International Journal of Engineering and Technology Innovation, vol. 3, no. 4, 2013, pp. 279-288

Estimation of Landfill Methane Gas Emissions from the Mallam No.1 and Oblogo No.1 Dumpsites in Ghana

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Received 15 June 2013; received in revised form 09 August 2013; accepted 16 September 2013

Abstract

The purpose of this paper is to estimate the theoretical methane gas emissions from two of the largest abandoned dumpsites in the Greater Accra metropolis from 1991 – 2035 using two first order decay models i.e. the LandGEM and BC MOE LFG generation estimation tool. Generally, the BC MOE LFG generation estimation tool results were slightly higher than those obtained using the LandGEM. However, both models predicted the time of peak production as occurring in 2002 and 2008 for the Mallam No.1 and Oblogo No.1 dumpsites respectively. The total combined peak annual methane production from the Oblogo No.1 and Mallam No.1 dumpsite within the study time frame was estimated to be in excess of 17,000 metric tonnes. The findings of this study seem to suggest that the two dumpsites especially the Mallam No.1 site are fast approaching the stabilization phase where there would be a drastic reduction in gas production.

Keywords: dumpsite, landfill gas, methane gas, Ghana

1. Introduction

Landfilling is one of the most common ways of municipal solid waste disposal in developing countries. Emissions of methane and carbon dioxide from landfill surfaces contribute significantly to global warming or the greenhouse effect. Operating landfills emits more CH_4 than closed landfills since the major part of degradation occurs in the first few years following disposal with decreasing emission rates with time after closure [1]. Following closure, a landfill still continues to emit greenhouse gases, possibly for several hundreds of years [2]. Methane has received recent attention as a contributor to global warming because on a molecular basis, it has a relative effect 20 to 25 times greater than carbon dioxide, it is more effective at trapping infrared radiation and tends to persist longer in the atmosphere owing to other species such as carbon monoxide with a greater affinity for hydroxyl ions, the oxidizing agent for methane [3].

However, the utilization of landfill gas components such as methane for energy generation also provides the opportunity for waste disposal sites to become a potential source of revenue for local government authorities in developing countries like Ghana. Additionally, the capture of LFG would result in the direct and indirect reduction in greenhouse emissions that contribute to climate change [4]. The Greater Accra Metropolitan Area has a number of waste disposal sites that are currently in operation or being earmarked for final closure. These sites could potentially be eligible for consideration for carbon credits under the Clean Development Mechanism in accordance with the Kyoto Protocol [5]. The purpose of this study was focused on the estimation of landfill methane emissions from the Mallam No.1 and the Oblogo No.1 dumpsites over a 45-year time frame using two different computer simulation models.

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2. Study Design

2.1 Description of study area

The Mallam No.1 and Oblogo No.1 dumpsites are located in the Ga South Municipality of the Greater Accra Region in Ghana. Fig. 1 shows the location map of the two disposal sites. The Mallam No.1 dumpsite covers an estimated area of 8.66 hectares and was in operation as the main dumpsite for the Accra Metropolis and peri-urban settlements between July 1991 and May 2001. The Oblogo No.1 dumpsite covers an estimated area of 1.30 hectares and was in operation between January 2002 and July 2007 [6].

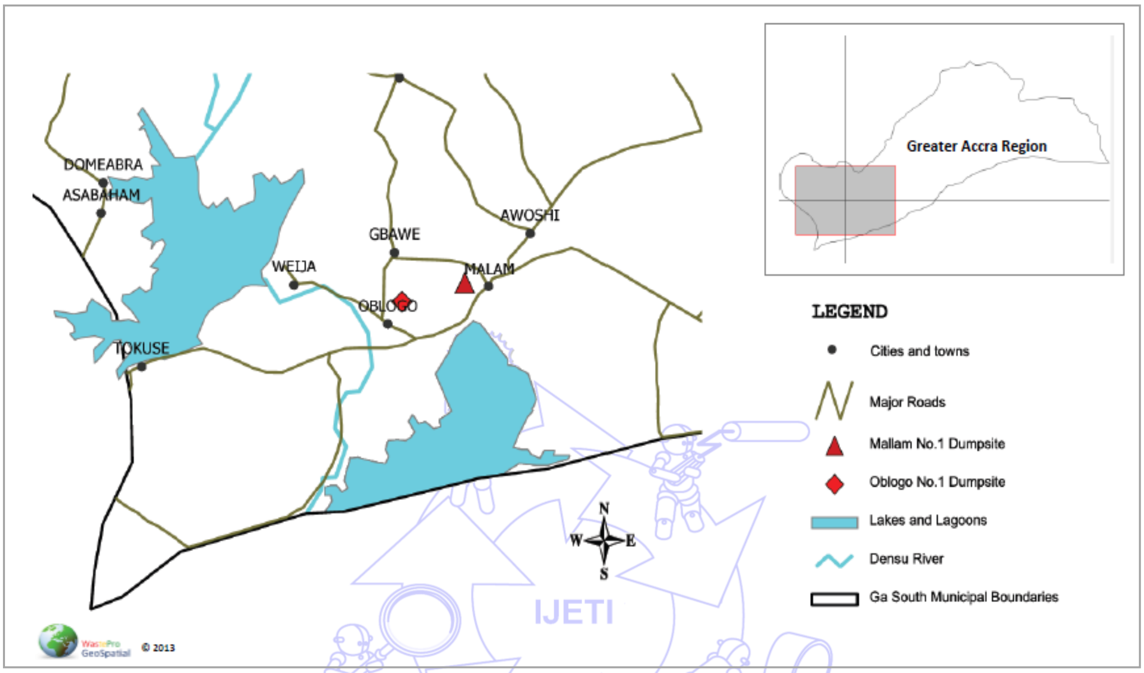


Fig. 1 Location map of dumpsites

Fig. 2 shows Google Earth images depicting the Mallam No.1 and Oblogo No.1 dumpsites respectively. The Ga South Municipality lies in the coastal climatic zone of Ghana. This zone has two rainy seasons with an average annual rainfall of 730-740 mm.

Mallam No.1 Dumpsite | Oblogo No.1 Dumpsite

Fig. 2 Google Earth images of dumpsites

G4ui Rainfall is usually convectional in nature with the highest occurring in the month of June. The hydrogeology of the Ga South Municipality is characterized by shallow groundwater levels and an overburden which consists of either argillaceous or arenous materials. The soils in this geographical belong to the Mamfe-oyarifa and Densu/Chichewere local series that are classified as eutrostox oxisols [6]. The two dumpsites are located within the catchment of the Densu River Basin which is the main source of water supply for western suburbs of the Accra metropolis.

Table 1 Site specific conditions at the Oblogo No.1 dumpsite

Parameter	Mallam No.1	Oblogo No.1
Geological conditions	Rocky {old stone quarry}	Rocky {old stone quarry}
Bottom lining	40% lined with clay	60% lined with clay
Side lining	No lining on side	No lining on side
Capping	Nil	Entire surface capped with about a 1m of laterite
Gas collection system	Nil	Nil
Leachate collection system	Nil	Nil
Estimated amount of waste deposited	2,698,570 metric tonnes	2,378,390 metric tonnes
Average depth	20.06 metres	35.54 meters

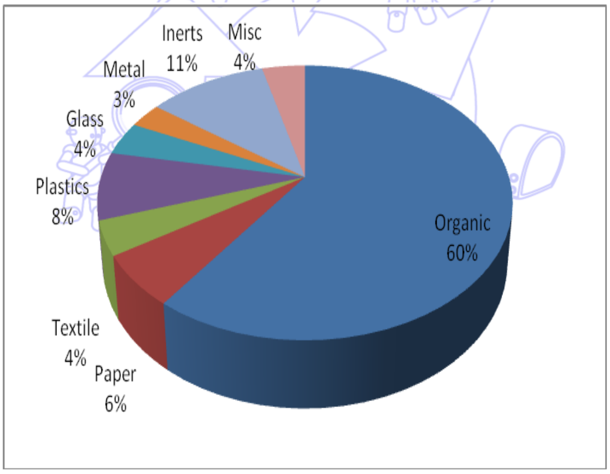


Fig. 3 Waste composition in the Accra metropolis

The amount of solid waste that was placed at the Mallam No.1 and Oblogo No.1 dumpsites is about 2,698,570 and 2,378,390 metric tonnes respectively based on the available landfill space and waste densities [6]. Table 1 presents a summary of the conditions at these two dumpsites. There is limited data on the actual characteristics of placed waste at this dumpsite. However, a review of relevant literature shows that solid waste generated in Accra has a high content of putrescible organic material [6-7]. This organic waste material largely consists of food waste from various domestic and commercial sources within the Greater Accra metropolitan Area. Fig. 3 shows the municipal solid waste composition in the Accra metropolis.

2.2 Landfill methane estimation

The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas (LFG), methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from municipal solid waste landfills [8]. LandGEM is a first order decay model which assumes that landfill methane generation can be projected using the following first order exponential equation in (1)

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0,1}^{1} kL_o (M_i /10)(e^{-kt_{ij}}) \tag{1}$$

where

Q_{CH4} = estimated methane generation flow rate (in cubic meters per year)

i = 1-year time increment

n = (year of the calculation) – (initial year of waste acceptance)

j = 0.1-year time increment

k = methane generation rate (yr-1)

L_o = potential methane generation capacity (m3 per megagram)

M_i = mass of solid waste disposed in the ith year (Mg)

t_{ij} = age of the jth section of waste mass disposed in the ith year (decimal years)

The required inputs for estimating the amount of landfill gas generated are the design capacity of the landfill, the annual acceptance rate, the landfill gas generation constant k, the landfill gas generation potential L_o and the number of year of waste acceptance. The LandGEM outputs include annual waste inputs, waste-in-place, and generation of total landfill gas, methane, carbon dioxide, and NMOCs. LFG and methane generation estimates are the output parameters that are used for non-regulatory LFG predictions [8].

The British Columbia Ministry of Environment Landfill Gas Estimation tool is a Microsoft Excel application which is based on the Scholl Canyon first order decay model [9]. The Scholl Canyon Model predicts LFG production over time as a function of the LFG generation constant (k), the methane generation potential (L_o), and the historic waste filling records and future waste projections at a site. The first-order equation is given in (2):

$$Q_{CH_{4i}} = \sum_{i=1}^{n} kL_o m_i e^{-kt} \tag{2}$$

where

Q_{CH4i} = methane produced in year i from the i^{th} section of waste (m^3/yr)

k = methane generation rate constant (1/yr)

L_o = methane generation potential (m^3 methane/tonne waste)

m_i = waste mass disposed of in year i (tonnes)

t = years after closure

This estimation tool model accounts the main factors responsible for LFG generation by providing a matrix approach that allows users to input detailed site-specific information including the waste characteristics and storm water management practices. Model input parameters include the waste characteristics; methane generation potential (L_o); landfill gas generation rate (k), methane content and the water addition factor. The model output is the annual methane production in tonnes/year for each year from the opening year.

2.3 Determination of LFG model parameters

In the absence of any field sampling or laboratory investigations, the determination of the LandGEM parameters such as methane generation rate, potential methane generation capacity, NMOC concentration and methane content were based on a review of relevant literature on US EPA landfill gas models [10-11].

The British Colombia Landfill Gas Management Facilities Guidelines [12] provides values of the various model parameters which are based on the annual precipitation at the site, landfill storm water management practices and the ease of waste decomposition. Table 2 and Table 3 present a list of the LandGEM and BC MOE LFG model parameters used for the two dumpsites respectively.

Table 2 LandGEM parameters for Mallam No.1 and Oblogo No.1 dumpsites

Parameter	Symbol	Value
Methane generation rate	k	0.09
Potential methane generation capacity	L_o	120
Methane content	P_{CH4}	50%

Table 3 BC MOE LFG model parameters for Mallam No.1 and Oblogo No.1 dumpsites

Parameter	Symbol	Value
Methane generation rate for relatively inert waste	k	0.02
Methane generation rate for moderately decomposable waste	k	0.04
Methane generation rate for decomposable waste	k	0.09
Potential methane generation capacity for relatively inert waste component	L_o	20
Potential methane generation capacity for moderately decomposable waste	L_o	120
Potential methane generation capacity for decomposable waste	L_o	160
Water addition factor	-	1.0
Methane content	P_{CH4}	50%

2.4 Determination of annual waste disposal rates

Historically, the actual volumes of waste flows to various landfill sites in the Accra metropolis have not been recorded due to the absence of weighbridges. However, the city authorities have estimates of the quantity of waste collected daily for the Accra Metropolitan Area since the year 1998 [6].

For this study, the waste disposed at the two dumpsites during each year of operation was determined from (3).

$$Qy,i = Py,i \times QT \tag{3}$$

where

$Q_{y,i}$ = Waste disposal in the ith year (Mg)

$P_{y,i}$ = Proportion of waste collected in the ith year relative to total collected in operational period

Q_T = Total estimate of waste disposal at dumpsite during operational period (tonnes)

Table 4 Estimated annual waste disposal rates for the Oblogo No.1 dumpsite

Year	Daily waste collection (Metric tonnes)	Annual waste disposal (Metric tonnes)
Jan. – Dec. 2002	1,300 – 1,500	411,944
Jan. – Dec. 2003	1,300 – 1,500	411,944
Jan. – Dec. 2004	1,163	342,208
Jan. – Dec. 2005	1,402	412,533
Jan. – Dec. 2006	1,752	515,519
Jan. – July 2007	1,656	284,519

Table 5 Estimated annual waste disposal rates for the Mallam No.1 dumpsite

Year	Daily waste collection (Metric tonnes)	Annual waste disposal (Metric tonnes)
July – Dec. 1991	-	80,382
Jan. – Dec. 1992	-	192,919
Jan. – Dec. 1993	-	192,919
Jan. – Dec. 1994	-	192,919
Jan. – Dec. 1995	-	192,919
Jan. – Dec. 1996	-	192,919
Jan. – Dec. 1997	-	192,919
Jan. – Dec. 1998	450 - 600	192,919
Jan. – Dec. 1999	600 - 800	257,225
Jan. – Dec. 2000	1,200 – 1,500	469,078
Jan. – May 2001	1,300 -1,500	514,451

Table 4 and Table 5 present the estimated annual waste disposal rates at the Oblogo No.1 and Mallam No.1 dumpsites respectively.

3. Computer Simulation Results

3.1 LandGEM methane gas estimates

The simulations results for methane gas production in metric tonnes from the Oblogo No.1 and Mallam No.1 dumpsites using the LandGEM are shown in Fig. 4. The maximum value for methane gas production at Oblogo No.1 is 11,026 tonnes which should have occurred one year after disposal operations had ceased at the dumpsite.

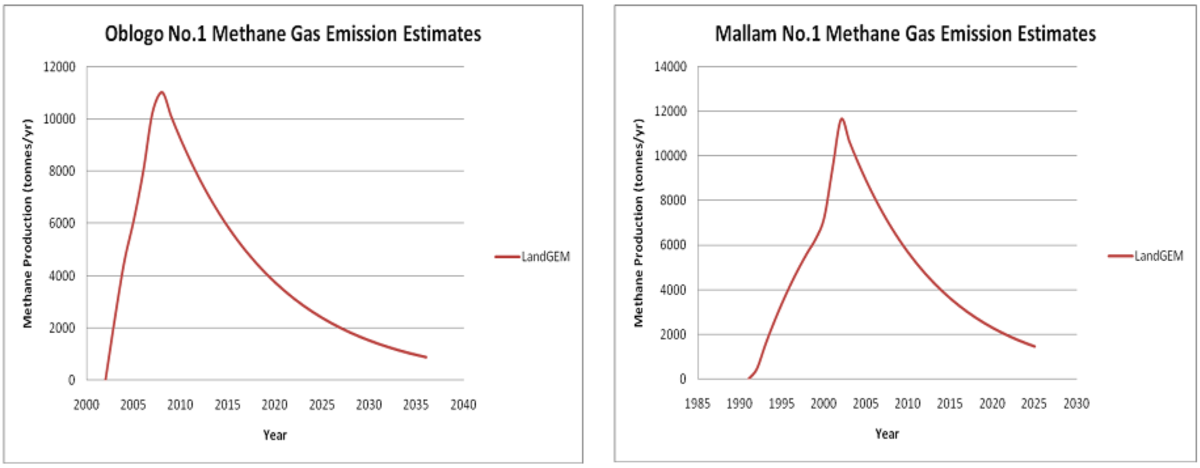


Fig. 4 LandGEM simulation results for Mallam No.1 and Oblogo No.1

The annual production of methane gas should fall below 10,000 tonnes in 2010 and 5,000 tonnes in 2017. The maximum value for methane gas production at Mallam No.1 is 11,623 tonnes which should have occurred one year after disposal operations had ceased at the dumpsite. The annual production of methane gas should fall below 10,000 tonnes in 2004 and 5,000 tonnes in 2012. Table 6 shows the LandGEM simulation results for combined maximum, minimum and mean methane gas production from the two disposal sites over a 45 year period from 1991 to 2035. The theoretical methane gas production from the two dumpsites is 17,799 tonnes which should have occurred in 2008.

Table 6 Maximum, minimum and mean methane emissions using the LandGEM

Parameter	**Methane Gas Production (tonnes/yr)**		
	Oblogo No.1 (2002 - 2035)	Mallam No.1 (1991 - 2024)	Combined (1991 -2035)
Minimum	971	464	464
Maximum	11,026	11,623	17,799
Mean	4,385	4,722	6,986

3.2 BC MOE LFG tool methane gas estimates

The simulations results for methane gas production in metric tonnes from the Oblogo No.1 and Mallam No.1 dumpsites using the BC MOE LFG estimation tool is shown in Fig. 5. The maximum value for methane gas production at Oblogo No.1 is 11,243 tonnes which should have occurred in year 2008. The annual production of methane gas should fall below 10,000 tonnes in 2010 and 5,000 tonnes in 2017. The maximum value for methane gas production at Mallam No.1 is 11,889 tonnes which should have occurred in year 2002. The annual production of methane gas should fall below 10,000 tonnes in 2004 and 5,000 tonnes in 2012. Table 7 shows BC MOE LFG estimation tool simulation results the combined maximum, minimum and mean methane gas production from the two disposal sites over a 45 year period from 1991 to 2035. The theoretical methane gas production from the two dumpsites is 17,799 tonnes which should have occurred in 2008.

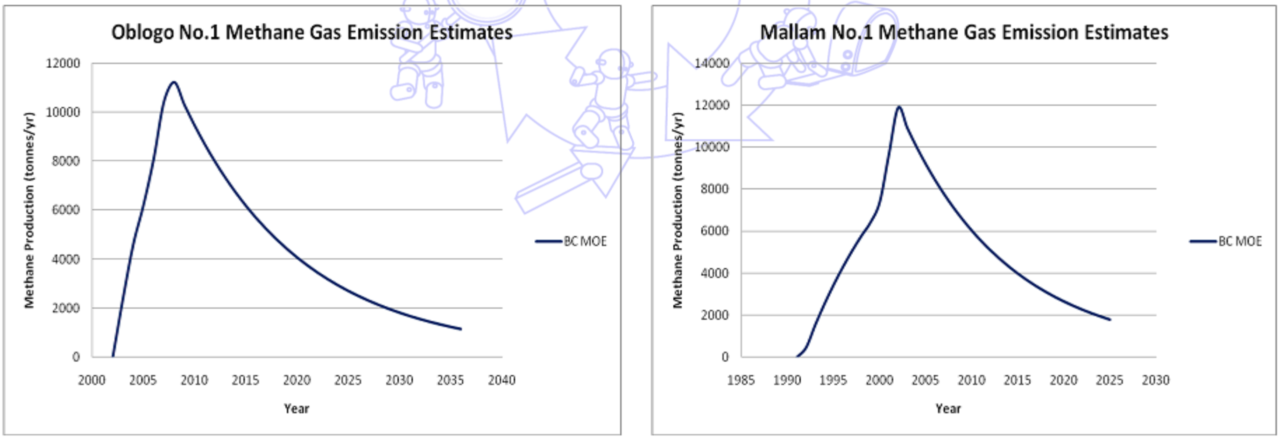


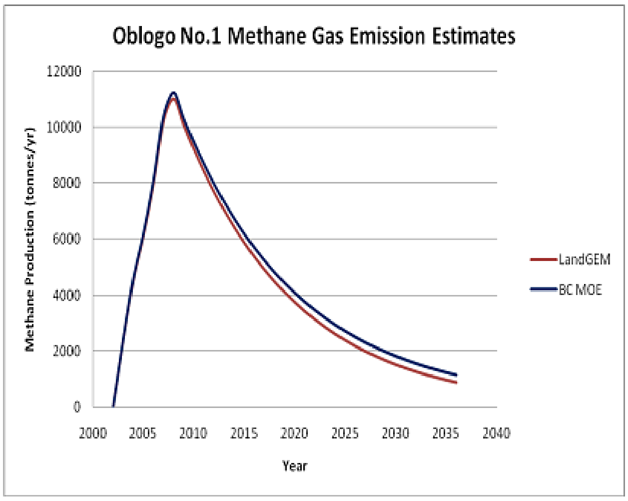
Fig. 5 BC MOE LFG tool simulation results for Mallam No.1 and Oblogo No.1

Table 7 Maximum, minimum and mean methane emissions using the BC MOE LFG estimation tool

Parameter	**Methane gas production (tonnes/yr)**		
	Oblogo No.1 (2002 - 2035)	Mallam No.1 (1991 - 2024)	Combined (1991 -2035)
Minimum	1,244	469	469
Maximum	11,243	11,889	18,379
Mean	4,652	4,989	7,395

3.3 Comparison of LandGEM and BC MOE LFG tool methane gas estimates

A comparison of the annual methane gas emissions from the various disposal sites using the two computer models is shown in Fig. 6. Both models predicted similar time of occurrence of the peak methane production i.e. Year 2002 for Mallam No.1 and Year 2008 for Oblogo No. 1.



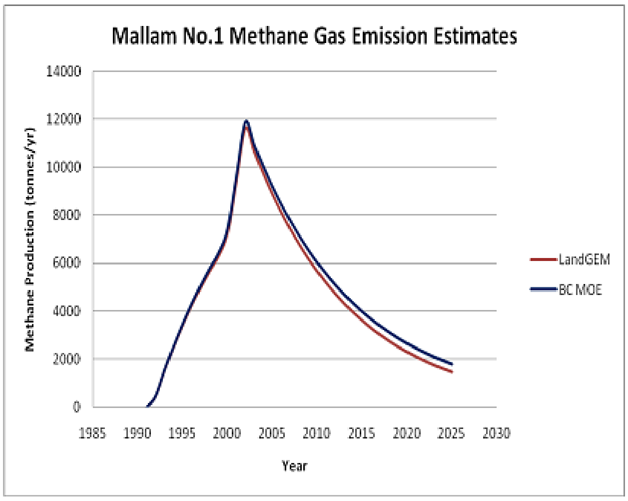


Fig. 6 Comparison of LandGEM and BC MOE LFG tool simulation results

The peak production predicted by the BC MOE estimation tool was 2% higher than the value obtained with LandGEM for both Oblogo No.1 and Mallam No.1. The production rates before the peak are also higher than the LandGEM estimates by the same magnitude. Beyond the peak period, the estimates computed with the BC MOE tool become significantly higher up to a magnitude of 28 % and 24 % for Oblogo No.1 and Mallam No.1 respectively.

4. Discussion of Results

4.1 Assessing the suitability of BC MOE LFG generation estimation tool

The use of the LandGEM has been widely documented in literature [13-15]. However, the accuracy of LFG emission estimates can be significantly affected by limitations due to the structure of the LandGEM. For example, changes in k or L_0 values in the same model run as well as changing landfill conditions such as the application of liquids to existing waste and the variations in waste composition over time cannot be modeled. This, therefore, requires that the LFG modeller to be circumspect in the selection of the various LandGEM parameters to best represent the site specific conditions. This has led to development of various countries specific LFG models under the U.S. EPA’s Landfill Methane Outreach Program [4].

The BC MOE LFG generation estimation tool which has been developed for use within the province of British Columbia in Canada is also a first order decay model just like the LandGEM. The BC MOE LFG estimation tool allows the user to categorize the waste composition into three components namely inert, moderately decomposable and readily decomposable and which can be varied for each year. The methane generation rate k for each category can also be varied. The addition of water to the waste can also be accounted for by the choice of a suitable correction factor. The BC MOE LFG generation estimation tool offers the flexibility that addresses the some of the limitations of the LandGEM that can be further aggravated by the inexperience of LFG modellers in a developing country such as Ghana. This model could also be adapted to suit the conditions in the various climatic zones in Ghana.

4.2 Control and utilization of methane gas from Oblogo No.1 and Mallam No. 1 dumpsites

Many projects in developing countries are taking advantage of the United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) to earn carbon credits by capturing methane from landfills. The Certified Emission Reductions (CERs) can be purchased by industrialized countries to make up for shortfalls in reaching targets in emission reductions under the Kyoto Protocol targets [15]. The Oblogo No.1 and Mallam No.1 dumpsites currently have no gas collection or control systems therefore collection efficiencies would be very low [16]. The Mallam No.1 site which ceased operation in 2002 can be said to have reached a stage of stabilization where methanogenic bacteria starts to produce less methane amounts due to low moisture content and low fresh biodegradable solid waste. The peak production rates from the Oblogo No.1 dumpsite should also have occurred by now. These factors seem to suggest that these two dumpsites are not suitable candidates for energy recovery projects.

5. Conclusion and Recommendation

This study aimed at estimating theoretical methane gas emissions from two of the largest abandoned dumpsites in the Greater Accra metropolis using two first order decay models namely LandGEM and the BC MOE LFG generation estimation tool. Generally, the BC MOE LFG generation estimation tool results were slightly higher than those obtained using the LandGEM. However, both models predicted the time as peak production as occurring in 2002 and 2008 for the Mallam No.1 and Oblogo No.1 dumpsites respectively. The total combined peak annual methane production from the Oblogo No.1 and Mallam No.1 dumpsite within the study time frame was estimated to be in excess of 17,000 metric tonnes.

It was also determined that the BC MOE LFG generation estimation tool could be adapted for using in the Greater Accra Metropolis as the preferred methane gas estimation model since it addresses some the limitations that are inherent in the structure of the LandGEM.

Acknowledgement

This research study was fully funded by Kspyx Ltd/WastePro Software. The author would also wish to express his gratitude to staff of the Department of Civil Engineering at Kaaf University College.

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