*LAUTECH Journal of Engineering and Technology 18 (3) 2024:144-153*
10.36108/laujet/4202.81.0351

# Estimation and forecast of methane emission from solid waste generation within LAUTECH, Ogbomoso, using IPCC model and LANDGEM

**Oladejo O. S., Abdulazeez A. O., *Oyeleke M. D., Olusola A. M. and Labeeb J. T.**

*Department of Civil Engineering, Ladoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria.*

**Article Info**

***Article history:***

**Received:** July 3, 2024
**Revised:** Sept 20, 2024
**Accepted:** Sept 30, 2024

***Keywords:***

Climate Change, Methane Gas Emission, IPPC, LandGEM, Open dumps, Solid Waste Management

***Corresponding Author:***
meleyotanoyeleke@gmail.com

**ABSTRACT**

***Estimating and predicting methane emissions from various sources have become crucial for understanding their environmental impacts, preparing effective reduction plans against their hazards or converting them to be useful. This study examined the emission of methane gases from solid waste in open dumps at Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Southwest Nigeria. Procedures from the well-established Landfill Gas Emission Model (LandGEM) and the Intergovernmental Panel on Climate Change (IPCC Model) were used to calculate the production amount of methane ($CH_4$) gas, a greenhouse gas. Study areas were defined, assumptions were clarified and points for consideration were laid out. The results revealed a negligible existence of methane emissions in the LAUTECH campus, with the IPCC model and LandGEM showing 1.5617E-04 Mg/year and 3.877E-07 Mg/year, respectively, at the end of the study years.***

## INTRODUCTION

In recent years, the emission quantification of greenhouse gases (GHG) such as methane ($CH_4$), carbon dioxide gases ($CO_2$), trace gases, and volatile organic compounds has been underway. This is due to the recognised importance of comprehending the environmental impact of these gases. Since most greenhouse gases are known to be usually harmful, several studies have attempted to develop effective strategies to mitigate their hazardous effects or facilitate their beneficial conversion. $CH_4$, for example, has been highlighted as a major greenhouse gas with global warming potential that exceeds those of carbon and non-methane organic compounds (NMOC).

Notably, a significant contributor to the generation of methane ($CH_4$) gas is municipal solid waste (MSW) from open dumps (Chandra and Ganguly, 2023). Open dumping of solid waste has significantly increased greenhouse gas emissions in many developing countries. Much information is obtained about the contribution of these greenhouse gas emissions in cities and towns, but there is little from Universities and other institutions of higher learning that now act like municipalities (Sandhya *et al.*, 2016; Oladejo *et al.*, 2020; Adeniran *et al.*, 2017).

Universities, defined as institutions of higher learning, are now regarded as small cities due to their large population size, consumption of energy and materials and changing lifestyles. The various complex activities taking place on campuses have some severe direct and indirect impacts on the environment (Alshuwaikhat and Abubakar, 2008).

Reports have shown that there are non-integrated waste management systems in institutions of higher learning with rapidly expanding municipal solid waste, like in developing countries. Like in developing countries, solid waste in universities is collected, dumped, and burned openly in a secluded place (Adeniran *et al*., 2017; Kaushal and Sharma, 2016). This is responsible for the waste not being properly managed thereby, creating environmental problems such as water and soil contamination that affect human and animal health and, ultimately, agricultural productivity (Staley *et al.*, 2009).

Furthermore, the issue concerns both local and global fronts. At the local level, the problem lies in the limited understanding of the scale and dynamics of these emissions, as well as the absence of proactive measures to control them.

On the other front, the problem extends to a global context. Methane, a greenhouse gas, drives climate change and its associated effects. The uncontrolled release of methane from open dump sites contributes to the bigger challenge of global warming and environmental disruption with no energy recovery. Therefore, this study recognizes the bigger climate change issue and aims to address it by beginning at the local level, within the university campus.

The project aimed at assessing the generation of open dumps gases, primarily methane, from solid waste generated in LAUTECH using the IPCC and LandGEM 3.02 version model developed by USEPA for a period of 30 years, 2023–2053, with the following objective: i. quantifies the current methane emissions from the open dumps at Ladoke Akintola University of Technology using the IPCC model and LandGEM for the study year 2023; ii. Use the IPCC Model and LandGEM to forecast future methane emissions from the open dumps for the periods of 2024–2053; and iii. Estimate energy potential values of methane emissions. Literature has revealed different methodologies and models to estimate the methane quantities of landfills and open dump sites in many places, including in Nigerian universities and areas. For example, (Oladejo *et al.*, 2020) evaluated and analysed gaseous emissions such as carbon dioxide and methane in an open dump area using LandGEM software in Landmark University, Omu Aran, between 2011 and 2031. Their study revealed that there were vast differences in the results of emission estimates calculated with the two methods of the IPCC Default Method and the Landfill Gas Emission Model Version 3.02. Also, the contribution of methane emissions to the environment is still relatively small, as reflected in the values of 11.65 and 2.48 Mg/year, although there is a tendency for this to increase as the population grows. Adeniran et al., (2017) estimated the daily waste generation of the University of Lagos Akoka campus to be about 32.2 tons, with polythene products representing the largest portion of waste, 34%, and concluded that University waste has high recyclable potential (75%). (Abdu Daura *et al*., 2014) studied the annual methane emission from four municipal solid waste disposal sites in Kano and estimated it using the LandGEM landfill gas model to discover that there will be decline in the value of methane emission in the last years of projection, the study revealed that for the four sites considered for the assessment, the maximum methane emissions would be 6.014 × 104 $m^3$/year occurring at the Ubagama dumpsite in 2040. Given the above literature, it is found that there is a noteworthy research gap within the context of Ladoke Akintola University of Technology (LAUTECH). While previous research has provided valuable insights into methane emissions from open dump sites and the applicability of the IPCC Model and LandGEM in some places and universities in Nigeria, there remains work on the estimation of $CH_4$ emissions from municipal solid waste open dump sites using landfill gas emission models in more Nigerian Universities.

Furthermore, in the Nigerian context, research endeavours have primarily focused on shorter periods when evaluating the amount of methane emissions from dumpsites. This limitation allows this study to extend the timeframe under consideration.

## MATERIALS AND METHOD

### Study Area

Ladoke Akintola University of Technology (LAUTECH) Campus, located in Ogbomoso, Southwestern Nigeria, lies within Latitudes 4° 15′ and 4° 16′ N and Longitudes 8° 9′ and 8° 10′ E. It is a public university with a few open dumps that harbour solid waste from a teeming population of over 30,000 students. The LAUTECH Campus houses most of the University's teaching, research, and central administration offices, with thirteen faculties and a postgraduate school where courses are taught in various fields. The study proceeds to measure unquantified methane gas from open dump sites situated within the campus. The absence of precise data on the extent of methane emissions, and information on specific strategies for its reduction, supports the need for the present study.

### Present method of waste management in LAUTECH

Solid waste is handled, collected, transported and disposed of to the several open dump sites in LAUTECH by the Physical Planning Division of the university uses the 'Stationary Container System' from 240-litre waste bins which are positioned strategically around the university and then transferred to a dumpsite location, where natural decomposition and open air burning is attempted. About 200 workers of the Physical Planning Division collect and transport the garbage to the dump sites, which have been receiving waste for over a decade. They were majorly shallow and each dumpsite had a waste height of less than 2m.

### Sample Collection and Sorting

The open dump sites were assessed based on zones. For a wide and thorough assessment of the study area, the total school landmass was divided into sixteen (16) strategic zones: 1. Pure and Applied Sciences, 2. Environmental Sciences, 3. Agricultural Sciences, 4. Management Sciences, 5. Basic Medical Sciences, 6. Open Distance Learning, 7. Senate Building, 8. School Parks, 9. Bakery Area, 10. Student Union Building, 11. Health Centre, 12. Sport Arena, 13. Cafeterias, 14. Religious Centres, 15. Banking Area, 16. Engineering. The components of the solid wastes at the dumpsites located within the campus from 2019 through 2022 were obtained from the Civil Engineering Department of LAUTECH. The present year 2023 data followed the process of a brief reconnaissance survey to have a general overview of solid waste generation areas in the study area, temporary collection and sorting points to observe the physical conditions regarding quantity and quality of solid waste on the campus. The scientific processes of accurately weighing and recording the waste gathered into categories of Paper, Plastic, Nylon, Metals/ Can, Flowers, Dry Leaves, Food wastes, Glass, Leather, Wood Rags, E-wastes, Polystyrene, Bones and Dirt every day for a week.

### Population estimation

The population data for the years 2010-2023 were obtained from the campus's registry and leveraged to determine LAUTECH's population growth rate. The population for each year of the plan period was estimated using a statistical technique of linear forecasting.

## Models Methods

### *IPCC model*

The IPCC model in the revised IPCC (2006) guidelines, based on the theoretical gas yield (a mass balance equation) and the first-order decay (FOD) method was used. The formula for calculating methane emission from the dump sites is as provided in Equation 1:

$$Q_{CH4} = MSW_t \times MSW_f \times MCF \times DOC \times DOC_f \times F \times (16/12 - R) \times (1\text{-}OX) \quad (1)$$

where: $Q_{CH4}$: annual CH4 generation (Gg/yr); $MSW_t$: Total MSW generated (Gg/yr); $MSW_f$: Fraction of MSW disposed at SWDS (generally 80%); **MCF**: $CH_4$ correction factor (fraction); **DOC**: Degradable organic carbon [fraction (Gg C/ Gg MSW)]; $DOC_F$: Fraction DOC dissimilated; **F**: Fraction by volume of $CH_4$ in Landfill gas; **R**: recovered $CH_4$ (Gg/year); **OX:** oxidation factor (fraction).

### *Assumptions for IPCC Model*

**$CH_4$ Correction Factor (MCF)**: This study assumed an unmanaged solid waste dumpsite (SWDS) which yields less $CH_4$ than the managed one. In the former, a large fraction of waste in the top layer undergoes aerobic decomposition, therefore, the MCF of solid SWDS varies with the site conditions and management techniques used. The MCF for different categories of SWDS is given in Table 4. Since the LAUTECH open dump sites are shallow, unmanaged sites, the MCF was assumed to be 0.4.

**Degradable organic carbon (DOC)**: It is based on the composition of waste and can be calculated using Equation 2:

$$DOC = (0.4 \cdot A) + (0.17 \cdot B) + (0.15 \cdot C) + (0.3 \cdot D) \quad (2)$$

where **A**: fraction of paper and textiles; **B**: fraction of garden waste and park waste or other non-food organic putrescibles; **C**: fraction of food wastes; and **D**: fraction of MSW as wood or straw. $DOC_F$: It is the fraction of carbon that is ultimately degraded and released from SWDS. It represents the amount of organic carbon in SWDS which either does not degrade or degrades very slowly and was calculated based on Equation 3"The EPA LandGEM Guide (2005)":

$$DOC_F = 0.014*T+0.28 \quad (3)$$

where, T: atmospheric temperature of area.

**$CH_4$ recovery (R):** It is the amount of $CH_4$ generated at SWDS and can be recovered as an energy source. The default value for $CH_4$ recovery was assumed zero as the $CH_4$ recovery is not considered at the site.

**Oxidation factor (OX):** It is the amount of $CH_4$ from SWDS that is oxidised in the soil or other materials of the waste. If OX is zero, no oxidation has occurred, and OX 1 means 100% $CH_4$ oxidation (Akolkar et al., 2004). The OX factor in IPCC Guidelines was assumed zero for these dump sites.

**Fraction of $CH_4$ in landfill gas (F)**: The fraction of $CH_4$ (F) is usually taken as 0.5, but it can vary between 0.4 and 0.6, depending on the waste composition and site conditions. It was assumed to be 0.5 in this study.

### *LandGEM model (v 3.02)*

The LandGEM (v3.02) equation which was developed by the United States Environmental Protection Agency (USEPA) for estimating emissions is shown in Equation 4. Using LandGEM software, the amount of $CH_4$ gas produced (Mg/year) was estimated. The general form of the formula is as follows:

$$Q_{CH4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o(M_i/10)e^{-kt_{i,j}} \quad (4)$$

where; $\mathbf{Q_{CH4}}$: Methane production in a year ($m^3$/year).

The first year of entering waste in the landfill N: The last year of entering waste in the landfill-The first year of entering waste in the landfill

**j**: Intervals of 0.1 years.

**k**: Methane production rate (year).

$\mathbf{L_o}$: Methane production potential ($Mg/m^3$).

$\mathbf{M_i}$: The amount of the waste accepted by the landfill site in the year i (Mg).

$\mathbf{t_{ij}}$: The lifetime of the j waste section has been accepted, in the year i.

**Assumptions and Default values for the LANDGEM model**

**The $CH_4$ generation rate constant (K):** It is the rate of waste decay and $CH_4$ production, also known as the Refuse Decay Rate Constant or $CH_4$ Generation Constant (per year). It was determined based on USEPA (2004) provided in Equation 5.

$$\mathbf{k = 3.2 \times 10^{-5} (R) + 0.01} \quad (5)$$

where, **R**: average annual precipitation in mm. The values of K for the LAUTECH Campus are computed in Table 1. From the linear forecast of available data for rainfall in the River Ogun-Osun basin for the years 1982–2012. The geographical closeness of the data area and the study area made it reasonable to assume that the rainfall levels would exhibit comparable trends because there are often similarities in climate patterns and weather systems of close areas. Therefore, an average rainfall of 24mm was used.

**Table 1: Methane generation potential and methane generation rate**

| Dumpsite | $K(y^{-1})$ | $L_o(m^3/Mg)$ |
|---|---|---|
| LAUTECH, Ogbomoso | 0.018 | 0.021 |

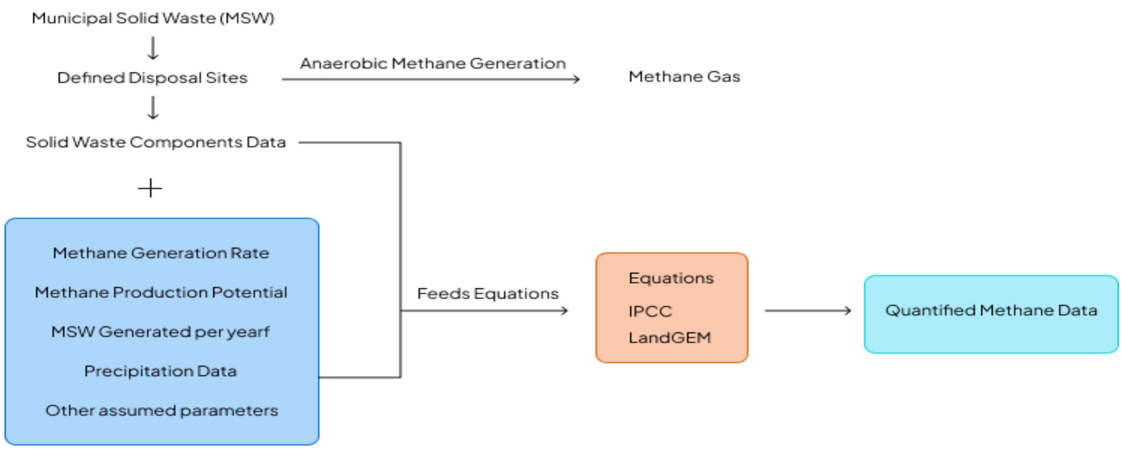


**Figure 1: Methodology flow chart**

**$CH_4$ Generation Potential ($L_0$):** It is the amount of $CH_4$ ($m^3$) generated per Mg of MSW decomposed and is a function of moisture content and organic content of the refuse and depends on waste composition (% wet basis). Noteworthy that it is often site-specific, it was taken as $0.6m^3/Mg$ (default value) in this study. The schematic of the methodology is shown in Figure 1

## RESULTS

### Solid Waste Component

The component of solid wastes at the dumpsites located within the campus revealed that the composition by weight of nylon, plastics, paper, food wastes, flowers/dry leaves and other dirt was tens of thousands of grams sum. When combined with other categories, it gave 98,583.55g of total waste. From Figure 2, Nylon contributed most to the waste generated value having 15,136.2 g, a 19% percentage of the whole followed by Plastics (15%), Paper (15%), Food Waste (14%), Flowers/Dry Leaves (13%) then others (43%).

### Rate of Generation of Solid Waste

The total solid waste determined for the study area was obtained from the Civil Engineering Department, LAUTECH provided data for four years of 2019-2023 and was used to project the amount of municipal solid waste expected in the forecast years 2024-2053. The rate of solid waste generated using a graphical estimation technique is shown in Figure 3.

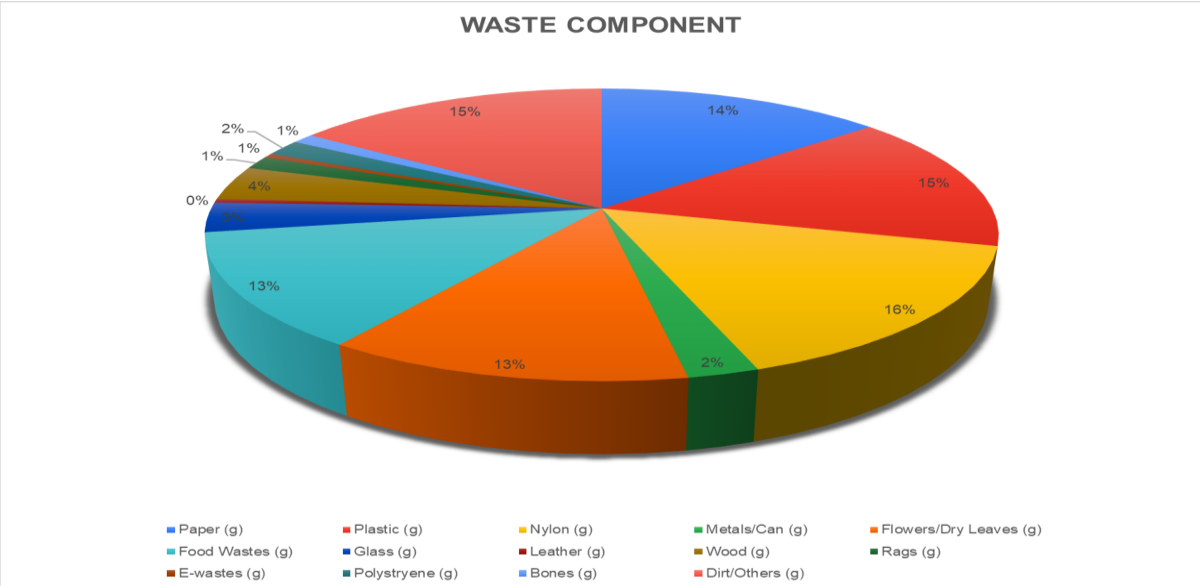


Figure 2: Waste composition chart

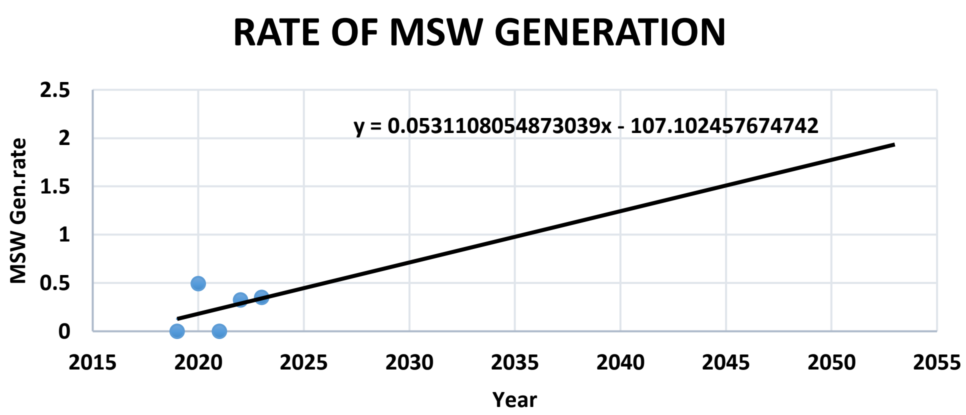


Figure 3: Graph of MSW Generation Rate

**Population forecast**

The product of the population value of each year by the average waste per capita values was used to determine the amount of waste generated for the study years. Figure 4 shows the available population data and population estimate for the forecast years using statistical linear forecast.

**Solid Waste Generated**

The overall solid waste generated ($MSW_t$) in LAUTECH over the entire study was estimated as an evaluation of the product of per capita generation of waste (for a selected year) and the population of the city (for the same year). The amount of solid waste generated is represented on a graph shown in Figure 5.

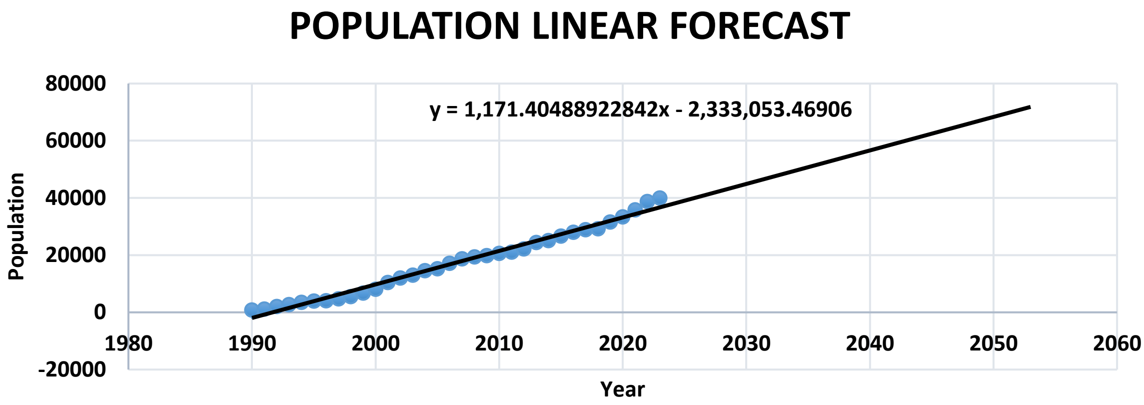


Figure 4: Graph of Population forecast

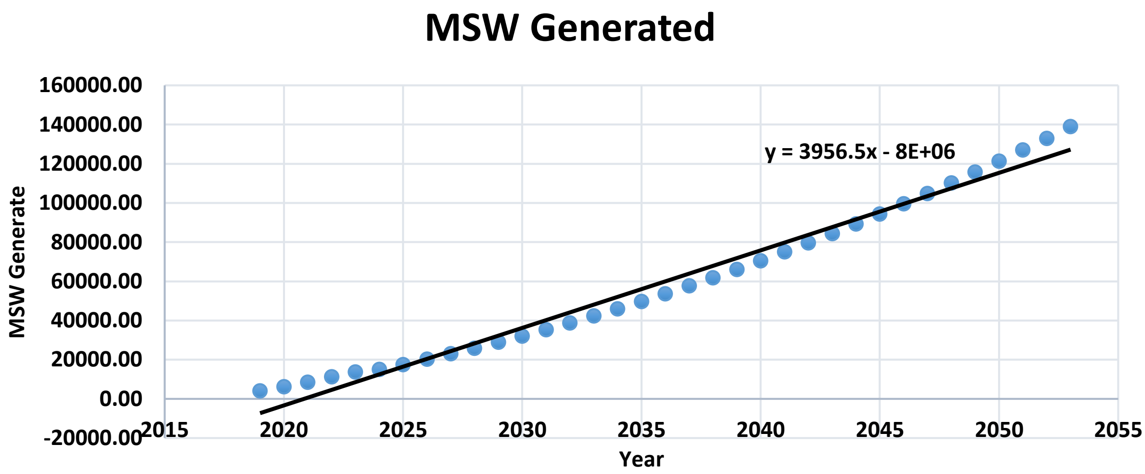


Figure 5: Graph of total MSW generated

**Methane emission estimation**

The values for the IPCC Default Method ranged from 1.2217E-05 Mg/year in the year 2023 which would peak to 1.5617E-04 Mg/year in the year 2053, and a gradual linear increase between the two ends, whereas using the Landfill Gas Emission Model Version 3.02 method, the methane emission ranged from 4.432E-09 Mg/year in the year 2023, which would peak to 3.877E-07 Mg/year in the year 2053, and would drop to 4.913 Mg/year in the year 2159, reflecting a variation.

**Discussion**

The result of the solid waste component agrees with (Adeniran *et al*, 2017) who reported that nylon and plastic packaging represents the largest stream of waste generated on campus. The population peaked at the end of the study year, 2053, with 40,000 people as the quantity of solid waste generated.

Table 2: Annual Methane Emission using IPCC Default Method and Landfill Gas Emission Model Version 3.02 (2012-2031)

| Year | IPCC DM Methane Emissions (Mg/Year) | LandGEM Methane Emissions (Mg/Year) |
|---|---|---|
| 2019 | 3.2557E-06 | 0 |
| 2020 | 5.7211E-06 | 6.184E-10 |
| 2021 | 7.6084E-06 | 1.532E-09 |
| 2022 | 9.9058E-06 | 2.786E-09 |
| 2023 | 1.2217E-05 | 4.432E-09 |
| 2024 | 1.3483E-05 | 6.423E-09 |
| 2025 | 1.5907E-05 | 8.572E-09 |
| 2026 | 1.8483E-05 | 1.106E-08 |
| 2027 | 2.1216E-05 | 1.391E-08 |
| 2028 | 2.4107E-05 | 1.713E-08 |
| 2029 | 2.7159E-05 | 2.073E-08 |
| 2030 | 3.0375E-05 | 2.472E-08 |
| 2031 | 3.3759E-05 | 2.911E-08 |
| 2032 | 3.7312E-05 | 3.391E-08 |
| 2033 | 4.1038E-05 | 3.914E-08 |
| 2034 | 4.4939E-05 | 4.536E-08 |
| 2035 | 4.9019E-05 | 5.146E-08 |
| 2036 | 5.3279E-05 | 5.801E-08 |
| 2037 | 5.7724E-05 | 6.503E-08 |
| 2038 | 6.2355E-05 | 7.253E-08 |

| | | |
|---|---|---|
| 2039 | 6.7177E-05 | 8.051E-08 |
| 2040 | 7.2190E-05 | 8.899E-08 |
| 2041 | 7.7399E-05 | 9.797E-08 |
| 2042 | 8.2806E-05 | 1.075E-07 |
| 2043 | 8.8414E-05 | 1.175E-07 |
| 2044 | 9.4226E-05 | 1.280E-07 |
| 2045 | 1.0024E-04 | 1.391E-07 |
| 2046 | 1.0647E-04 | 1.507E-07 |
| 2047 | 1.1291E-04 | 1.629E-07 |
| 2048 | 1.1957E-04 | 1.757E-07 |
| 2049 | 1.2644E-04 | 3.402E-07 |
| 2050 | 1.3353E-04 | 3.51E-07 |
| 2051 | 1.4085E-04 | 3.626E-07 |
| 2052 | 1.4840E-04 | 3.748E-07 |
| 2053 | 1.5617E-04 | 2.3394E-01 |

The population peaked at the end of the study year, 2053, with 40,000 people as the quantity of solid waste generated. A total of 138941.1g of waste was generated in one week in June 2023. The emission estimates calculated with the two methods of the IPCC Default Method and the Landfill Gas Emission Model Version 3.02 method show that the two methods produced different results. The values were way lower than those of similar studies, and the graph trends show a tendency to increase emissions as the university's population grows and various kinds of solid waste increase. This study noted that the sites do not strongly possess landfills, but methods for estimating emissions from landfills were used, which means there might have been slight inaccuracies in landfill assumptions.

Having compared various models for methane emission from various landfill sites in other reports, the conclusion has been reached that the LandGEM model estimated methane emission with better accuracy compared to other models. As the LAUTECH open dump site produces little value of $CH_4$ and does not contribute to higher $CH_4$ emissions, there is a tendency for high values of $CH_4$ emissions in the future, according to results obtained by the IPCC method.

## CONCLUSIONS

This study explained the process of estimating methane emissions, a greenhouse gas, from open dump sites that are assumed to be landfills using the LandGEM and IPCC models of LAUTECH, Ogbomoso. The results obtained from these models showed an increasing linear trend in population, waste generation rate, waste generated, and methane emission quantities. The determined trend provides predictions, and it is useful to inform the school's policymakers so they can create awareness or improve their waste management system before the emissions harm the environment. For increased quality of information, it is recommended that further studies be carried out to provide methane-specific properties of the solid waste generated at LAUTECH University and other institutions of higher learning to build data on methane emission and its parameters.

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