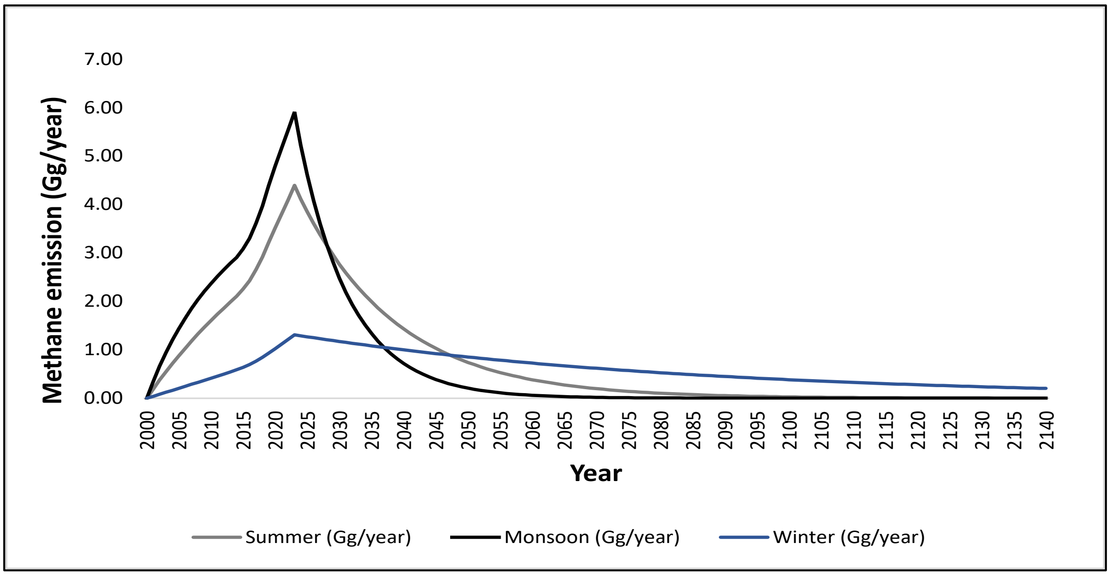

Figure 6: Methane emissions in different seasons using LandGEM 3.03

4. CONCLUSIONS

Khulna is producing a growing amount of MSW on a daily basis, due to economic independence and population growth. The management of MSW is mostly done by dumping in the landfill site. In Khulna, MSW is dumped in Rajbandh open dump site which produces methane and other GHGs. This study used the LandGEM software model to estimate the site's methane emissions. The peak value was found $4.16x10^3$ Mg/year in the year 2023. Emissions have since decreased, but significant emissions will continue until 2045. This study also compares the site-specific value with default values. Results show that CAA conventional default predicts the highest methane emission which is $8.8x10^3$ Mg/year and other defaults like CAA arid and inventory conventional predict emissions close to the site-specific value. Nonetheless, the CAA conventional forecasts the highest rate of emissions reduction. Moreover, estimates of seasonal fluctuations in methane emission suggest that the rate is highest during the monsoon when precipitation is at its highest, and lowest during the winter when temperature and precipitation are at their lowest. The estimated emission can be used to design a gas collection system that will prevent environmental gas emissions. Finally, the waste management masterplan that KCC is developing may benefit from this study.

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