Estimation of greenhouse gas emissions from Muhammad wala open dumping site of Faisalabad, Pakistan

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ABSTRACT

Landfills and open dumping sites around the world are adding to the global warming issue. This is because of the existence of the main greenhouse gases in landfill gas (LFG); namely, methane (CH₄) and carbon dioxide (CO₂). The current study was focused on the determination of air emissions from the Muhammad wala dump site. This site was constructed in 1992 and expected to have lifespan of 28 years. Utilizing LandGEM software, the landfill emissions were estimated with taking into consideration the 60% content of methane, the methane generation rate constant of 0.02125 year⁻¹, and methane generation potential capacity constant of 23.25 m³/Mg. The outcomes of this study indicated that the maximum volume of emitted gas is at the next year after the site closure (2021). It was estimated that total volume of LFG, methane, carbon dioxide, and non-methane organic compounds were 2.257 × 10⁸, 1.354 × 10⁸, 9.026 × 10⁷, and 5.416 × 10⁵ m³/year, respectively.

1. Introduction

These days, one of the major environmental issue facing our world is climate change. In this regard, the developing nations are confronted with the most noteworthy harm and dangers. Mismanagement of solid waste is among the major reasons of climate change. Today, there is a worldwide attention to emission of greenhouse gases (GHG) from municipal solid waste treatment and disposal processes as among the main sources of anthropogenic emissions (Kreith & Tchobanoglous, 2002; Tian et al., 2013). Developing countries were accountable for 29% of GHGs emissions in 2000. This quantity is anticipated to be 64 and 76% in 2030 and 2050, respectively. Landfill sites are one of the main reasons of such increase (Tian et al., 2013). Global warming is caused mainly due to the increase in GHG concentration in the atmosphere. Collectively, methane (CH₄), carbon dioxide (CO₂), nitrous oxide (N₂O), and chlorofluorocarbons are called GHG (Hardy, 2003). Methane emission from landfills caused by degradation of organic matter is a major contributor to the greenhouse effect (Scharff, Manfredi, Tonini, & Chris, 2009). Atmospheric methane concentration has been increasing in the range of 1–2% per year (Solomon et al., 2007). The quantity of methane in the atmosphere has doubled during the last 200 years and this boom, keeps, despite the fact that at a slower pace (Kamalan, Sabour, & Shariatmadari, 2011).

In terms of global warming potential (GWP), methane has 25–30 times more effective than CO₂. It is also estimated that the quantitative contribution of CH₄ is about 18% and it has the second rank among GHGs (Aydi, 2012; Georgaki et al., 2008; Nolasco, Lima, Hernández, & Pérez, 2008). The waste sector is a significant contributor to GHG emissions, accountable for approximately 5% of the global greenhouse budget (Eggleston, Buendia, Miwa, Ngara, & Tanabe, 2006).

It is also estimated that 3.8% of the GWP in the United States is related to methane emissions from landfill sites (Chalvatzaki & Lazaridis, 2010). In Europe, 30% of anthropogenic sources of methane emissions are from landfill sites (Georgaki et al., 2008). Anaerobic decomposition of wastes in landfills by micro-organisms under suitable conditions leads to GHGs emission. Measurement of the emission rate of GHGs from landfill is essential to reduce uncertainties in the inventory estimates from this source.

Gas production normally starts 2–6 months after internment of the wastes and continues as much as 100 years. Landfill gas (LFG) typically consists of 45–60% methane (CH₄) and 40–60% carbon dioxide (CO₂). It also include small amounts of nitrogen (N₂), oxygen (O₂), ammonia (NH₃), hydrogen sulphide (H₂S), hydrogen (H₂), carbon monoxide (CO), and non-methane organic compounds (NMOCs) such as trichloroethylene, benzene, vinyl chloride (Aydi, 2012; Saral,
Demir, & Yildiz, 2009). Several mathematical models have been evolved among which, LandGEM model is the most bendy one (Bove & Lunghi, 2006). United State Environmental Protection Agency (Alexander, Burklin, & Singleton, 2005) built-up this model; it provides a completely specific estimation of methane quantity produced over numerous years. This model is recognized as an automatic estimation tool for modelling LFG emissions from MSW. The LandGEM estimates the quantity and composition of the generated gas throughout time due to the degradation of organic matter in the landfill (Alexander et al., 2005). The purpose of this study was focused on the estimation of greenhouse gases emissions from Muhammad wala dumpsite over a 28-year time frame using LandGEM, version 3.02.

2. Methodology

2.1. Study area

The dumping site is located at Muhammad wala village near Makkuna Jaranwala road geographically it is situated at 31° 23' 8" northern latitude and 73° 14' 26" eastern longitude at 182.93 m above sea level. This site was constructed in 1992 and its area is 50 acres. And this site is at distance of 15 km approximate from Faisalabad. The collected waste is currently being disposed of at “Muhammad wala” dump site without any soil cover.

This site has been used since last 25 years and expected to close in 2020. The city is still deprived of a sanitary landfill. Waste remains uncovered and leachate generated from this waste seeps through the soil and contaminates ground water. No gas collection system and composting plant. For the purpose of waste transfer and transport tractor trolleys, dumper trucks, mini tippers, arms rolls are used. Vehicles are dependent on physical layout of roads and cost of manpower available. These vehicles are loaded both by manual loading and tractor loader. Use of tractor loader is an inefficient, time consuming, and produces health concerns.

2.2. Description of LandGEM

The LFG emissions model is a modelling tool for quantifying uncontrolled emissions of various compounds present in the LFG over a time period, from municipal solid waste Landfills (Paraskaki & Lazaridis, 2005). It is developed by the Control Technology Centre of the American Environmental Protection Agency. The mode determines the mass of methane generated using the methane generation capacity and the mass of waste deposited. LandGEM is based on a first-order decomposition rate equation given below by (1) (Alexander et al., 2005).

$$Q_{\text{CH}_4} = \sum_{i=1}^{n} \sum_{j=1}^{1} kL_0 M_i e^{-kt_{ij}} \quad (1)$$

where, $Q_{\text{CH}_4}$ = annual methane generation in the year of calculation (m³/year); $I$ = the yearly time increment; $N$ = the difference (year of the calculation) – (initial year of waste acceptance); $J = 0.1$-year time increment; $K = $ the methane generation constant (year⁻¹); $L_0$ = the potential methane generation capacity (m³/Mg); $M_i$ = the mass of waste in the $i$th year (Mg); $t_{ij}$ = the age of the $j$th section of waste $M_i$ accepted in the $i$th year (decimal years).

To conduct our study, the required inputs for estimating the amount of generated LFG are the landfill opening year, the landfill closure year, the annual waste acceptance rates from the opening to the closure year, the methane generation constant $k$, the potential methane generation capacity $L_0$, NMOC concentration, and methane proportion in the biogas.

2.2.1. Model parameters

2.2.1.1. Methane generation constant ($k$). Organic waste is composed primarily of cellulose, lignin, hemicelluloses, and protein. These components (with the exception of lignin) are also the main components converted to methane via physical, chemical, and biological processes (Reinhart & Barlaz, 2010). The degradation rates of cellulose and lignin vary considerably under landfilling conditions; for example, lignin is thought to be recalcitrant under anaerobic conditions. There are optimal ranges of temperature and pH for micro-organism activities in the waste (Mehta et al., 2002). Also, moisture content affects the methane generation by providing better contact conditions among micro-organisms (Barlaz, Staley, & de los Reyes III, 2009)

$k$ values in the open literature generally range from 0.01 to 0.21 year⁻¹ with 0.04 year⁻¹ being a commonly applied value. But values of 0.3 and 0.5 year⁻¹ have also been reported under specific conditions such as for bioreactor operating landfills or rapidly degradable fractions of waste (Faour, Reinhart, & You, 2007). Default values for $k$ are shown in Table 1. Site-specific values can be introduced using the Equation (2).

$$k = 3.2 \times 10^{-5} \text{(annual mean rain fall)} + 0.01 \quad (2)$$

Average annual rainfall is approximately 375 mm (14.8 in) and highly seasonal. It is usually at its highest in July and August (Asghar Cheema, Farooq, Rashid, & Munir, 2006) during monsoon season, with a highest value of 264.2 mm (10.40 in) was recorded on 5 September 1961 (Pakistan Meteorological Department, n.d.). Putting the average annual rainfall value into the Equation (2) we get

| Emission type | Landfill type       | $k$ (year⁻¹) |
|---------------|---------------------|--------------|
| Clean Air Act | Conventional        | 0.05 (default) |
| Clean Air Act | Arid area           | 0.02         |
| Inventory    | Conventional        | 0.04         |
| Inventory    | Arid area           | 0.02         |
| Inventory    | Wet (bioreactor)    | 0.07         |
2.2.1.2. Potential methane generation capacity \( (L_0) \). The potential methane generation capacity \( L_0 \) depends mainly on the nature of waste disposed in the landfill. The \( L_0 \) value will be greater for waste containing a lot of cellulose. The five \( L_0 \) values given for household waste are given in Table 2.

\[
L_0 = \text{DOC} \times \text{DOC}_F \times \text{MCF} \times F \times 16/12
\]  

(3)

Some assumptions and calculation for the parameters in Equation (3) are discussed below.

2.2.1.3. Degradable organic carbon \( (DOC) \). For the estimation of degradable organic carbon, IPCC Guidelines provide the following equation:

\[
\text{DOC} = 0.4 \times (A) + 0.17 \times (B) + 0.15 \times (C) + 0.3 \times (D)
\]  

(4)

where \( A \): fraction of paper and textiles; \( B \): fraction of garden waste and park waste or other non-food organic putrescible; \( C \): fraction of food wastes and \( D \): fraction of MSW as wood or straw. Where values for DOC related to \( A, B, C, \) and \( D \) are as presented in Table 3.

2.2.1.4. \( DOC_F \). This factor is based on a theoretical model where the variation depends on the temperature in the anaerobic zone of the landfill and can be calculated as “EPA LandGEM Guide (2005)”:

\[
\text{DOC}_F = 0.014 \times T + 0.28
\]  

(5)

where \( T \) is the temperature. The normal temperature in that area is 24.5 °C. Putting the normal temperature value into Equation (5) we get

\[
\text{DOC}_F = 0.014 \times 24.5 + 0.28 = 0.623 \times \frac{\text{Mg C decomp}}{\text{Mg C}}
\]

2.2.1.5. \( F \) – Fraction of \( \text{CH}_4 \) in LFG. LFG from undisturbed solid waste disposal site (SWDS) zones in the main anaerobic phase has a composition of mainly \( \text{CH}_4, \text{CO}_2 \) and a large number of trace components, normally accounting for less than 1% of volume. Various sources operate with a \( \text{CH}_4 \)-content in LFG between 50 and 60%, and the default value in the IPCC Guidelines is 50%. It is assumed as 0.6 for \( \text{CH}_4 \) for Muhammad wala dump site.

2.2.1.6. 16/12. Conversion of \( C \) to \( \text{CH}_4 \).

2.2.1.7. \( \text{CH}_4 \) correction factor (MCF). It assumes that unmanaged SWDS yields less \( \text{CH}_4 \) than the managed one. In the former, a large fraction of waste in the top layer undergoes aerobic decomposition and therefore, MCF of solid SWDS varies with the site conditions and management techniques used (Kumar, Mondal, Gaikwad, Devotta, & Singh, 2004). MCF for different category of SWDS is given in Table 4. Since the Muhammad wala landfill is a shallow unmanaged site, the MCF is assumed as 0.4. The MCF for different category of SWDS is given in Table 4. These values are as per IPCC guideline for National Green House Inventory.

Incorporating the above values with a unit mass of 1 Mg, \( L_0 \) can be calculated using Equation (3).

\[
L_0 = \frac{0.0836 \times \text{Mg C}}{\text{Mg MSW}} \times 0.623 \times \frac{\text{Mg C decomp}}{\text{Mg C}} \times 0.6 \times 16 \cdot \frac{\text{mol}}{\text{mol}} \times \frac{0.0166 \times \text{Mg CH}_4}{\text{Mg MSW}}
\]

This raises an important issue regarding the calculation of LFG quantity. While IPCC has adopted a mass/mass definition of \( L_0 \), landfills continue to measure LFG in volume. Using the STP density of methane (0.714 kg/m³) the mass of methane per mass of waste can be calculated as a volume per mass of waste.

\[
L_0 = \frac{0.0166 \times 1000}{0.714} = 23.25 \text{ m}^3 / \text{Mg}
\]

2.2.1.8. NMOC concentration. The concentration of NMOC varies with the type of waste. Applying the default values of the model, it can be 600 ppmv for landfills containing only household waste and 2400 ppmv for those receiving both household waste and other types of waste (Alexander et al., 2005). Up until 2016, Muhammad wala open dump site received all types of waste so we have chosen a NMOC concentration of 2400 ppmv.

3. Result and discussion

3.1. Population and waste generation scenario of Faisalabad

The population growth rate of Faisalabad city was quite high amid 1940s–1970s. That was the period amid which population was growing at a high rate, due to the exodus in movement from India following autonomy. The 1981 Census demonstrates moderate growth which was extremely astounding to numerous demographers and

| Emission type | Landfill type | \( L_0 \) value (m³/Mg) |
|---------------|--------------|-----------------------|
| Clean Air Act | Conventional | 170 (default)         |
| Clean Air Act | Arid area    | 170                   |
| Inventory    | Conventional | 100                   |
| Inventory    | Arid area    | 100                   |
| Inventory    | Wet (bioreactor) | 96                   |
The Ministry of Environment and Urban Affairs Division, Government of Pakistan undertook a study during 1996 on "Data Collection for Preparation of National Study on Privatization of Solid Waste Management in Eight Selected Cities of Pakistan." The examination uncovered that the rate of waste generation by and large from all kinds of city controlled zones fluctuates from 0.283 to 0.613 kg/capita/day. This study shows that the rate of waste generation in Faisalabad was 0.391 kg/capita/day. Basic Survey of Municipal Solid Waste Management in eight major cities of Pakistan shows that the rate of waste generation is 0.45 kg/capita/day (JICA Report, 2010). The present populace of Faisalabad is 3.5 million and around 1600 tons of MSW is generated in the city consistently. Faisalabad Waste Management Company (FWMC) is now working at a collection rate of 45–63% while before the foundation of FWMC, the City District Government Faisalabad was working at the collection rate of 40%. Annual waste Acceptance rate by Muhammad wala open dump site is given in Table 5.

3.2. Estimation of LFG emissions

The estimation via LandGem model is displayed in Figure 1. The landfill site has nearly achieved its maximum capacity so it is normal that there will be no waste store after 2020. The first year of waste deposit the model assumes that there is no biogas production. For sure, in the literature, it is stated that the methanogenesis step begins at least 2–6 months after tipping of waste. Waste degradation depends on many factors: type of waste, moisture in the waste, climatic conditions, material which covers the waste, etc. To simplify the computations, the LandGEM does not take into account all these parameters to establish the beginning of methanogenesis and considers that after a year, all criteria are met for the start of this step.

As per the model yields, the dumping site has produced $7.359 \times 10^{4}$ m$^3$/year of biogas in 1993 incorporating $4.415 \times 10^{4}$ m$^3$/year of CH$_4$ and $2.944 \times 10^{4}$ m$^3$/year of CO$_2$. Throughout the years, the production of biogas would develop until the point during 2021 when we record the greatest biogas generation rate with $4.289 \times 10^{6}$ m$^3$/year. As saw in all investigations utilizing this model, the maximum production occur one year after the closure of the landfill. After 2021, the generation of biogas decreases exponentially. This rapid reduction in biogas production is clarified by the fact that there are lesser and lesser waste to degrade. As per LandGEM, the site should have produced between 1992 and 2132 at least $4.415 \times 10^{4}$ m$^3$/year of CH$_4$. It was assessed that total volume of LFG, CH$_4$, CO$_2$, and NMOC were $2.257 \times 10^{8}$, $1.354 \times 10^{8}$, $9.026 \times 10^{7}$, and $5.416 \times 10^{6}$ m$^3$/year, respectively. Annual GHGs emission produced between 1992 and 2024 calculated by LandGEM model is shown in Table 6.
from 7.359 \times 10^{+04} \text{ (m}^3/\text{year}) \text{ in 1993, first year after waste acceptance while the} \text{ greatest biogas generation rate occurred during 2021 where show as the peak of generation by around 4.289 \times 10^{+06} \text{ (m}^3/\text{year}). \text{ On the premise of data introduced above, it can be said that} \text{ the volume biogas of produced from solid waste has significant effect on the climate of Faisalabad.}

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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