Spatial variation in landfill gas composition under different precipitation condition and waste age in Sri Lanka

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Field Code Changed

Abstract

A study was conducted to assess the effect of precipitation and age of waste on the stabilization of the dumped waste. Landfill gas samples at 1-m depth were collected from 13 waste landfill sites in Sri Lanka with different annual precipitation ranging from 1,000 to 4,000 mm and waste age ranging from 1 to 120 months. Typical landfill gases O_2, N_2, CH_4 and CO_2 were measured quantitatively by a gas chromatograph. Buried waste samples at 1-m depth were also taken from all locations to determine organic carbon contents in the residue (< 2 mm).

With the age of wastes, the measured O_2 and N_2 concentration (ranged in 1 - 20% and 2 - 80% respectively) in collected landfill gas samples were increased and the CH_4 and CO_2 concentration (ranged in 0-60% and 1-68%, respectively) decreased, implying the buried wastes are getting stabilized within 120 months after dumped (typically in several decades in mid-latitude regions). However, the correlations between measured gas concentrations and the annual precipitations at the sampling site show no definite results.

Organic carbon contents in the waste residues (ranged in 24-236 mg g^{-1}) were not fully related to the waste age and the precipitation amount, while significant time-dependent decreases of the organic carbon contents can be observed in some investigated landfill sites. Further studies are needed with continuous monitoring of rainfall with gas emission.

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Keywords: Landfill gas, Organic carbon, Sri Lanka

1. Introduction

Uncontrolled final disposal of the municipal solid waste is commonly observed in developing countries. Such inadequate waste disposal system creates serious environmental burden which affects public health and ecosystem thus causes serious economic and other welfare losses (Zurbrügg, 2003). Furthermore, it is emphasized that this kind of burden lasts for not less than several decades to hundreds years (Rees, 1980).

Despite landfill gas is an important factor which causes odor and firing and provides information on the stability of the waste in landfill sites (Rees, 1980), there are very few such studies on the uncontrolled landfills. Koide *et al.* (2012) shown that the surface layer of the dumped waste in an abandoned open dump located at the Central Province, Sri Lanka reached 'stabilized phase' as the organic matter in the waste has decreased and N_2 and O_2 concentrations in the landfill gas have increased due to the intrusion of the air into the waste, within seven years after the disposal. This may be due to the high temperature and high amount of precipitation prevailing in the area.

The objective of this study is to observe typical landfill gas composition and organic carbon contents in the buried waste at several landfill sites in Sri Lanka which has different amounts of precipitation to observe the effect of precipitation on the landfill stability. Since the selected landfills contents are of different ages, it is also possible to evaluate temporal variation of processes.

2. Materials and Methods

2.1 Site description

The present study was conducted between November 2011 and June 2012 in Sri Lanka. Thirteen (13) open dump sites and sanitary landfill sites with different scale, age and annual precipitation were selected (Figure 1, Table 1). Coordinates, precipitations, and the ages of the respective sites are shown in Table 1.

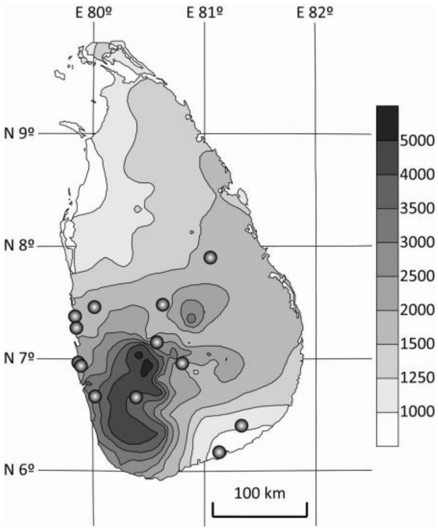

Figure 1: Location of the sites investigated. The shades of black indicate the amount (mm) of precipitation (Department of Meteorology 2012).

Table 1: Detailed information of the study sites

Site	*Scale*[*]	*Latitude*	*Longitude*	*Waste Age*[**] *(month)*	*Precipitation (mm)*	*Sampling date (yyyy/mm/dd)*
Nuwara-Eliya	*MC*	*N06º57'36''*	*E80º48'31''*	*1*	*1905.3*[†]	*2011/11/29*
Nawadewita	*UC*	*N07º08'33''*	*E80º34'42''*	*6, 84*	*2250*[‡]	*2011/12/01*
Matale	*MC*	*N07º28'07''*	*E80º37'56''*	*1*	*1750*[‡]	*2012/01/30*
Hambantota	*MC*	*N06º10'36''*	*E81º07'42''*	*1, 60*	*1049.6*[†]	*2012/02/07*
Kataragama	*PS*	*N06º25'38''*	*E81º18'49''*	*1*	*1125*[‡]	*2012/02/09*
Bandaragama	*PS*	*N06º40'08''*	*E80º01'23''*	*1*	*3250*[‡]	*2012/03/07*
Madampitiya	*MC*	*N06º57'42''*	*E79º52'26''*	*72*	*2423.8*[†]	*2012/03/08*
Kolonnawa	*MC*	*N06º56'17''*	*E79º53'25''*	*1, 6*	*2423.8*[†]	*2012/03/08*
Kuliyapitiya	*UC*	*N07º27'33''*	*E80º01'02''*	*1*	*1750*[‡]	*2012/03/09*
Negombo	*MC*	*N07º16'24''*	*E79º51'14''*	*5*	*2250*[‡]	*2012/05/29*
Wennappuwa	*PS*	*N07º21'20''*	*E79º51'36''*	*1*	*1750*[‡]	*2012/05/29*
Rathnapura	*MC*	*N06º40'03''*	*E80º23'34''*	*1*	*3749.2*[†]	*2012/06/05*
Thamankaduwa	*PS*	*N07º54'14''*	*E81º03'14''*	*1, 120*	*1750*[‡]	*2012/06/06*

[*]This parameter indicates the size of the main source of the waste dumped in each site. MC, UC and PS are municipalities which have a large, middle and small size of the population in their urban area, respectively; [**]Personal communication; [†]Obtained from a website of the Department o f Census and Statistics, Sri Lanka (Department of Census and Statistics 2010); [‡]Read from a web site of the Department of Meteorology, Sri Lanka (Department of Meteorology 2012).

2.2 Sampling and analyses

Either perforated PVC pipe, 13.2 mm in diameter, or metal pipe, 4.1 mm in diameter, was installed at the depth of 1 m in the sampling sites 30 minutes prior to gas sampling. The pipe was sealed by three-way cocks to allow the gas in the pipe to equilibrate with the landfill gas. Gas sample (500 mL) was taken into an air-tight aluminium bag using vacuum syringe. The samples were transferred to the laboratory to analyze the concentrations of typical landfill gases such as O_2, N_2, CH_4 and CO_2. The concentration of the each gas in the samples were analyzed using gas chromatography (GC) equipped with Thermal Conductivity Detector (GC-14A, Shimadzu, Kyoto, Japan and 6890 series, Agilent, Santa Clara, USA).

Waste samples were collected from 1 m depth (if it's not possible, shallower than 1 m) in each plot. The samples were dried at 60 ºC for more than 48 hours and sieved by 2 mm sized sieves to get the residue. The residue samples were transferred to the laboratory to analyze the carbon contents (MT-5, Yanaco, Kyoto, Japan).

Simple and multiple regression analyses were carried out to see the effects of waste age and precipitation amount on the landfill gas composition and carbon contents in the waste residue. Significance for all statistical analyses was accepted at $P = 0.05$. The statistical analyses were done using R (ver. 2.11.1; R Development Core Team 2010).

3. Results

The landfill gas concentrations obtained for each site are presented in Table 2.

Measured O_2 and N_2 concentrations in the landfill sites ranged between 0.7% - 20.1% and 2.1 - 80%, respectively. As shown in Fig. 2a and 2c for both gases, gas concentrations positively correlated with the waste age. On the other hand measured CH_4 and CO_2 concentration in the landfill gas ranged between 0.0% - 59.7% and 1.1 - 67.9%, respectively. A negative correlation was found with the waste age for CH_4 and CO_2 (Figure 2e, 2g). The outliers on Figure 2a, 2c and 2e were obtained at the highest position of the dumpsite. In this kind of area, the O_2 and N_2 concentration were low and the CH_4 concentration was high even at long waste age.

There was no significant relationship observed between the each gas concentration and the precipitation amount (Figure 2b, d, f, h).

Table 2: Landfill gas compositions and carbon contents of waste residues for each site

	Waste Age (Month)	O_2† (%)	N_2† (%)	CH_4† (%)	CO_2† (%)	C‡ ($mg\ g^{-1}$)	Remarks
Nuwara-Eliya	1	2.5	15.9	57.4	24.2	69.2	
Nawadewita	6	1.6	5.9	57.7	34.8	93.5	*Highest position of the landfill*
	6	2.3	23.8	42.4	31.5	224.3	*Middle of slope*
	6	3.5	57.9	19.5	19.1	135.5	*Bottom of slop*
	84	2.6	65.0	12.5	19.8	26.1	*Top of slope*
	84	17.9	79.4	0.0	2.7	23.8	*Middle of slope*
	84	13.0	80.0	0.0	7.0	36.9	*Bottom of slop*
Matale	1	2.1	7.3	56.5	34.0	52.7	
Hambantota	1	2.4	24.1	33.5	40.0	50.0	
	60	16.2	78.5	0.0	5.3	32.0	
Kataragama	1	0.7	2.4	51.2	45.7	-	*Residential area*
	1	2.7	38.8	27.4	31.1	-	*Market area*
	1	4.1	17.3	43.7	34.9	-	*Holy city area*
Bandaragama	1	0.7	2.1	59.8	37.4	30.7	
Madampitiya	72	1.4	9.8	53.7	35.1	107.3	*Highest position of the landfill*
	72	20.1	78.8	0.0	1.1	80.1	*Edge of the landfill*
Kolonnawa	1	1.7	6.7	5.3	67.9	236.1	
	6	1.1	3.8	59.7	35.4	71.7	
Kuliyapitiya	1	1.2	12.1	47.4	39.3	51.6	
Negombo	5	2.5	9.4	49.9	38.2	96.8	
Wennappuwa	1	3.1	11.6	41.1	44.1	48.6	
Rathnapura	1	1.9	18.6	40.4	38.9	46.8	
Thamankaduwa	1	2.3	28.9	34.3	34.5	98.0	
	120	16.8	71.6	5.2	6.4	68.7	

†Measured landfill gases; ‡Measured carbon contents in the waste residue

Measured carbon content in the waste residue varied from 23.8 to 236.1 mg g^{-1} (Table 2). The carbon content is correlated with neither waste age nor precipitation amount (Figure 3a, b).

A multiple regression analyses was carried out to evaluate the influence of waste age and the amount of precipitation to the measured landfill gas concentration and carbon content of waste residue (Table 3). The results showed that only waste age show effect on the landfill gas concentration. The carbon content was affected by neither waste age nor precipitation.

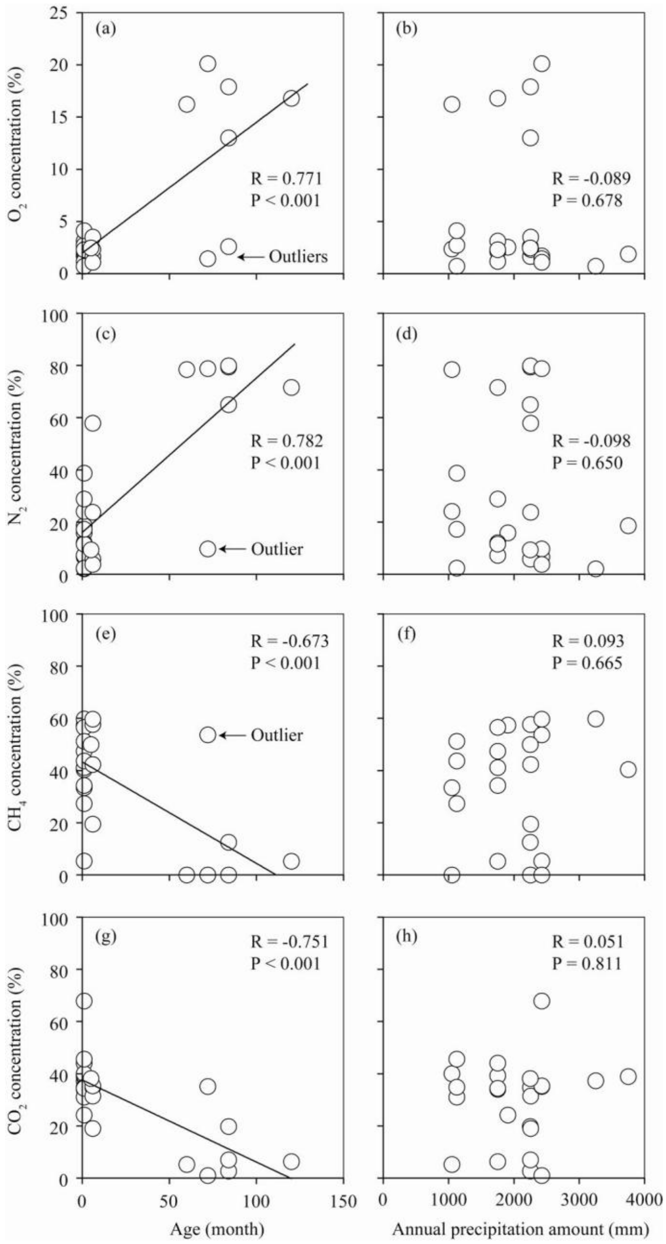

Figure 2: The relationship between CO_2 concentration and waste age (a, c, e, g) and annual precipitation (b, d, f, h), respectively.

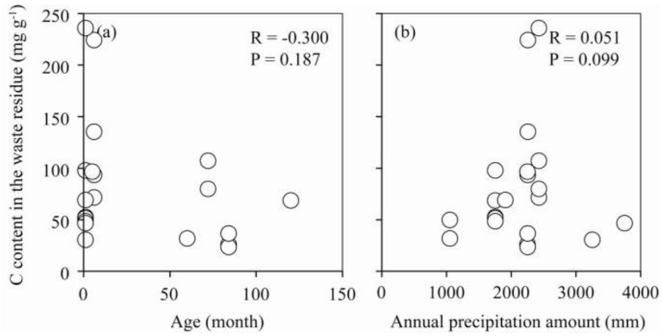

Figure 3: The relationship between carbon content in the waste residue and waste age (a) and annual precipitation (b), respectively.

Table 3: Partial regression coefficients obtained from multiple regression analyses

	P value of partial regression coefficients		P value of the multiple regression
	Waste age	Precipitation	
O_2†	< 0.001	0.358	< 0.001
N_2†	< 0.001	0.313	< 0.001
CH_4†	< 0.001	0.433	0.001
CO_2†	< 0.001	0.540	< 0.001
C‡	0.210	0.762	0.408

†Measured landfill gases; ‡Measured carbon contents in the waste residue

4. Discussion

The measured O_2 and N_2 concentration in the landfill gas increased and CH_4 and CO_2 decreased with the waste age (Figure 2). This implies the invasion of the air into the waste was occurring in the older sites. It is reported that the air invasion would start several decade after the termination of the landfilling in temperate region (Rees, 1980). The waste age of the oldest site in our study is only 120 months, so that it suggests the stabilization of landfill site in Sri Lanka is much more rapid than what has being observed in temperate regions. Measured carbon content of the waste residue, which is the more direct indicator to judge landfill stability than landfill gas composition, showed a decreasing trend with the waste age, although the reductions were not significant (Figure 3, Table 3). There was a tendency that start of the air invasion into the waste at highest positions was delayed comparing with the lower positions (Table 2, Figure 2). Lohila et al., (2007) suggested that the higher emissions from the highest positions are due to the uncovered surface and the daily deposition of new waste. Although the studied site has no difference in cover treatment between the highest position and lower positions and no daily deposition of new waste, the waste buried in deeper layers may play a role on the above phenomenon. Also, the buried waste at the highest positions may be newer than that at the lower positions.

Correlation between measured landfill gas concentrations and precipitation was not definite (Figure 2, Table 3). This suggests that without long-term continuous monitoring, relating precipitation amount with landfill gas composition in spot studies has no meaning. Koide *et al.* (2012) suggested that a washing out of the organic carbon of the landfilled waste because of high amount of precipitation causes the rapid stabilization. The carbon content of waste residue as mentioned was not correlated with precipitation amount in this study (Figure 3, Table 3). However, comparing the carbon contents in the waste residue among the sites those are located nearby each other, significant time-dependent decreases of the carbon contents can be observed (Figure 4). Especially, the decrease was stronger in the landfill sites located in wet zone (Nawadewita and Kolonnawa, where annual average precipitations are 2250 and 2423.8 mm, respectively) than that in the landfill sites in dry zone (Hambantota and Thamankaduwa, where annual average precipitations are 1049.6 and 1750 mm, respectively), though only two samples from each zone is available. This result indicate that although the wash out of organic carbon from the landfilled waste due to precipitation would be surely occurring, that is not the only reason for rapid stabilizations observed in Sri Lankan landfill sites. Further a study on the effects of seasonal precipitation on gas composition and the other inter-regional differences such as composition of buried waste is required to reveal the precise mechanism of this rapid stabilization.

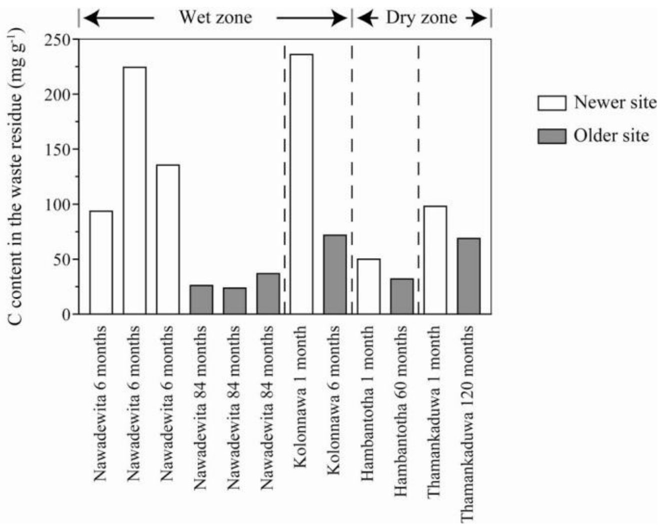

Figure 4: Comparison of carbon contents in waste residue among the sites those are located nearby each other. The bars between two dashed/non-dashed lines are indicating the carbon contents of the samples obtained from nearby each other.

5. Conclusion

The measured O_2 and N_2 concentrations in the landfill sites positively correlated with the waste age. On the other hand a negative correlation was found with the waste age for CH_4 and CO_2. There was no significant relationship observed between the each gas concentration and the precipitation amount. Measured carbon content is correlated with neither waste age nor precipitation amount. The present study revealed that the wash out of the organic carbon in the buried waste in Sri Lankan landfill due to precipitation is not only reason why the rapid stabilization is occurring in it. To detect the effect of the precipitation on the landfill stability, a further study regarding the effects of the seasonal precipitation and the other inter-regional differences is required to remove the noise.

6. Acknowledgements

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