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Estimation of Methane from Municipal Solid Waste Landfill

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Abstract
Land filling is one of the most common ways of municipal solid waste (MSW) disposal in developing countries. Large quantity of methane gas is emitted from no-regulated municipal solid waste landfill to the atmosphere and recognized as an important contributor to global warming. Many researchers have been done with the purpose to estimate the quantity of generated methane gas, capture, utilize and to use of this energy source to produce electricity or heat, since then many models have been developed to calculate landfill gas generation. In this paper the IPCC (Intergovernmental panel for climate change) default model, is presented to estimate emission of methane from municipal solid waste landfill, Addis Ababa, Ethiopia.Obtained result revealed that solid waste generation rate increased from 731,738 m3 in 2003 to 1,022,814 m3 in 2012. The quantity of waste generated in Addis Ababa is increasing this is because of rapid population growth and urbanization. Between the years 2003 and 2012, the population of Addis Ababa City raised from 3,015,498 to 4,218,278. Similar trend was observed for estimated Net Annual methane emission value. The estimated Net Annual methane emission value from solid waste landfills was 7.11 (Gg yr-1) in 2003, while the maximum methane production rate by the IPCC default model was calculated to be 9.98 (Gg yr-1) and was observed during the year 2012 . It can be assumed that, the increased volume of generated methane from increased solid waste in this landfill is sufficient enough to be considered for new standard landfill site construction with methane capturing facilities. Stabilization of methane emissions has an immediate impact on national energy security and mitigating potential climate change.
Keywords: Global warming; Methane; Municipal Solid Waste; Climate change, IPCC default model

1. Introduction

A substantial amount of methane is emitted by waste decaying in landfills. Methane is the second most important anthropogenic greenhouse gas. Methane gas release from landfill is a serious threat to our environment as its global warming potential is more than 20 times of that of carbon dioxide (CO2) and atmospheric methane concentration has been increasing in the range of 1–2% yr^{-1} [1].

On a kilogram-to-kilogram basis, methane is a more potent greenhouse gas than CO2 [2]. Methane has a shorter atmospheric lifetime than other greenhouse gases. Methane lasts for around 11 years in the atmosphere, whereas CO2 lasts for about 120 years [3]. Due to methane's high potency and short atmospheric lifetime, stabilization of methane emissions will have an immediate impact on mitigating potential climate change [4].

Waste landfills have been recognized as the large source of anthropogenic methane emission and an important contributor to global warming [1]. Methane emission from landfill is estimated to account for 3–19% of the anthropogenic sources in the world [1].

At gaseous concentrations of 5 to 15 percent, methane is explosive. Thus the buildup of methane in landfills and sewage poses a serious safety hazard. Increased use of degasification systems may improve safety by lowering the methane level [5].

Landfill gas is produced continuously by microbial action on biodegradable wastes under anaerobic conditions [6]. Methane and carbon dioxide are the major constituents of landfill gas and greatly contribute to the greenhouse effect [7].

But unfortunately solid waste (SW) management and the maintenance of record in this respect is at infant stage in Ethiopia. Solid waste management is in crisis in many of the world's largest urban areas as populations attracted to cities continues to grow and this has led to ever increasing quantity of domestic solid waste while space for disposal decrease [8].

The potential of solid waste for methane capturing is recognized in reducing the potential of GHG emissions while utilizing methane gas for power generation. In this regard, it is important to estimate the potential methane emission or generation from the landfills and disposal sites. The methane is generally used as a source of energy in various parts of the world [9, 10]. Utilization of biogas, environmentally sound eliminates the emission of CH4, one of the two greenhouse gases emitted which is about 20 times more dangerous than carbon dioxide for the greenhouse effect [11]. Methane emission reduction strategies offer one of the most effective means of mitigating global warming.

In many countries, especially the developing economies of the world, the available data on waste generation are not consistent, leading to a large uncertainty in the estimates. The main objective of this paper is to quantify methane emissions that may be generated from landfills in Addis Ababa for the period 2003-2012 and recommend possible methane abatement strategies. IPCC default method (DM) is used for the estimation of methane potential from the disposal sites.

2. Methodology

2.1 Description of the study area

Geographically, Addis Ababa is located between 8055'and 90 0 5'N Latitude and 380 40' and 38050' E Longitude. The city is located at the center of Ethiopia with an area of 540 km2 of which 18.174 m2 is rural and its altitude ranges from 2000 masl - 2800 masl [12].

There are 10 sub-cities (*Kifle ketema*) and about 99 kebeles [12]. The household size are 7.6, 6, 5 persons per household in lower, middle, and higher income families respectively [15]

The Addis Ababa landfill site "Repi" landfill site is located in the south-western expansion areas of Addis Ababa in Lafto-Nifas-Silk Kifleketema (Sub-City). In 1960s, the site was considered to fall outside the city''s master plan since it was inhabited by only a few farmers. The municipal administration of Addis Ababa started to use the site in 1964. Even though it has been the only solid waste disposal site for nearly 50 years, there is still no documented information regarding the site's feasibility, geological and hydrological conditions, lifespan, and possible impacts on the local environment. The Repi dump site which has an area of 36.4 hectare located at 13 km from the city center in south western direction.

2.2. Models for methane production from landfills

The IPCC Guidelines describe two main methods:

(A): The default IPCC methodology that is based on the theoretical gas yield (a mass balance equation).

(B): Theoretical first order kinetic methodologies, through which the *IPCC Guidelines* introduces the "First order decay model" (FOD).

The main difference between the two methods is that method A does not reflect the time variation in SW disposal and the degradation process as it assumes that all potential methane is released the year the SW is disposed. The timing of the actual emissions is reflected in method B. Only if the yearly amounts and composition of waste disposed as well as disposal practices have been nearly constant for long periods, the method A will produce fairly good estimates of the yearly emissions. Increasing amounts of waste disposed will lead to an overestimation, and decreasing amounts correspondingly to underestimation, of yearly emissions. Method B gives a more accurate estimate of the yearly emissions. Many countries may, however, have problems getting the necessary data and information (historical data on SW disposal, rate constant for the decay) to establish the proper basis for emission inventories with acceptable accuracy.

Among the available methods, the simplest one for the estimation of methane emissions from landfills is based on mass balance approach, i.e. the default methodology. This method was developed by Bingemer and Crutzen [16] and is being used in the revised IPCC [1] guidelines as the default methodology for estimating methane emissions from solid waste disposal sites. The detailed methodology for estimation of methane emissions from solid waste disposal sites is explained in further detail below. A number of empirical constants, like methane correction factor, DOC, dissimilated organic fraction converted into LFG, have been considered while developing the default methodology and accordingly the emissions are calculated. Though IPCC has claimed that the default methodology provides reasonable annual estimate of actual emissions and this has been widely used in the situations where detailed data are not available, but it may not provide realistic estimate as it is assumed that all potential methane is released in the year the waste is disposed of.

IPCC Model / IPCC default method

According to IPCC Guidelines, the formula for calculating GHG emission from solid waste landfills is as follows [4, 14].

EMethane = Methane emissions (Gg/yr) = (MSWT ● MSWF ● MCF ● DOC ● DOCF ● F ● 16/12-R) ● (1-OX)

EMethane = MSWT x MSWF x DOC x MCF x **(**16/12) x 0.5

Where:

ECH4 = Methane emission from landfills.

MSWT = Total MSW generated (Gg/yr).

MSWF = Percentage of urban waste actually land filled; in this paper MSW equals the quantity of urban waste sent to landfills, so MSWF = 70%. The remaining 30% is assumed to be lost due to recycling, waste burning at source as well as at disposal site, waste thrown into the drains and waste not reaching the landfills due to inefficient solid waste management system

MCF = methane correction factor (fraction) = Three default values ranging from 1.0 to 0.4 are included, depending on the site management and with 0.6 as general default value

DOC = degradable organic carbon (fraction) (kg C/ kg SW) = Content of degradable organic carbon in the waste, recommended to be 15% by IPCC.

DOCF : fraction DOC dissimilated = Percentage of actually decomposed DOC in the waste (recommended to be 77% by IPCC)

F = fraction of CH4 in landfill gas (IPCC default is 0.5)

16/12 = conversion of C to CH4
R = recovered CH4 (Gg/yr)
OX = oxidation factor (fraction – IPCC default is 0)
The method assumes that all the potential CH4 emissions are released during the same year the waste is disposed of. The method is simple and emission calculations require only input of a limited set of parameters, for which the IPCC Guidelines provide default values, where country-specific quantities and data are not available.

3. Result and Discussion
Population and solid waste generation Dynamics
Landfilling is one of the most common ways of municipal solid waste (MSW) disposal in Ethiopia .Percentage of urban waste actually land filled; the quantity of urban waste sent to landfills was70 percent so MSWF(fraction) = 70%. The remaining 30% is assumed to be lost due to recycling, waste burning at source as well as at disposal site, waste thrown into the drains and waste not reaching the landfills due to inefficient solid waste management system. The estimated solid waste volume generated in ten years (2003—2012) and the population dynamics is summarized below.

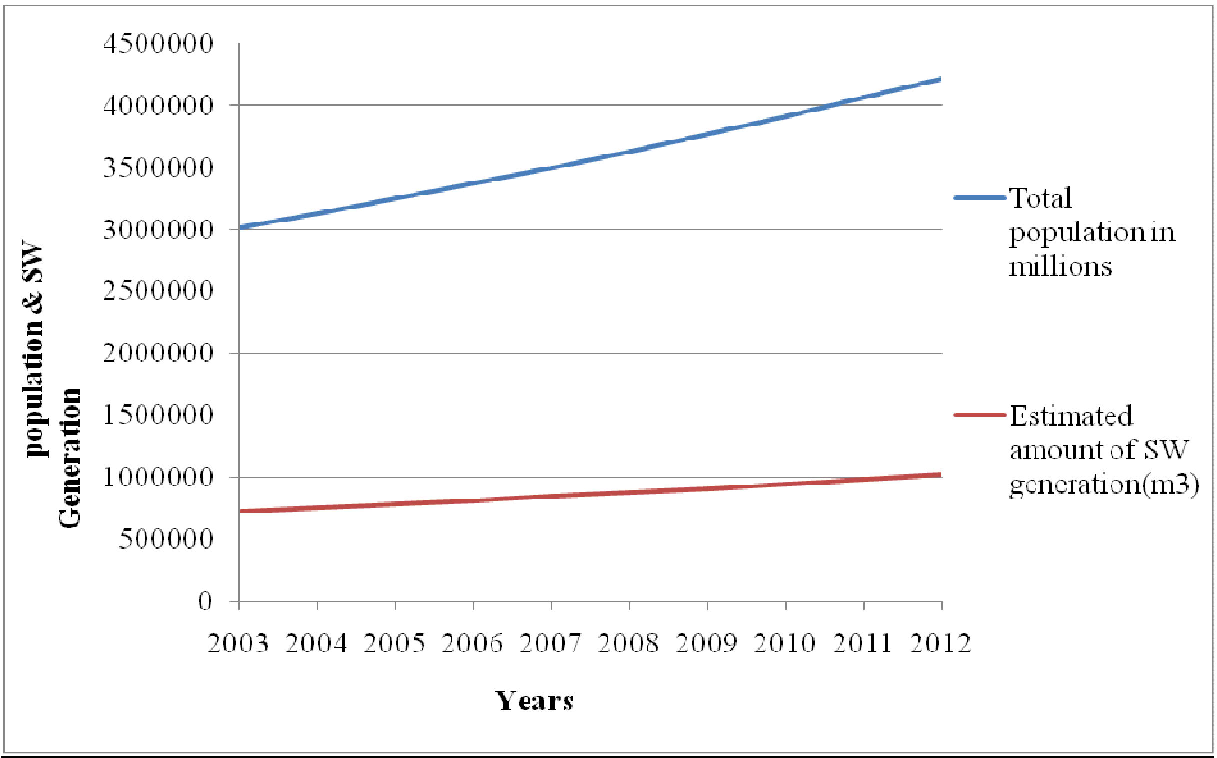

Figure1: Population and SW generation dynamics (2003 to 2012)
Source: Annual Activity Report of Health Bureau, Addis Ababa,2003 – 2012
For Population Figures CSA, 1994 Census Projection

The given line graph illustrates information on the population and solid waste generation dynamics between 2003 and 2012. As indicated from Figure 1 the population of Addis Ababa City raised from 3,015,498 in 2003 to 4,218,278 in 2012 [13]. In this regard waste generation rate increase from 731,738 m3 in 2003 to 1,022,814 m3 in 2012. The quantity of waste generated in Addis Ababa were increasing this is because of rapid population growth and urbanization. This requires huge financial and manpower resource of municipalities to deal with provision and management of services of solid waste. On the top of this, increasing the quantity of solid waste in an open landfill has led to air and water pollution and decreased availability of landfill space

In order to compute net annual methane emission in Gg the Annual amount of MSW generated in m^3 has to be converted in to the annual amount of MSW generated in Gg the following formula was used from IPCC guideline.

Annual amount of MSW generated (Gg MSW) = Population whose waste goes to SWDSs * MSW generation rate (kg/capita/day) * 365)/10^6 * Fraction of MSW disposed to SWDSs

Table 1: Total Annual MSW disposed to SWDSs (Gg MSW) (2003 to 2012)

Year	Population whose waste goes to SWDSs	MSW generation rate (kg/capita/day)	Fraction of MSW disposed to SWDSs	Total annual MSW disposed to SWDSs(Gg MSW)
2003	3015498	0.2	0.7	154
2004	3130087	0.2	0.7	160
2005	3249030	0.2	0.7	166
2006	3372493	0.2	0.7	172
2007	3500648	0.2	0.7	179
2008	3633673	0.2	0.7	186
2009	3771752	0.2	0.7	193
2010	3915079	0.2	0.7	200
2011	4063852	0.2	0.7	208
2012	4218278	0.2	0.7	216

Based on the above formula the annual amounts of MSW generated in Gg were computed. As indicated in table 1 the annual amount of MSW generated in Gg in 2003 was 154Gg while 216Gg in 2012.

Methane Gas Production

.The estimation of methane emission from municipal solid waste disposal sites for years 2003–2012 in Addis Ababa has been estimated by the default methodology taking the values of methane correction factor as 0.6, fraction of DOC in MSW taken as 0.15, fraction of DOC which actually degrades as 0.77, fraction of carbon released as methane as 0.5, conversion ratio as 16/12, potential methane generation rate as 0.08 and realized methane generation rate per unit of waste as 0.05. The methane emission for different population ranges 7.11Gg in 2003 to 9.98Gg in 2012 as indicated in figure 3. It can be assumed that, volume of generated methane from solid waste in this landfill is sufficient enough to be considered for install the methane capturing facilities.

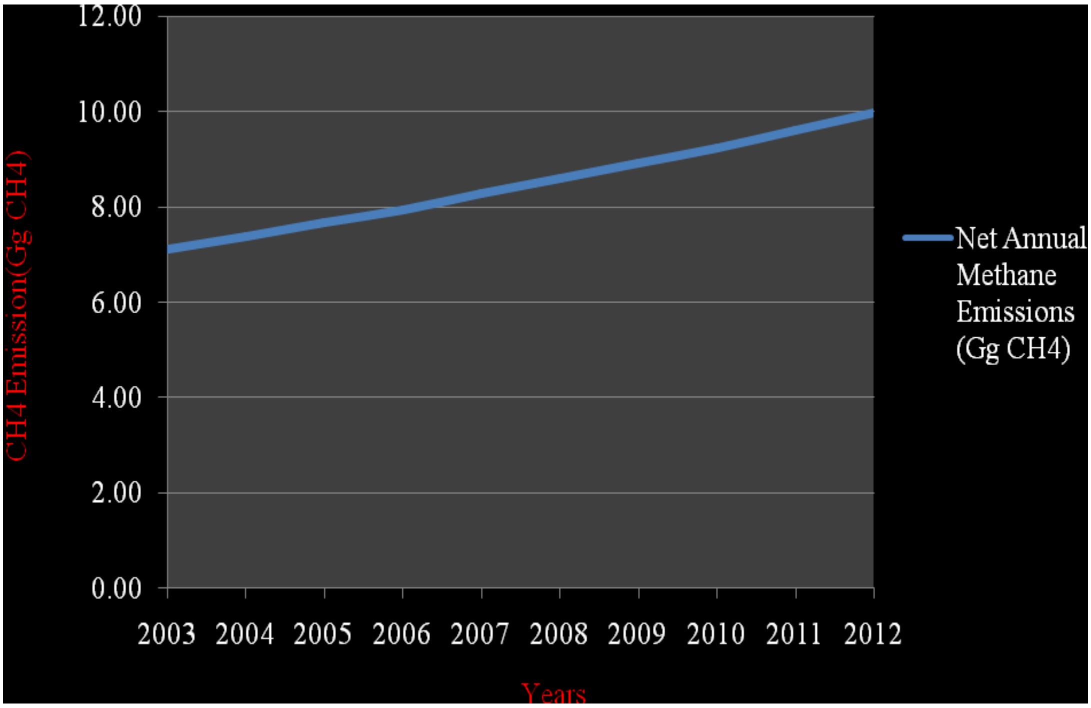

Figure 2: Net annual CH_4 emissions (Gg CH_4) (2003 to 2012)

The above line graph indicates the net annual methane emission value from solid waste landfills estimated using the default methodology between 2003 and 2012. The values estimated using the default methodology indicates that they increase from 2003 to 2012. The assumption made in the default methodology is that the potential methane is emitted in the same years from 2003 to 2012 for which the solid wastes are deposited yearly.

4. Conclusion and Recommendation

Based on the work presented in this study, a number of conclusions have been drawn. In turn,certain suggestions are made for further pursuing the present research effort. The followingparagraphs present the conclusions and recommendations.

The methane emission has been estimated by using IPCC default model for Addis Ababa City, solid waste disposal sites. This landfill starts operation at 2002 with the purpose to receive the generated solid waste at surrounded area until the year 2012.

The quantity of waste generated in Addis Ababa is increasing because of rapid population growth and urbanization. Solid waste generation rate increased from 731,738 m3 in 2003 to 1,022,814 m3 in 2012 while, the population of Addis Ababa City raised from 3,015,498 to 4,218,278. The quantity of waste generated in Addis Ababa is increasing due to rapid population growth (2003 to 2012) and urbanization. Similar trend was observed for the estimated net annual methane emission. Its value from solid waste landfills dramatically increased from 7.11Gg in 2003 to 9.98Gg in 2012

Methane emissions from landfills in Addis Ababa will continue to increase unless necessary measures has been taken

Integrated Solid Waste Management is considered as one of the most effective approach of addressing the environmental degradation and to protect cities in a sustainable manner. Stabilization of methane emissions will have an immediate impact on national energy security and mitigating potential climate change.

Modern techniques for recovering methane from landfills and sewage can significantly reduce the amount of methane. Another option to effectively utilize this untapped resource is to produce energy. Encourage strategic marketing of compost and digestate.

Land filling requires special attention; standard measures should be exercised to control contamination of surface and ground water.

Waste generation is increasing from time to time, as a result the dump site is getting full and beyond the capacity to sink the waste generated. Therefore, new landfill site is urgently needed with proper selection of the site/ environmental impact assessment, construction and methane capturing facilities. The suitable land fill site selection should consider the geology, biodiversity, water bodies, settlement and transportation cost.

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