ESTIMATION OF GAS EMISSION FROM OPEN DUMPSITES IN COLOMBO DISTRICT

BY

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Declaration

The analysis describe in this thesis was carried out by my self at Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya under supervision of Mr. A.K. Karunaratna, Research Associate, Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya. And Dr. P.A.D.E. Kodithuwakku, Senior Lecturer, Department of Natural Resources, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka, during the project period from 3rd April 2006 to 14th July 2006.

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Abstract

Carbon dioxide and certain other trace gases, including methane (CH_4), nitrous oxide (N_2O) chlorofluorocarbons (CFCs), and tropospheric ozone (O_3), are accumulating in the atmosphere as a result of human activities. Global warming occurs because these gases retain infrared radiation, which normally would dissipate into space from Earth in the atmosphere, thus the atmosphere warms up. Some of the heat from the atmosphere is transferred to the oceans and raises their temperature as well. As the atmosphere and oceans warm, the overall temperature of the Earth rises. Because carbon dioxide and other gases trap the sun's radiation in much the same way as the glass does in a greenhouse. Global warming produced in this manner is known as the greenhouse effect.

This study will be used to develop plans for rehabilitating and mining of dumpsites in the Colombo District. Most of the disposal sites were small scale and suffered by operation problems such as the lack of man power and heavy machines and from the environmental impacts such as ground water contamination and odor problem.

The methane emissions have been determined by the Intergovernmental Panel on Climate Change (IPCC) using a method on the basis of mass balance approach incorporates no time factor and can be applied to the total waste emanating from the area. The calculation based on the amount of waste generation and open dumpsites, the fraction of Degradable Organic Carbon (DOC) that actually degraded into biogas and the fraction of biogas that actually released as methane.

Therefore, secondary data and information were gathered on disposal of wastes in the Colombo District and three dumpsites, namely at Buthgamuwa, Karadiyana and Maharagama were monitored for a period of seven days and a closed flux chamber method was used to determine the rate of gas emissions and the composition of the gas was analyzed.

As expected the new dumpsite generated higher rate of Landfill Gases (LFG) than the old ones. Thus, an average gas generation was obtained for the three sites and when compared with the reported value was much higher than IPCC method for Sri Lanka. The experimental value may be an over estimation and verification is needed and further studies are recommended. Interestingly considerable oxidation of methane takes place, perhaps in the cover soil. However, this oxidation is limited when methane generation levels exceed threshold levels. Also depending on the partial pressures, only moisture is given out while curtailing gas emissions. All of these aspects needs in depth studies.

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List of Abbreviation

AIT	Asian Institute of Technology
ASTM	American Society for Testing and Materials
bgl	below ground level
°C	degree Celsius
CFC	Chloro-fluorocarbon
CH_4	methane
cm	centimeter
CO_2	carbon dioxide
dia	diameter
DOC	Degradable Organic Carbon
Eh	Oxidation Reduction Potential
g.	gram
GC	Gas Chromatography
Gg	10-3 million tons
GHG	Greenhouse Gas
GWP	Global Warming Potential
H_2O	water
h	hour
ha	hectare
HCFC	halochloro-fluorocarbon
H_2S	hydrogen sulfide
in	inch
IPCC	Intergovernmental Panel on Climate Change
L	liter
LEL	Lower Explosive Limit
M	meter
MC	Municipal Council
min	minute
ml	milliliter
mm	millimeter
MSW	Municipal Solid Waste
MSWM	municipal Solid Waste Management
NA	gas flux
N_2O	nitrous oxide
N_2	nitrogen
Non-DOC	None Decompose Organic Compound
NRI	National Research Institute
OECD	Organization for Economic Co-operation and Development
ORP	Oxidation Reduction Potential
PCD	Pollution Control Department
ppm	part per million
PS	Pradeshiya Sabaha
UEL	Upper Explosive Limit

Chapter 1

Introduction

1.1 General Introduction

An open-dump is a solid disposal site without waste compaction during placement, neither with liner material nor cover soil. The land is used without proper planning for the specific use of disposing wastes. The uncontrollable emissions takes place of the wastes which are placed either in low lying lands or pilled up to Form Mountains of waste. It is normally a source of infection, odor pollution, and environmental contamination.

Municipal solid waste (MSW) contains large proportion of organic waste. Anaerobic reactions within the dumpsites generate leachate and contaminate water, which plays significant roles on the pollution of ground water. The reactions also generate various gases, mainly methane and carbon dioxide. The exact percentage distribution varies with the age of the dumpsites.

However, typical constitutions found in MSW landfill gas are methane 45 - 60 % and carbon dioxide 40 - 60 %. Open dumpsites are one of the most anthropogenic sources of methane, important in greenhouse gas that causes global warming. As methane, due to its higher absorption coefficient for infrared radiation and longer atmospheric residence time, has potential global warming impact up to 21 times of CO_2, depending on time. (Brown and Maunder, 1994) This might cause changes in precipitation pattern, rising sea level, effect on some living organism and agriculture. The gases emission from open dumpsite should be evaluated as being responsible to global warming effect.

In the Colombo District, the Municipal Councils resort to open dumping of MSW as the dominant method of disposal. From these dumpsites, vast quantities of Methane & Carbon dioxide gases are generated. Since the population density of the Colombo District is high, the amount of waste generated and managed is also high. Therefore, open dumpsites scattered in the urban centre causes environmental pollution and affects the health of the habitants. Unfortunately very few research studies have been undertaken for quantifying the amount of gas emissions from dumpsites. Therefore the aim of this study is to adduce and quantify gas emissions from dumpsites and the objectives of the study are given below

1.2 Objectives and Scope of the Experiment

Objectives

- To determine bench mark values of gas emissions from open dumpsites.
- To quantify gas emissions from the dumpsites in the Colombo District.
- To determine and asses the number an extent of dumpsite in Colombo District.

Scope of the Experiment

- The flux of landfill gas was measured only by closed flux chamber method.
- Landfill gas was measured on-site by portable infrared gas chromatography. Some Samples were collected in sealed bags and analyzed at Sri Jayawardhanapura University laboratory

Chapter 2

Literature Review

2.1 Solid Waste Situation in Colombo District

Colombo is geographically divided into four Municipalities namely, Colombo, Kotte, Dehiwala-Mount Lavinia, Moratuwa and three Urban Councils, Maharagama, Kesbewa and Kolonnawa. Hierarchical system in the Municipal Solid Waste Management (MSWM) of Sri Lanka shown as follows.

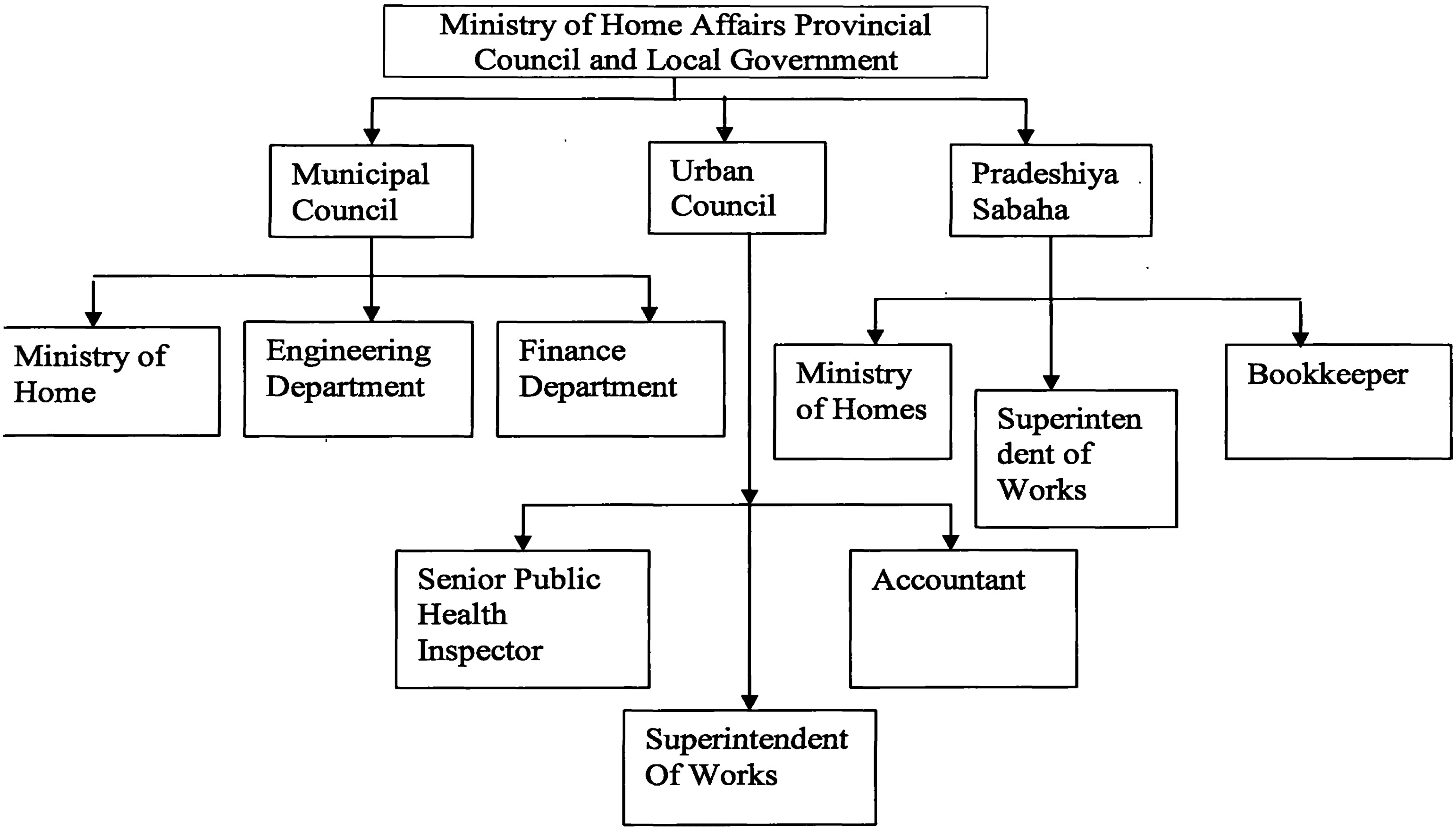

Fig: 2.1 Hierarchical systems in the MSWM of Sri Lanka

The quantity of solid waste has also increased over the period of years in Sri Lanka with changes in consumption patterns. Analysis of data has revealed that the per capita per day waste generation on the average was .85 Kg in Colombo Municipal Council (CMC), 0.75 kg in other Municipal Councils (MC), 0.60 kg in Urban Councils (UC), and 0.40kg in Pradeshiya Sabaha (PS), the smallest local administrative unit. The primary sources of the MSW are households, markets and commercial establishment while the secondary sources are industries and hospitals. The data available that would help estimate the total quantity of municipal solid waste generated in the country was not entirely accurate, since the collection values ranged between (10-15)% except for Colombo, Dehiwala-Mt Lavinia and Kotte which have a little higher values of 30-40%. Daily waste collection by Local Authorities (LA) is

estimated at 2863 tons. However, the total MSW generated in Sri Lanka is assumed to be around 6,400 tons per day (UNEP, 2001). The waste composition in developed and developing countries indicated by Blight (1996) is given in
Table2.1. Sri Lanka's information is added to compare the waste characteristics.

Table 2.1 Physical Waste Composition in Developed and Developing Countries

Composition (% by mass)	Developed countries			Sri Lanka	Cities in developing countries				
	USA.	Holland	UK.		India (Delhi)	China (Wuhan)	S.Africa (Soweto)	Peru (Lima)	Mexico (Mexico city)
DOC									
Garden and food waste	25	48	25	**80**	47	16	9	56	56
Paper	33	24	30	**6**	6	2	9	14	17
Textile	3	3	3	-	-	0.6	1	4	6
Non-DOC									
Metals	10	3	8	**1.85**	1	0.5	3	4	6
Glass	9	9	12	**1.64**	0.6	0.6	12	3	4
Plastic	8	7	5	**6.69**	0.9	0.5	3	7	6
Wood	4	1	-	**5.02**	-	1.8	3	12	5
Dust, ash, others	6	2	17		44.5	78	-	-	-
Refuse density	-	-	145	-	420	600	400	350	-
Refuse generation rate ton/person/yr. (Kg/person/day)	0.61 (1.7)	0.61 (1.7)	0.5 (1.4)	**1.2**	0.14 (0.38)	0.2 (0.54)	0.15 (0.41)	0.3 (0.9)	.55 (1.5)

. * Classified in dust, ash and others.
Source: Blight (1996)

2.2 Global Warming by Greenhouse Gases and Sri Lanka's Contribution

Carbon dioxide and certain other trace gases, including methane (CH_4), nitrous oxide (N_2O) chlorofluorocarbons (CFCs), and tropospheric ozone (O_3), are accumulating in the atmosphere as a result of human activities. Global warming occurs because these gases retain infrared radiation, which normally would dissipate into space from Earth, in the atmosphere, thus the atmosphere warms up. Some of the heat from the atmosphere is transferred to the oceans and raises their temperature as well. As the atmospheric and oceans warm, the overall temperature of the Earth rises. Because carbon dioxide and other gases trap the sun's radiation in much the same way the glass does in a greenhouse, global warming produced in this manner is known as the greenhouse effect. Table 2.2 shows the concentration of greenhouse gases affected by human activities estimated by IPCC (1996).

Table 2.2 Sample of Greenhouse Gases Affected by Human Activities

	CO_2	CH_4	N_2O	CFC-11	HCFC-22 (CFC substitute)	CF_4 (perfluoro carbon)
Pre-industrial concentration	~280 ppmv.	~700 ppbv	~275 ppbv	zero	zero	zero
Concentration in 1994	358 ppmv	1720 ppbv	312 .ppbv.	268. pptv..	110 pptv	72. pptv
Rate of concentration change *	1.5 ppmv/yr. 0.4%/yr.	10 ppbv/yr. 0.6%/yr	0.8 ppbv/yr. 0.25%/yr.	0 ppbv/yr. 0 %/yr.	5 ppbv/yr. 5%/yr.	1.2 ppbv/yr. 2%/yr.
Atmospheric lifetime (years)	50 - 200..	12...	120	50	12	50,000

*Estimated from 1992 - 93 data.

. 1 pptv = 1 part per trillion (million million) by volume.

.. No single lifetime for CO_2 can be defined because of the different rates of uptake by different sink process.

... This has been defined as an adjustment time takes into account the indirect effect of methane on its own lifetime.

* The growth rates of CO_2, CH_4 and N_2O are average over the decade beginning 1984; halocarbon growth rates are based on recent years (1990s).

Source: IPCC (1996)

Waste is produced either as solid waste or as wastewater. It can be classified as municipal or industrial waste. The disposal and treatment of both solid waste and wastewater cause the emission of GHGs. Under aerobic conditions, micro-organisms normally present in the waste decompose organic matter into CO_2, whereas under anaerobic circumstances, methane is produced. However, the global warming potential of CH_4 is nearly 21 times more than GWP (Global Warming Potential) of CO_2. It has a possibility in which CH_4 is the most important GHGs in the future.

2.3 Global GHG Emission from Waste Sector

In 1992, it was reported that global methane emission from anthropogenic sources was 360 million tons/yr., of which emission from landfill accounted for between 6-20%, 20-70million tons/yr. In order to update global emission of CH_4 from landfill, IPCC and AEERL regressions were used. It was found that the largest emission coming from North America (23.4 million tons) while Asia accounted for 11.80 million tons (TEI, 1996). On the global scale, methane emission from wastewater treatment in Asia is one of the main sources of GHGs. Because many countries in Asia have enough land for anaerobic treatment which also cheaper than aerobic system. Therefore, methane emission in Asia is the most. Methane emission from landfill in Asian countries is presented in Table 2.3. It shows that Sri Lanka is not the principal emitter of methane from landfill. The IPCC method based on the mass balance approach incorporates no time factor and can be applied to the total waste emanating from the country. The calculation based on the amount of waste generation and landfill, the fraction of DOC that actually degraded into biogas and the fraction of biogas that actually released as methane.

Table 2.3 Methane Emission Estimated from Landfill in Asian Countries Using IPCC and AEERL Regression Methods

Country	IPCC method		AEER regression method
	million ton methane	%	Million tons of methane (lower bound – upper bound)
Bangladesh	0.42	3.60	0.06-0.19
China	3.87	32.80	0.59-1.77
Iran, Islamic Republic of	0.80	2.60	0.05-0.14
India	0.31	6.80	0.12-0.37
Iraq	0.12	1.00	0.02-0.05
Japan	1.04	8.80	0.28-0.72
Korea, People's Democratic Rep.	0.14	1.20	0.02-0.06
Korea, Republic of	0.64	5.50	0.1-0.29
Kuwait	0.02	0.17	0.00-0.01
Malaysia	0.08	0.67	0.01-0.04
Mongolia	0.01	0.08	0.00-0.00
Myanmar	0.16	1.40	0.02-0.07
Pakistan	0.75	6.40	0.11-0.34
Philippines	0.42	3.60	0.06-0.19
Saudi Arabia	0.10	0.85	0.01-0.04
Sri Lanka	**0.01**	**0.08**	**0.01-0.04**
Thailand	0.28	2.40	*0.04-0.13*
Turkey	0.20	1.70	0.07-0.18
United Arab Emirates	0.01	0.08	0.00-0.01
Vietnam	0.22	1.90	0.03-0.1
Other Asia	2.04	17.30	0.32-0.94
Total	11.80	100	1.93-5.70

Source: TEI (1996)

2.4 Definitions of Disposal Sites

Non-Engineered Landfill: Non-engineered landfill is defined as a disposal site either has been excavated of non-excavated, with daily cover soil or when the site is full. The site is managed without an engineering design, operation and monitoring. Therefore, public health and environmental impact from water, air and soil contamination are not minimized.

Open-Dump Site: An open-dump site is a solid disposal site without waste compaction
During placement, neither compact nor cover with soil. The land is used without preparation of engineering planning. The uncontrollable wastes are placed as mountain of waste. It is normally a source of infection, odor pollution, and environmental contamination.

2.5 Sri Lankan Government Legal Aspect on MSW Management.

National Strategy on Solid Waste Management (NSSWM) should also cover the directives for mining and safe closure of dumpsites. The NSSWM lacks adequate provisions and methods for promoting the use of compost in agriculture. The government should consider environment impact assessment (EIA) as a prerequisite for solid waste disposal site that includes risk assessment and economic feasibility of the project.
It is necessary to plan strategies in the NSSWM for the following activities.

- Closure and mining of dumpsites;
- Production and sale of compost;
- Glass, paper and plastic recycling;
- Textile and rubber reclamation or recycling

The government should also impose stringent regulations to prevent and discourage indiscriminate littering of waste by individuals, government and non-government organization as well as penalize illegal dumping.

2.6 Landfill Gas Generation, Principal Gases and Their Properties

Solid waste landfill contains mostly organic waste and water which promote the biochemical reactions. Their major products are landfill gases and leachate (liquid that has percolated through solid waste and has extracted dissolved or suspended materials, mostly; the liquid has entered landfill from external sources such as rainfall, surface drainage). However, leachate generations from the wastes itself is the worse form of pollution.

Gases found in landfill include ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulfide (H_2S), methane (CH_4), nitrogen (N_2), and oxygen (O_2), Methane and carbon dioxide are the major principal gases produced from the anaerobic decomposition of the biodegradable organic waste components in municipal solid waste. Typically, landfill gas is composed of 45 - 60% methane and 40 - 50% carbon dioxide. In addition, gas from older landfills which accepted hazardous wastes that contained volatile organic compounds (VOC's) may contain significant amounts of VOC's. The landfill gas generation rate varies with time. Normally, the generation is separated into five phases.

I The initial adjustment phase:
The biological decomposition occurs under aerobic conditions, because it still has certain
amount of air in a landfill.

II Transition phase
Oxygen depletes and anaerobic condition begins to develop. The measurement of Oxidation/reduction potential at -150 to -300 mill volts shows the occurrence of methane
production.

III Acid phase
In acid phase, hydrolysis of high molecular mass compound takes place and its products are compounds suitable for microorganism to use as energy or carbon sources. In addition, acidogenesis process (utilization of compounds from former steps) produces carbon dioxide as major gas in the third phase.

IV Methane fermentation phase
Methanogenic bacteria converts acetic acid and hydrogen formed in acid phase to CH_4 and CO_2.

V Final phase
The final phase is maturation. It occurs when available biodegradable waste has already
Convert to CH_4 and CO_2. The rate of gas generation diminishes because most of nutrients have been removed with leachate during the previous phases and substrates that remain in landfill are slowly biodegradable.

During anaerobic condition, the generalized chemical reaction for anaerobic decomposition of solid waste can be written as:

$$\underset{\text{(Solid waste)}}{\text{Organic matter}} + H_2O \xrightarrow{\text{Bacteria}} \underset{\text{organic matter}}{\text{biodegraded}} + CH_4 + CO_2 + \text{other gases} \qquad \text{Eq. 2.1}$$

(Reaction is under the presence of water.)

There are a lot of methods for theoretical maximum methane yield (Emcon Associates, 1980; Tchobanoglous et al., 1994). However, the methane generation rate is mostly calculated from biodegradable portion of waste. If the individual organic constituents found in MSW (with exception of plastic) are represented with the general formula of the term $C_aH_bO_cN_d$, then the total volume of gas can be estimated using Eq. 2.2, assuming the complete conversion of biodegradable organic waste to CO_2 and CH_4.

$$C_a H_b O_c N_d + \frac{(4a - b - 2c + 3d)}{4} H_2O \longrightarrow \frac{(4a + b - 2c - 3d)}{8} CH_4 + \frac{(4a - b - 2c + 3d)}{8} CO_2 + d\,NH_4 \qquad \text{Eq. 2.2}$$

Table 2.4 presents a brief review of various gases in isolation. In practice, gases will be presented as mixtures, which, in conjunction with temperature, pressure and ignition source effects (Cairney and Smith, 1993).

Waste gas usually consists of hydrocarbon or a mixture of hydrocarbon in air. It may be in such concentrations that it may not combust within the ignitable limits until more air is added such mixtures are said to be above upper explosive limit (UEL). Mixture of hydrocarbon vapor in air that can be ignited are said to be with explosive range. Mixtures which have such low hydrocarbon concentration that they can not ignite are said to be below the lower explosive limit (LEL).

Table 2.4 Principle Properties of Major Landfill Gases (in Isolation State)

GAS	CHARACTERISTICS
Methane	Colorless, odorless Soluble in water Lighter than air (specific gravity 0.55) Explosive (concentration from 5% - 15% by vol. of air *) Non toxic to plant but cause oxygen depletion in root zone
Carbon dioxide	Non combustible Colorless, odorless Soluble in water 1.5 times heavier than air (specific gravity 1.53) Risk as asphyxiation Toxic to plant (more than 5-10% by vol. in the root zone) Highly toxic by inhalation, occupational limits of maximum acceptable 0.5 and 1.5% by volume for occupational long term (8 h.) And short-term (10 min.) exposure, respectively. **
Oxygen	Colorless, odorless Slightly soluble in water Heavier than air (specific gravity 1.11) Highly toxic by inhalation, less than 18% by vol.
Ammonia	Explosive limit 15-26.6% by vol. Specific gravity of 0.07 Found during the anaerobic non-methanogenic stage Explosive limit 4.0-74.2% by vol.
Hydrogen	Non toxic colorless, odorless Specific gravity of 0.07 Found during the anaerobic non-methanogenic stage Explosive limit 4.0-74.2% by vol.

Hydrogen sulfide	Distinctive odor of "rotten egg", colorless Soluble in water Specific gravity of 1.19 Highly flammable (explosive in the range 4.4-45% by vol.) Occupational limits of 10 ppm and 15 ppm for 8 h and 10 min., respectively.
Carbon monoxide	Colorless, odorless Slightly soluble (specific gravity 0.97) Produced by incomplete combustion of organic materials (in this case, underground combustion) Explosive in the range 1.25-74.2% by vol. Highly toxic by inhalation, occupational limits of 50 ppm and 300 ppm for 8 h and 10 min., respectively.

* the lower and upper explosive limits, LEL and UEL, respectively.
** Health and Safety Executive (EH40/91)
Source: adapted from Cairney (1993) and Lagrega (1994)

2.7 Landfill Gas Measurement

Landfill gas emission can be measured in many ways such as soil chamber techniques and micrometeorological (Mosier, 1993). In micrometeorological method, gas transport accomplishes by Eddy motion and the transport of gas provided by turbulent diffusion. This method has been less generally used for measuring CH_4 flux but is conceptually ideal for measuring trace gas emissions over large ecologically uniform areas. Soil chamber method is one of the popular measurements because it can be used for large area and its process is not complicated. The soil chambers can be classified in two types. Those with forced flow through air circulation indicated as "open soil chambers", and those with closed-loop air circulation, are "closed soil chambers". In the open chamber method, cleaned air must be forced to the chamber. The pressure of out side air should exceed a pressure of soil gas and velocity of outside air must be controlled. Pressure deficits in chamber caused by induced air flow can cause artificial high flux. The closed chamber method is less complicated. It is simple to construct, do not disturb a site, easy to install or remove, can be used in a place with no electrical supply. Gas flux from soil can be calculated from the change in concentration with time. These two types of soil chambers are compared within the Table 2.5

Table 2.5 Comparison of Closed and Open Flux Chamber for Landfill Gas Measurement

CLOSED CHAMBER	OPEN CHAMBER
Characteristics Simple cylindrical chamber for Homogenous mixing of landfill gas.	Coupled to the atmosphere by air inlet through which outside air is continuously drawn, forced dry sweep air flow over soil surface at significantly exceeding the Gaseous release rate.
Gas Flux Determination The change in concentration with time (periodically collecting gas Sampling).	The concentration difference between Incoming and outgoing air.
Advantages Small flux can be measured. No electrical demand. Simple to construct No disturbance to the site. Easy to install and remove.	Maintain environmental conditions closer to those of the uncovered field. More applicable for continuous long term Monitoring of gas flux.
Problems 1. Inhibition of normal gas distribution by the increasing of gas concentration in enclosure Head space. *solved by short collection period And correction equation.* 2. Pressure change in soil by Inserting chamber into the soil. *solved by installing collar to the soil and sealing the cover to the Collar.* 3. the change of temperature in the soil and atmosphere under the Chamber. *solved by insulating the chamber and reflective material covering And short gas collection period.* 4. disturbance of soil air boundary Layer.	1. Sensitive to pressure deficit inside the Chamber caused by the induced air flow. 2. Artificially high flux. *solved by larger inlet gas orifices than size of outlet* 3. Requirement of electricity for clean air Pressurization. 4. Requirement of laboratory tests; mixing Efficiency, bias testing, sweep air flow rate test, etc. 5. For high purity, sweep air is proposed to be nitrogen or oxygen- difficult for on-site installations.

Source: adapted from Reinhart, 1992 and Mosier, 1993.

The methane emission potential can be valuated by three different methods.

- Default method proposed by Intergovernmental Panel on Climate Change.
- Landfill Gas Emission Model (LandGEM)
- Close Flux Chamber method

Default method proposed by Intergovernmental Panel on Climate Change.

IPCC has proposed this method for estimation of methane emission from the waste disposal site by default method as following equation. (Proposed by Intergovernmental Panel on Climate Change)

Total CH_4 emission = $(MSW_T * MSW_F * MCF * DOC * DOC_F * F * 16/12 - R) * (1 - OX)$

Where,
MSW_T = Total solid waste generated (Giga gram yr^{-1})
MSW_F = Fraction of solid waste disposed to landfill
MCF = Methane correction factor
DOC = Degradable organic carbon
DOC_F = Fraction DOC dissimilated
F = Fraction of CH_4 in landfill gas
R = Recovered CH_4 (Giga gram yr^{-1})
OX = Oxidation factor

Using above equation we can estimate total CH_4 emission in open dumpsite.

Landfill Gas Emission Model (LandGEM)

United State Environmental Protection Agency has developed a programmed called Landfill Gas Emission Model for the estimation of methane from degradation of solid wastes in the waste disposal site with time. The model is based on first order decay equation.(Proposed by United State Environmental Protection Agency)

$Q = L_0 R (e^{-kc} - e^{-kt})$

Where,
Q = Methane generated in current year ($m^3\ yr^{-1}$)
L_0 = Methane generation potential (m^3 Mega gram $waste^{-1}$)
R = Average annual waste acceptable rate during active life (Mega gram waste yr^{-1})
K = Methane generation rate constant (yr^{-1})
C = Time since MSW landfill closure (yr^{-1})
T = Time since MSW landfill opened (yr)

Close Flux Chamber method

The actual methane emission rates from waste disposal sites have been measured in the field using flux chamber method. The chamber is made of stainless steel with a diameter of 50 cm and 25 cm height. It has a cover with heat insulator and acrylic sheet at the top where a thermometer and an incline manometer for temperature and pressure measurement inside the chamber can be installed. A gas sampling port is also attached to the top cover of chamber so that an increasing rate of methane gas composition in the chamber can be determined. The flux can then be computed using the following equation

$J = (V/A)\ dC/dt$

Where,

J	= Methane flux (mol $m^{-3}\ h^{-1}$)
V	= Volume of chamber (m^3)
A	= Covered area of chamber (m^2)
DC/dt	= Increasing rate of methane gas in chamber (mol $m^{-3}\ h^{-1}$)

Chapter 3

Background Information of the Experimental Site

3.1 General Information

Maharagama dumpsite is situated approximately 0.5 km. from Maharagama .The total surface area of the dumpsites is around 05 acres and commenced operations in 1991. The dumpsite received refuse from all wastes of Maharagama Pradeshiya Sabaha, until very recently. According to the management contract, at least 120 tons of waste per day of solid waste must be transferred to Sedawatta Composting plant. Currently, Maharagama dumpsite receives around 100-120 tons of waste per day.

The experimental site of 05 acres is a closed dumpsite now and the total wastes disposed may amount to 2005 since 1991. At present, it is controlled by Maharagama PS and it is used as a transfer station to handover the waste to the Private Company.

Buthgamuwa dumpsite is situated approximately 0.25 km. from Rajagiriya. The total surface area of the dumpsites is around 03 acres and it is operated since 1990. The dumpsite received refuse from part of wastes of Kotte Municipal Council (MC). At least 125 tons of MSW/day was disposed at one time of its operations. Currently, Kotte MC uses another dumpsite to dispose the wastes. Also the dumpsite has around 20 cm thick of soil cover.

Karadiyana dumpsite is situated approximately 5 km. from Piliyandala. .The total surface area of the dumpsites is around 10 acres and commenced operations in 1996. The dumpsite received refuse from all wastes of Kesbewa UC, Moratuwa MC and Dehiwala-Mt Lavinia. According to the management contract, at least 400 tons of waste per day. Currently, Karadiyana dumpsite receives around 400 - 500 tons of waste per day. The dumpsite consists of an office building, equipment workshop and residential facilities for the staff. The experiments were conducted in the 10 acre site having a depth of 20m and there are two caterpillars operating at the dumpsite. Also a farm is located near to the dumpsite.

The summary of dumpsite operations at Maharagama, Buthgamuwa and Karadiyana is presented in Table 3.1.

Table 3.1 Dumpsite Operation at Maharagama, Buthgamuwa and Karadiyana

List	
Maharagama	
	Method
Waste Layer	Waste was compacted by bulldozer, to compact.
Cover Material	Local soil was used as cover material.
Leachate Collection System	No Leachate Collection System
Buthgamuwa	
Waste Layer	Waste was compacted by bulldozer compacted
Cover Material	Local soil was used as cover material.
Leachate Collection System	No Leachate Collection System
Karadiyana	
Waste Layer	Waste was compacted by bulldozer, compacted
Cover Material	Local soil was used as cover material.
Leachate Collection System	No Leachate Collection System

3.3 Waste Characteristics

Physical characteristics of waste are shown in Table 3.2.

Table 3.2 Physical Waste Composition of Colombo Solid Waste,

Waste Composition	**Percentage (Average % w/w)**
Biodegradable (Short term)	68.15
Biodegradable (Long term)	11.63
Paper	5.99
Plastic	6.69
Wood	5.02
Glass	1.64
Metal	1.85
Total	100

Source: NRI Sri Lanka, 2003.

Chapter 4
Methodology

Introduction

A preliminary study was undertaken to familiarize with the equipment used for gas measurements at the Gohagoda dumpsite in Kandy. Furthermore, existing models of gas emissions were examined to correlate with the preliminary study. The research study entailed gathering of secondary data from the local authorities of the existing dumpsites and few representative dumpsites were monitored for a period of seven days. The design of the flux chamber used for monitoring of the gas was given by Kassart University, Bangkok, Thailand. The research work was coordinated by the University of Peradeniya and the gas measurements were done at the University of Sri Jayewardenepura. The Figure 4.1 illustrates the research methodology adopted in this project. The Fig. 4.1 Shows the research approach to obtain primary and secondary data and information which is separated into parts;

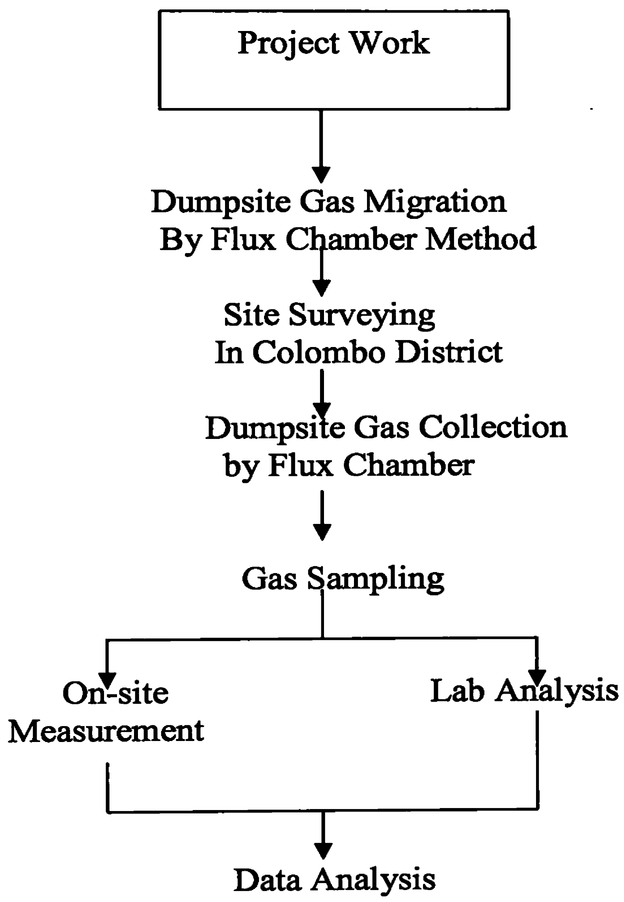

Fig. 4.1 Methodology Diagram

4.1 Experimental Methods

4.1.1 Flux Chamber

The flux of landfill gas was measured by simple static closed flux chamber. The flux chamber used in this research is shown in Fig. 4.2. The volume of the chamber was 0.04 m^3. A 19 mm thick, Plexiglas cover was fastened to a stainless steel cylinder with nuts and bolts. The rubber ring was set between the stainless steel body and plastic cover. The stainless steel body was covered around with insulating fiber.

At first, at the center of the lid, a port was built with stainless steel elbow connected to a rubber pipe. To facilitate gas withdrawal, a gas valve was installed connected to the flexible rubber pipe instead of the former steel elbow. Thermometer with rubber cork was fixed together at the center of the flux chamber. Before the actual use, the chamber was tested with soap water bubble and air pump at every point susceptible to leak. There were no leaks at any point on this flux chamber.

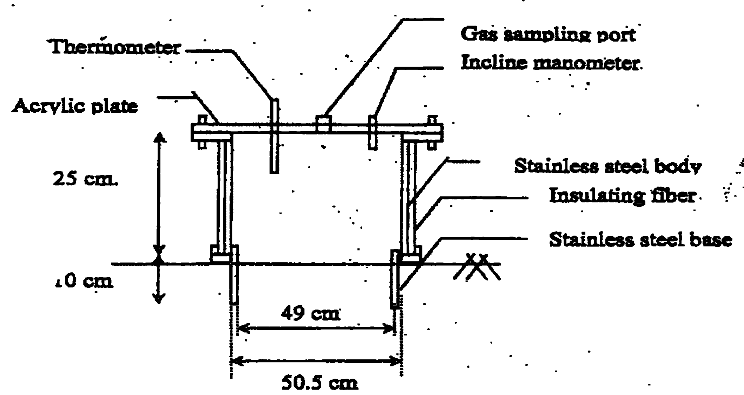

Fig. 4.2 Details of Flux Chamber

4.1.2 Sampling Method

At each time the experiment was set, work was separated into steps as followed:

Sampling Point Selection

- Sampling point was selected were moisture, cover soil and decomposed wastes could be found and designated as an ideal place of experimental site.
- Each day samples were taken from same place, where ideal experimental sites were located.

Flux Chamber Gas Collection

- The flux chamber was placed over the excavated ridge on the soil surface and driven to the required depth to get the predetermined volume (the exact volume that was used for flux calculation, Appendix K).
- The chamber was sealed with very moist soil with adequate consistency was used to cover over the collar to protect any leakage.
- Portable GC was used to measure % (v/v) of landfill gas.
- Repeated the above process again for the next day.

The parameters that were analyzed are shown in Table 4.1.

Table 4.1 List of Parameters Analyzed for Landfill Gas

PARAMETER	MEASUREMENT METHOD
On-site Measurement	
Gas temperature, °C	Temperature probe
Ambient temperature, °C	Temperature probe
Pressure, bar	Inclined manometer
Laboratory Measurement	
Methane (CH_4)	Portable Gas Chromatography
Carbon dioxide (CO_2)	Portable Gas Chromatography

4.1.3 Gas Measurement

Equipment and materials used in gas analysis are presented as follows:

Portable Gas Chromatography

The infrared GC used during the field experiment was PPU 6m. It can measure CO_2, CH_4 H_2S, and Nitrogen in % (volume by volume). Its operation is set by pumping landfill gas into the GC for 50 mille seconds and gas concentration is shown on the screen. The range of gas concentration read by PPU 6m is presented in Table 4.2.

Table 4.2: Operation Criteria of PPU 6m

Operating temperature	-10 to 40 °C	
Gas	Operating range	Accuracy
Methane	0 - 100 %	0.1
Carbon dioxide	0 - 50 %	0.1
H_2S	0 – 25 %	0.1

Source: Operation Manual (2001)

Thermometer

The thermometer used in the experiment was normal thermometer with metal probe. It can measure both gas and soil temperature within the range of 10 to 100 °C, with an accuracy of 1 °C.

Inclined Manometer

An inclined manometer of plastic tube filled with water was used. The accuracy was 0.1 cm.

Secondary Data Collection

In this study to collect the required information on dumpsites a questionnaire was prepared. The primary information was on the quantity of wastes collected and different disposal sites during the last ten years. This information was gathered from two different types of local authorities, namely; two Municipalities of Dehiwala-Mt.Lavinia and Kotte and one Urban Council of Maharagama.

Chapter 5

Results and Discussions

5.1 Results of the Investigation on Solid Waste Disposal in Colombo District

The data from the collected can be used to determine the amount of municipal solid waste (MSW) collected in the Colombo District over the last six years. It is evident from the large quantities generated; appropriate management systems should be practiced. However, various disposal methods currently used and these can not overcome high levels of pollution. In future, there will be systematic disposal processes (for example landfill, composting or incineration) to reduce uncontrolled management of open-dumping.

5.1.1 Type of Landfilling

In this study, the chosen disposal sites were open-dumping with daily soil cover. However, not all of the dumpsites are engineered with a soil cover. Such that indiscriminate dumping is 10% as compared to 90% with cover soil in the district. Unfortunately, all of the disposal sites lack adequate protection of leachate emissions. Thus, liner materials are not used to prevent migration of organic materials far away from the disposal site.

Over ninety percent of disposal sites were found to be non-engineered landfills based on operation criteria: method of covering. The non-engineered landfills must be operated at least with:

- Compacted waste layer and
- Daily covering.

The practice of just covering of soil once a lift is completed is not accepted and it is considered as indiscriminate dumping. Such practices cannot be accepted and although the survey indicates 90% of disposal sites with the practice of soil cover, it cannot be relied on, because the budgetary allocations have been very poor for disposal.

Nevertheless, the local authorities, particularly in the Colombo District are forced to allocate sufficient funds for disposal activities. Unfortunately, none of the local authorities with the assistance of the private sector have suitable processing and disposal facilities. At least, the involvement of the private sector ensures the use of cover soils since it can reduce odor and vector problems. It seems that efforts are being made by the municipalities to allocate funds for disposal and they are willing to take the correct path in managing the wastes.

5.2 Results and Discussions of Experiment

5.2.1 Landfill Gas Flux

As mentioned in the Chapter three, the landfill gas was analyzed by using a flux chamber technique. The experiment was carried out on the top surface of the dumpsites. The results of gas emissions and also the gas concentrations are shown in Appendix A.

The results of 40 minutes gas collections have shown three types of gas composition dynamics. Whenever, high emissions of methane have been recorded, the carbon dioxide concentrations were low. Vise-versa when low emissions of methane occurred. This could be attributed as mentioned by many authors that methane oxidation takes place near to the surface, particularly having a cover soil. Thus, the methane is converted to carbon dioxide at a fixed rate of oxidation, depending on the depth of cover. However, if the methane generation rates are higher than rate of oxidation, residual methane emissions are likely to take place as can be deduced from the results.

Another, perhaps one of the most important controlling factors for methane emissions is moisture. Such that whenever, high moisture contents prevail in the landfill body, methane emissions are high and the temperature increases within it. However, when the temperatures and the heat built up is above latent heat of condensation, a rapid loss of moisture from the landfill body seems to take place. On such occasions, the partial pressure of condensing moisture is high, preventing gases from migrating and the result in the GC indicate as 100% of other gasses of total volume. It should be noted that lateral gas migration is assumed to be zero.

Also, the phenomenon of decreasing step of gases could have occurred because gas flux into the chamber is controlled by pressure difference, a build up of pressure above barometric pressure will occur in the chamber and flux decreases with time (Kjeldsen, 1995). Also the diffusion flux will decrease due to increased concentration in the air space above soil surface in the chamber.

5.2.2 Landfill Gas Production and Migration

Gas concentration (%v/v) from these experiments at 7 days collection is presented in Table 5.1.

Table 5.1Landfill Gas Measurement by Flux Chamber Method in 7 Day Collection

Depth (m.)	Layer type	CH_4 Average Gas Generation ($ml/hr.m^2$)	CO_2 Average Gas Generation ($ml/hr.m^2$)	Others Average Gas Generation ($ml/hr.m^2$)
		Budgamuwa		
0.0	Surface Layer	2.69	6.36	6.70
		Maharagama		
0.0	Surface Layer	.08	.09	2.68
		Karadiyana		
0.0	Surface Layer	.15	.24	7.00

The differences of gas migration between Maharagama site and other two sites (Budgamuwa and Karadiyana) that were monitored were because of different ages of disposal in the dumpsites. Maharagama is the oldest dumpsite then Budgamuwa and Karadiyana respectively and it is not operational. At Karadiyana, not only the old wastes but also the new wastes are disposed, whereas at Budgamuwa, the disposing wastes are from recent times.

The average gas migration from the experimental sites was $0.2gCH_4/m^2/d$. This value is within the lower range of gas emissions as can be deduced when compared with the overall range of LFG emissions, 0.003 - 3,000 $g/m^2/d$ (Lagerkvist, 1995). This comparison confirmed that LFG production was by the degradation of slowly decomposable waste and the migration of gas was low. However, the total quantity of methane generations for the entire Colombo District could be as high as 1341 kg per year. This calculation was based on the extent of the three dumpsites and the total disposals over the ten years. Also if these results could be extrapolated for the entire country, since the disposal practices require large extents of land. The value of 0.11875kg/tonne/year over a period of 10 years at a collection rate of 2700 tonnes/day yields a total of 1.17 million tons of methane. This value is much more than reported figure of 0.01 million tones of methane. Indeed it is more than the emissions from Japan, since the technologies employed in Japan control the emissions of methane.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

The indiscriminate dumping is taking place in most parts of the Colombo District. Most of the local authorities in the Colombo District are aware of the grave situation and pollution levels caused by the present practices. They are relying on the private sector to develop the required processing and disposal facilities to sustain an appropriate management system. In the mean time with the lack of proper protection measures for controlling emissions, the LFG upward movement through the cover soil is high due to rapid decomposition of wastes.

This movement is governed by the rate of methane oxidation in the cover soil and thus carbon dioxide concentrations were high, lowing methane generations. Whenever the methane oxidation rates were superseded with high rate of methane generations in the landfill body, it resulted in high methane levels. The gas emission dynamics were dependent on the partial pressures of individual gases and evaporation of condensing vapor dictated methane and other gas emissions. However, the methane emissions from the surfaces of dumpsites had been considerable. These emissions represent slow decomposing wastes, like coconut husk but the total emissions from the District of Colombo and the Country are important. These results should be verified considering the large discrepancy of methane emissions being reported as being low. Furthermore, leachate diffused in to wetlands contributes to additional emissions of methane.

6.2 Recommendations for Future Work

Some recommendations on landfill gas experiment are given as:

- A small scale landfill or lysimeter is a better choice for further studies to eliminate on-site limitations such as uncontrolled parameters, limitation of night experiment or operation obstructions.

- Municipal solid waste used for small scale landfill should be separated into rapidly decomposable and slowly decomposable waste to determine chemical formulas and the rate of gas migration from each type.

- The comparison of landfill gas estimation should be determined among: a) formulas based on waste characteristic, b) a formula based on cover soil characteristic and gas concentrations at surface and bottom of cover soil, and c) actual emission rate measured from small scale landfill.

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Site- Buthgamuwa

Date	Sample size, ml/40min	Sample size, ml/1hr	sample intake GC (ml)	CO_2
18-07-06	9	13.5	6	99.64
19-07-07	10	15	6	89.54
20-07-08	9	13.5	6	72.58
21-07-09	6	9	6	12.87
22-07-10	12	18	6	0.00
23-07-11	7	10.5	6	2.59
24-07-12	8	12	6	4.47
Total Generation %				**281.69**
Total Gas Generation ($ml/hr.m^2$)				
Total Gas Generation ($ml/day.m^2$)				
Percentage of Gas emission from Total gas Volume (%)				

Site- Maharagama

Date	Sample size, ml/40min	Sample size, ml/1hr	sample intake GC (ml)	CO_2
18-07-06	7	10.5	6	5.83
19-07-07	12	18	6	3.21
20-07-08	8	12	6	0.31
21-07-09	9	13.5	6	0.00
22-07-10	14	21	6	0.00
23-07-11	11	16.5	6	4.53
24-07-12	7	10.5	6	3.90
Total Generation %				**17.79**
Total Gas Generation ($ml/hr.m^2$)				
Total Gas Generation ($ml/day.m^2$)				
Percentage of Gas emission from Total gas Volume (%)				

Gas composition analysis by GC (%)

Ethane	Methane	Nitrogen	H_2S	Propane		Other	Cha. Area (m^2)
0.00	0.03	0.01	0.05	0.04	99.77	0.23	0.20
1.37	1.42	0.13	0.41	0.27	93.14	6.86	0.20
27.42	0.00	0.00	0.00	0.00	100.00	0.00	0.20
0.25	61.37	0.00	0.00	0.00	74.49	25.51	0.20
0.00	0.00	0.84	0.01	0.00	0.85	99.15	0.20
0.30	10.07	12.25	1.49	0.44	27.14	72.86	0.20
4.19	10.77	7.16	0.00	0.00	26.59	73.41	0.20
33.53	**83.68**	**20.38**	**1.96**	**0.75**		**278.02**	
3.09	0.47	3.17	0.00	2.60	15.16	84.84	0.20
1.90	1.09	3.71	0.00	0.70	10.60	89.40	0.20
0.37	1.24	8.29	0.00	0.99	11.20	88.80	0.20
0.00	4.32	0.00	0.00	0.00	4.32	95.68	0.20
0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.20
0.47	5.02	5.41	15.19	0.54	31.16	68.84	0.20
0.44	7.39	2.04	0.00	0.67	14.45	85.55	0.20
6.26	**19.53**	**22.62**	**15.19**	**5.50**		**613.12**	

Site- Karadiyana

Date				
18-07-06	18	27	6	4.26
19-07-07	20	30	6	0.24
20-07-08	17	25.5	6	0.63
21-07-09	16	24	6	0.02
22-07-10	22	33	6	1.21
23-07-11	21	31.5	6	8.47
24-07-12	16	24	6	0.02
Total Generation %				**14.85**
Total Gas Generation ($ml/hr.m^2$)				
Total Gas Generation ($ml/day.m^2$)				
Percentage of Gas emission from Total gas Volume (%)				

1.24	1.53	2.96	0.00	3.99	13.98	86.03	0.20
0.03	0.15	0.52	0.00	0.28	1.22	98.78	0.20
1.51	0.64	0.81	0.00	0.45	4.04	95.96	0.20
0.01	0.01	0.01	0.00	0.04	0.08	99.92	0.20
0.00	12.56	0.00	0.40	0.00	14.18	85.82	0.20
0.36	10.11	26.97	0.00	0.20	46.11	53.89	0.20
0.00	0.01	0.00	0.01	0.00	0.03	99.97	0.20
3.15	**25.01**	**31.27**	**0.41**	**4.95**		**620.37**	

Site- Buthgamuwa	Gas Flux CO_2 (ml/hr)	Ethane (ml/hr)	Methane (ml/hr)
Date			
18-07-06	0.44	0.00	0.00
19-07-07	0.36	0.01	0.01
20-07-08	0.32	0.12	0.00
21-07-09	0.09	0.00	0.41
22-07-10	0.00	0.00	0.00
23-07-11	0.01	0.00	0.06
24-07-12	0.02	0.02	0.05
Total Generation %	**1.25**	**0.15**	0.53
Total Gas Generation (ml/hr.m^2)	**6.36**	**0.77**	**2.69**
Total Gas Generation (ml/day.m^2)	**152.63**	**18.57**	**64.46**
Percentage of Gas emission from Total gas Volume (%)	**37.09**	**4.51**	**15.67**
Site- Maharagama			
Date			
18-07-06			
19-07-07	0.03	0.02	0.00
20-07-08	0.01	0.01	0.00
21-07-09	0.00	0.00	0.01
22-07-10	0.00	0.00	0.02
23-07-11	0.00	0.00	0.00
24-07-12	0.02	0.00	0.02
Total Generation %	0.02	0.00	0.04
Total Gas Generation (ml/hr.m^2)	**0.08**	**0.03**	**0.09**
Total Gas Generation (ml/day.m^2)	**0.43**	**0.15**	**0.47**
	10.33	**3.68**	**11.29**

Nitrogen (ml/hr)	H_2S (ml/hr)	Propane (ml/hr)	Other (ml/hr)	
0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.03	
0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.17	
0.00	0.00	0.00	0.33	
0.07	0.01	0.00	0.42	
0.04	0.00	0.00	0.37	
0.11	**0.01**	**0.00**	**1.31**	
0.56	**0.05**	**0.02**	**6.70**	
13.36	**1.27**	**0.46**	**160.71**	**411.4674**
3.25	**0.31**	**0.11**	**39.06**	**100**
0.02	0.00	0.01	0.48	
0.01	0.00	0.00	0.30	
0.04	0.00	0.00	0.44	
0.00	0.00	0.00	0.43	
0.00	0.00	0.00	0.29	
0.02	0.06	0.00	0.25	
0.01	0.00	0.00	0.49	
0.10	**0.06**	**0.03**	**2.68**	
0.53	**0.28**	**0.14**	**13.66**	
12.64	**6.76**	**3.42**	**327.79**	**375.9166**

Site- Karadiyana	**2.75**	**0.98**
Date		
18-07-06		
19-07-07		
20-07-08	0.01	0.00
21-07-09	0.00	0.00
22-07-10	0.00	0.00
23-07-11	0.00	0.00
24-07-12	0.00	0.00
Total Generation %	0.02	0.00
Total Gas Generation (ml/hr.m^2)	0.00	0.00
Total Gas Generation (ml/day.m^2)	**0.03**	**0.01**
	0.15	**0.04**
	3.66	**0.87**
	1.95	**0.46**

3.00	**3.36**	**1.80**	**0.91**	**87.20**	**100**
0.00	0.01	0.00	0.01	0.19	
0.00	0.00	0.00	0.00	0.20	
0.00	0.00	0.00	0.00	0.23	
0.00	0.00	0.00	0.00	0.25	
0.02	0.00	0.00	0.00	0.16	
0.02	0.05	0.00	0.00	0.10	
0.00	0.00	0.00	0.00	0.25	
0.05	**0.06**	**0.00**	**0.01**	**1.37**	
0.24	**0.31**	**0.00**	**0.06**	**7.00**	
5.80	**7.46**	**0.09**	**1.34**	**168.11**	**187.3238**
3.09	**3.98**	**0.05**	**0.72**	**89.74**	**100**

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