Methane and Volatile Organic Compounds Emission and Distribution from Solid Waste Disposal Activities in Thailand

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Abstract

The objective of this research was to evaluate the emission and distribution of methane and volatile organic compounds (VOCs) from solid waste disposal site in Thailand. Gaseous emissions from solid waste piles with and without soil cover were determined. Highest average methane emission rate was found to be 53.51 g/m^2.d from solid waste pile with cover soil during rainy season. This rate was significant higher than 20.87 g/m^2.d under dry season and 5.23 g/m^2.d and 3.99 g/m^2.d from open waste pile under rainy and dry conditions respectively. The emission of BTEX compounds was found highest from the waste pile with cover soil under dry condition at $7.11\text{x}10^{-2}$, $9.76\text{x}10^{-2}$, $4.8\text{x}10^{-2}$ and $7.62\text{x}10^{-2}$ g/m^2.d. The sources of VOCs were identified in fresh waste samples. The dispersion of methane and BTEX compounds in ambient air was modeled. The risk of BTEX compounds to workers and nearby communities was at low level as determined by hazard index.

Keywords: Gas Emission, Landfill, Methane, Solid Wastes, Volatile Organic Compounds

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Introduction

About 65% of municipal solid wastes collected in Thailand are disposed by unsanitary method (Asian Institute of Technology, 2004) which creates several environmental problems. The waste disposal activities also released gaseous pollutants, mainly methane and carbon dioxide. In addition to those greenhouse gases, volatile organic compounds (VOCs), though present at lower concentration, could pose severe hazard to human and the environment. In Thailand, it was estimated that about 0.28 million tons of methane was released from solid waste disposal sites to the atmosphere each year (Thailand Environment Institute, 1996). Globally, about 20-70 million tons of this greenhouse gas was emitted from waste disposal activities (IPCC, 1996). Non-methane organic compounds emission was estimated at 13,000 tons (Eklund et al., 1998). In the past decade, many countries have paid the attention on methane and VOCs emission from solid waste disposal site for adoption of mitigation measures. In developed countries, USA, municipal landfills in operation need to comply with regulations to reduce methane and VOCs emission from the diversion of organic and hazardous wastes from municipal landfills. Nevertheless, the study in developing countries on this issue is still very limited

Therefore, this research is focusing on the field investigation of methane and VOCs (Benzene, Toluene, Ethylbenzene and Xylene or BTEX compounds) emission from solid waste disposal site in Thailand. The scope of study includes determination of methane and VOCs emission rate from waste pile with and without cover soil, contamination of BTEX compounds in solid waste components, dispersive transport of methane and BTEX compounds off the site and their effect to workers and nearby community health risk.

Methodology

Site characteristic

The study was conducted at Nonthaburi solid waste disposal site. This site was situated in Sai Noi, one district in Nonthaburi, Thailand (Figure 1). The site covers an area of about 58 rais (1 rai equal to 1600 m^2) and was in operation from 1982 until now. Total amount of waste deposited at the site was more than 2 million tons. In 2007, this site has 3 closed waste cells and 2 waste dumping piles in operation. The quantity of solid wastes received at the site was about 800 tons/day. The wastes were disposed in open dumping manner forming a mountain of about 7-10 meters above ground. Cover soil was occasionally placed on the waste pile at every 6 months interval period. Leachate formed during raining period at the site was gravitationally drained from the waste pile through open channel and pumped into an open storage pond.

The surrounding topographic feature is flat terrain with maximum elevation difference of less than 2 meters. The site is surrounding by rice fields.

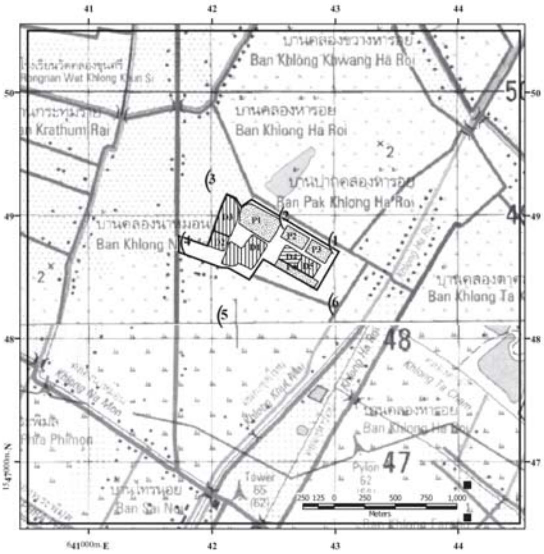

Figure 1. Geographical location of Nonthaburi solid waste disposal site

Residential areas were located about 1 kilometer adjacent to the site in northern, northeastern, eastern and southeastern directions. Khlong Na Mon and Khlong Ha Roi were the major natural water bodies where the water is utilized for agricultural and domestic consumption purposes.

Collection of samples and analysis

Surface isolation flux chamber operated under static mode (Chiemchaisri et al., 2006a) was used for the determination of methane and VOCs emission rate from the surface of the two operating waste piles (1 year old). The gas emission rate was measured at surface of waste pile with and without cover soil. The schematic diagram of closed flux chamber used for the determination of gas emission rate is shown in Figure 2. The chamber was made from stainless steel with 0.049 m^3 volume and 0.188 m^2 cover area.

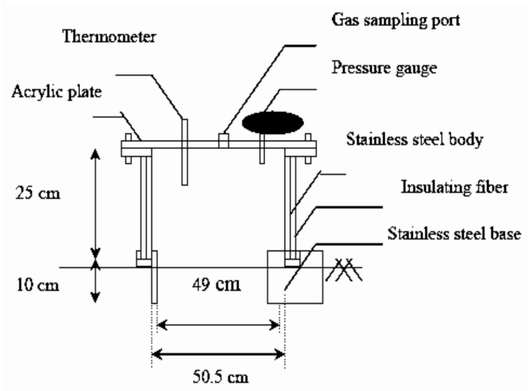

Figure 2. Schematic of closed flux chamber

After the chamber had been placed on the surface of the waste pile (either with or without cover soil), gas samples were collected at the starting time and consecutively at every 20 minute interval for 1 hour. The methane concentration in collected samples was then analyzed using gas chromatography (Agilent 6890-ECD detector).

The closed flux chamber was operated by allowing gas from surface of waste pile to accumulate inside the chamber and the increment of gas concentration was determined for a period of time. The increasing rate in gas concentration with time was used to determine the gas flux as described in equation 1.

$$F = \frac{\rho V \Delta C}{A \Delta t} \qquad (1)$$

where F is the flux of gas ($g/m^2.h$), D is the density of the gas (g/m^3), V is the volume of chamber (m^3), Ais the surface of chamber enclosed area (m^2), D C is the change of gas concentration, and Dt is the time interval which samples were taken (h).

For VOC determination, the gas samples were withdrawn from the chamber after 1 hour. The optimum sampling period was referred from our previous study (Chiemchaisri et al., 2006b). The collected gas sample was passing through the adsorbent tube (SKC-activated coconut shell charcoal-20/40mesh) at 30 ml/min flow rate for 20 minutes for VOC adsorption. The adsorbed VOCs in the adsorbent tube were then extracted by using carbon disulfide (CS_2) and analyzed by gas chromatography (Shimadzu GC14B-FID detector).

The emission rate from closed flux chamber samples were interpolated into spatial average emission by inverse distance weight (IDW) interpolation method. The VOC concentrations in ambient air were determined at upwind and downwind sampling stations (indicated as point No.1, 2, 5 and 6 in Figure 1). The ambient air sampling stations (point no.1 and 2) were located on downwind direction during the sampling period whereas point No.5 and No.6 were the sampling stations towards the residential area. The station No. 5 is located near Sainoi residential village and point No. 6 was at Khong Ha Roi agricultural village.

Pollutant dispersion model-AERMOD

The transportation of VOCs was determined by AERMOD model. The AMS/EPA regulatory model (AERMOD) is a steady-state gaussian plume modeling tool for assessing potential environmental and health effects of continuous emissions to the atmosphere. The AERMOD can be used to assess pollutant concentration downwind from a source, including point, area, volume and open pitch source type (U.S. Environmental Protection Agency, 2004). For the application of the AERMOD at solid waste disposal site, area sources characterization was used to simulate emission that initially disperse in two dimensions with little or no plume rise, such as ground-level or low-level emissions from this study site. It should be noted that the approach that AERMOD uses to address plume meander had not been implemented for area sources. As a result, concentration predictions for area sources may be overestimated under very light wind condition. In general, this is not expected to be a problem for meteorological data collected using standard wind instruments that threshold are generally too high and a worse case scenario was applied. In order to avoid over estimates for area sources during light wind condition, simulation using pseudo-point sources is used.

The assessment of methane and VOCs emission from two solid waste dumping piles currently in operation was based on direct field measurement, whereas the emission rates from other three closed waste cells were obtained from previous study (Chiemchaisri et al., 2006a; Chiemchaisri et al., 2006b). These emission rates were then input into AERMOD model. They were also varied with the presence or absence of cover soil. Seasonal effect was determined by varying precipitation and evaporation in each month using actual meteorological data. In this study year, the wet season started from July until October and other months were classified as dry season. Other required meteorological data were wind speed, wind direction, dry bulb temperature, cloud cover and ceiling height. They were obtained form Don Muang Airport Station, Bangkok which is the nearest site with available information. The surface meteorological data were then rearranged into format suitable for input (SCRAM) before transfer into preprocessing process for the calculation of planetary boundary layer. The upper air sounding data or rawinsonde was also obtained from Bangkok's Bang Na station. The cartesian grid receptor networks were defined in coverage domain of 4x4 km_2, each receptors were 100 meter interval. Thus, 1681 receptors were calculated for predictable concentration. In AERMOD model, three control parameters related to the surface characteristics were the surface roughness, albedo and the bowen ratio. These parameters were used to calibrate model by matching data from model and ambient air concentration sampling. These control parameters were then corrected using the values suggested by the model developer (U.S. Environmental Protection Agency, 2004).

Health risk

Non-carcinogenic health risk from dispersed VOCs exposed to the workers at the site and population in nearby communities was determined by hazard index. The VOC concentrations were derived from annual average concentrations from AERMOD model. Hazard quotient (HQ) or Hazard index (HI) was used to indicate level of non-carcinogenic risk by comparing the intake rate with reference dose

(RfD). The critical ratio is defined as 1.0 (Louvar, 1998). Inhalation intake was derived from Equation 2 and inhalation reference dose was retrieved from IRIS (Integrated Risk Information System, 2007).

$$I = \frac{CRt_E f_E Dt}{W_B t_{avg}} \qquad (2)$$

where I is the inhalation intake (mg/kg.d), C is the gas concentration (mg/m^3), R is the rate of inhalation (m^3/day), t_E is the time of exposure (hr/day), f_E is the frequency of exposure (day/year), D_t is the duration of exposure (year), W_B is the body weight (kg), and t_{avg} is the total days of exposure (days; equal to D_tx365)

Results

Methane and VOCs emission from waste pile

Surface emission rate of methane (M) and VOCs (BTEX compounds) from solid waste pile without cover soil was determined as shown in Table 1. For comparison, the emission from waste pile with cover soil was presented in Table 2. It was found that average methane emission rate from open waste pile ranged between 2.47 and 7.51 g/m^2.d during dry period with an average of 3.99 g/m^2.d. During wet period, the emission rate was 0.51-13.07 g/m^2.d (avg. 5.23 g/m^2.d). These emission rates were considerably lower than that of waste pile with cover soil (20.87 and 53.51 g/m^2.d during dry and wet period respectively) as shown in Figure 3. The results suggest that anaerobic condition and

Table 1. Methane and VOCs emission from waste pile without cover soil in dry and rainy seasons

	Emission rate (g/m^2.d)			
	Dry season		Rainy season	
	Range	Avg.	Range	Avg.
M	2.47-7.51	3.99	0.51-13.07	5.23
B	0.0107-0.0279	0.0214	0.0044-0.0203	0.0103
T	0.0067-0.0329	0.0194	0.0065-0.0203	0.0140
E	0.0080-0.0115	0.0101	0.0050-0.0105	0.0088
X	0.0098-0.0197	0.0151	0.0047-0.0122	0.0092

Table 2. Methane and VOCs emission from waste pile with cover soil in dry and rainy seasons

	Emission rate (g/m^2.d)			
	Dry season		Rainy season	
	Range	Avg.	Range	Avg.
M	3.20-53.93	20.87	20.01-86.70	53.51
B	0.0248-0.1401	0.0711	0.0046-0.0942	0.0325
T	0.0135-0.1921	0.0976	0.0191-0.1930	0.0833
E	0.0211-0.0794	0.0480	0.0090-0.0669	0.0297
X	0.0387-0.1070	0.0762	0.0205-0.0740	0.0490

moisture content in solid waste pile were the key factors governing methane emission from solid waste disposal site. The moisture content in cover soil affected the microbial activities, and microorganisms could be inactive when the moisture content dropped below 5% (Glinski and Stepniewski, 1986).

The emission rates of BTEX compounds from open solid waste pile during dry period were $2.14\text{x}10^{-2}$, $1.94\text{x}10^{-2}$, $1.01\text{x}10^{-2}$ and $1.51\text{x}10^{-2}$ g/m^2.d, higher than $1.03\text{x}10^{-2}$, $1.40\text{x}10^{-2}$, $0.88\text{x}10^{-2}$ and $0.92\text{x}10^{-2}$ g/m^2.d during wet period. Higher emission rates were detected from solid waste pile with cover soil during dry period, i.e. $7.11\text{x}10^{-2}$, $9.76\text{x}10^{-2}$, $4.80\text{x}10^{-2}$ and $7.62\text{x}10^{-2}$ g/m^2.d, whereas they were $3.25\text{x}10^{-2}$, $8.33\text{x}10^{-2}$, $2.97\text{x}10^{-2}$ and $4.90\text{x}10^{-2}$ g/m^2.d during wet period. The temperature in the waste pile was found to be the major factor affecting VOCs emission from solid waste pile (Chiemchaisri et al., 2006). During the higher temperature period especially in summer with dry condition, higher emission rates were detected as compared to the rainy season (Kim and Kim, 2002; Zou et al., 2003).

In our previous study (Chiemchaisri et al., 2006), the sources of VOCs in fresh waste samples were investigated. The emission VOCs from mixed and separated waste component was determined at 40 and 80°C simulating ambient and disposed waste conditions. The contamination of toluene and benzene were detected at 6.46 and 0.47 mg/kg. The elevated temperature increased VOCs emission from waste. The waste components contributing majority of VOCs were plastic and yard wastes. Toluene was found at highest concentration in mixed wastes.

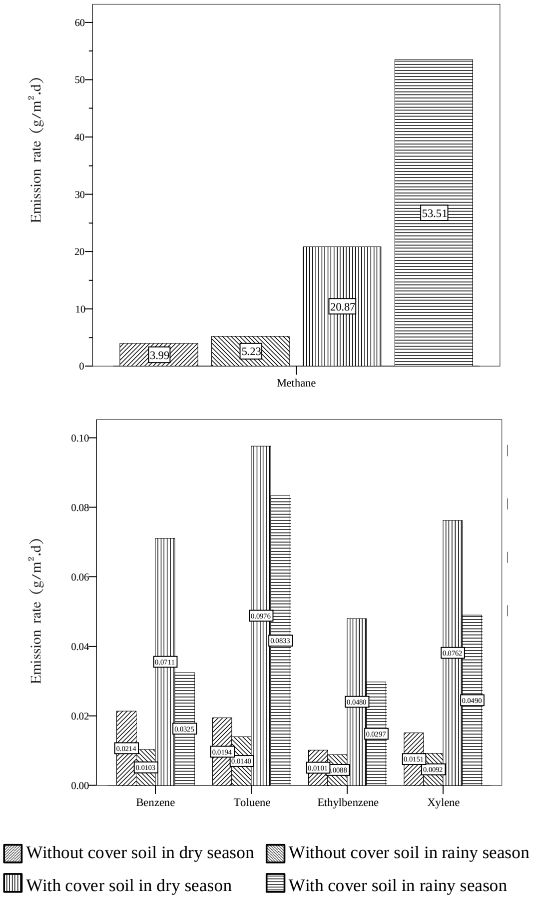

Figure 3. Comparison in methane and VOC emission from waste pile with and without cover soil during dry and rainy period.

Distribution of VOCs in ambient air

BTEX level in ambient air was determined by direct measurement at different sampling stations locating surround the site. Maximum BTEX concentrations detected were 0.71, 0.59, 0.17and 0.43 mg/m^3. These results were used to calibrate the control parameters (the surface roughness, albedo and bowen ratio) in AERMOD model. Moderate agreement (R=0.55) between the coefficients from the field measurement and model was obtained.

Table 3. Annual average BTEX concentrations in ambient air as suggested by AERMOD model

	Ambient air concentration ($\mu g/m^3$)			
	Waste disposal site		Nearby communities	
	Range	Avg.	Range	Avg.
B	0.06-0.40	0.20	0.003-0.28	0.03
T	0.07-0.65	0.28	0.004-0.41	0.05
E	0.03-0.28	0.13	0.002-0.18	0.02
X	0.05-0.44	0.20	0.003-0.28	0.03

Table 4. Highest monthly average ambient air concentration of BTEX compounds

	Ambient air concentration ($\mu g/m^3$)			
	Waste disposal site		Nearby communities	
	Range	Avg.	Range	Avg.
B	0.14-0.87	0.47	0.009-0.76	0.10
T	0.16-1.50	0.64	0.010-0.96	0.13
E	0.08-0.56	0.30	0.005-0.48	0.06
X	0.12-0.89	0.47	0.009-0.75	0.10

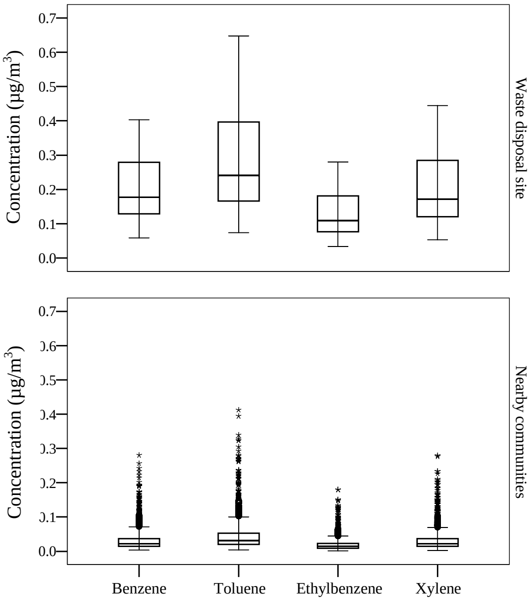

Figure 4. Box plot of annual average concentration of benzene

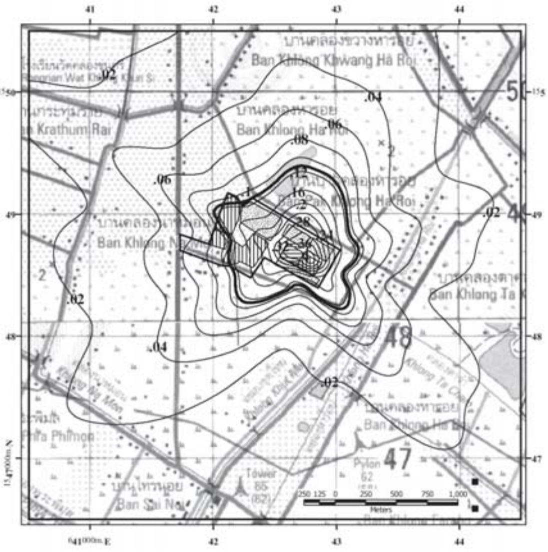

Figure 5. Annual average concentration of benzene from AERMOD model

Annual average concentrations of BTEX compounds within the site and at nearby communities, as suggested by AERMOD model are shown in Table 3. They were averaged at 0.20, 0.28, 0.13, 0.20 μg/m^3 and 0.03, 0.05, 0.02, 0.03 μg/m^3 respectively. Figure 4 presents the box plot showing minimum and maximum concentration range, 25th percentile, 75th percentile, median, and outlier which presenting extra higher concentration in ambient air outside the receptor area. Considering in nearby communities, the annual average concentration of BTEX is not exceeding 0.1 g/m^3, but higher concentration could be found over 0.1-0.5 g/m^3 in some other areas. Figure 5 shows the affected area from the dispersion of benzene surrounding the solid waste disposal site.

In Figure 5, the dispersive transport of benzene was mainly into the north and southeast direction from the site. As a result, the affected areas from this dispersion include Khlong Ha Roi agricultural village and Sai Noi residential village (station No.6 and 5 in Figure 1 respectively).

The annual average BTEX concentrations (Figure 5) were derived from constant input from the defined sources in 2007. In order to study the seasonal and wind effect, wind-rose diagram of the study area as shown in Figure 6 was used. From the diagram, wind direction covered most except northern direction. In addition to wind speed and direction, the temperature and cloud cover were also varied in each month giving different micro-climate condition. The emission rates from waste piles were also found varied monthly depend on seasonal condition. Therefore, monthly average concentration was also determined giving the possible impact from the source at any direction and period of the year.

Highest monthly average concentration of BTEX compounds to the workers within the site and nearby communities, as suggested by AERMOD model, were 0.47, 0.64, 0.30, 0.47 μg/m^3 and 0.10, 0.13, 0.06, 0.10 μg/m^3 respectively. The results in Table 4 and Figure 7 also show the variation of maximum monthly average value within the disposal site and nearby communities.

Figure 8 shows the dispersion pattern of benzene by using monthly average concentration in each month of the year. The concentrations were normalized by the difference between 95th percentile and 5th percentile of annual average as reference value and then shown as 0.5 and 1.0 level in map for each month.

From the model, highest concentrations were predicted during winter period (November and December) as a result of higher emission rate and wind effect. During summer (May and June), high dispersion was also observed.

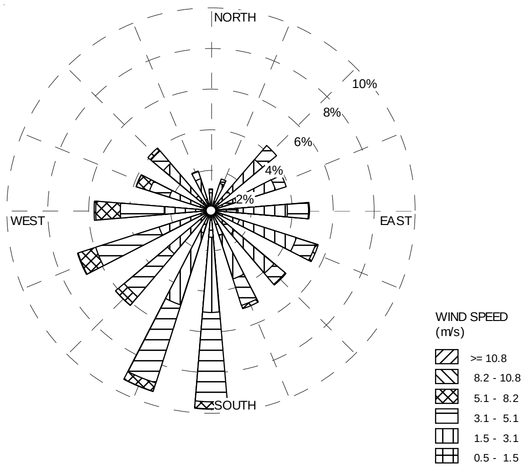

Figure 6. Wind rose diagram in year 2007 at Don Muang Station.

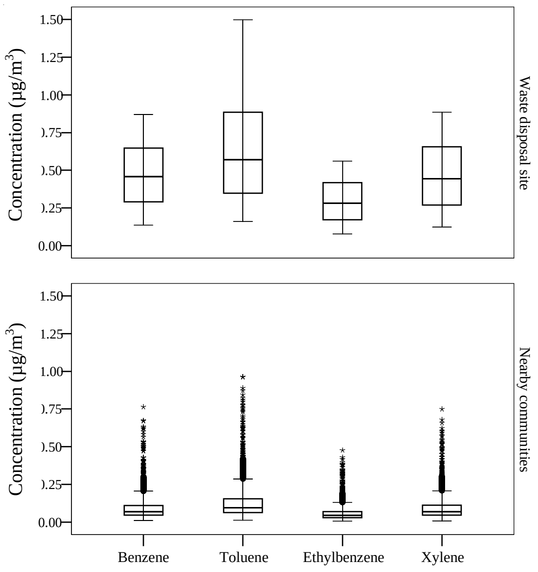

Figure 7. Box plot of highest monthly average concentration of benzene.

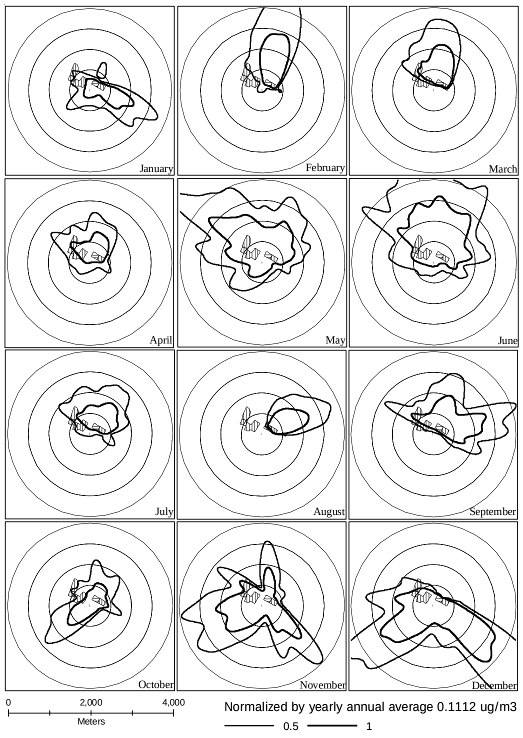

Figure 8. Normalized monthly average concentration of benzene from AERMOD.

Risk to workers and nearby communities

The evaluation of health risk from VOCs to the workers was estimated using maximum 8 hours time weight average (TWA) concentration of BTEX compounds obtained from AERMOD model and compared them to standard values, i.e. TLV (ACGIH), REL (NIOSH) and PEL (OSHA). In most cases, the VOC concentrations in ambient air were comparably lower than the standards suggesting low risk levels to the workers.

The non-carcinogenic risk of total BTEX in term of hazard index to the workers whom working 8hours/day 5days/week and 48 weeks/year for 45 years, were found to be between 0.02-0.15 which is less than the critical value of 1.0 (Figure 9). The health risks from solid waste activity to the people living in surrounding communities (24 hours/ day 7days/week 50weeks/year for 70 years) were ranged between 0.01-0.40, depending on the direction and distance from the site.

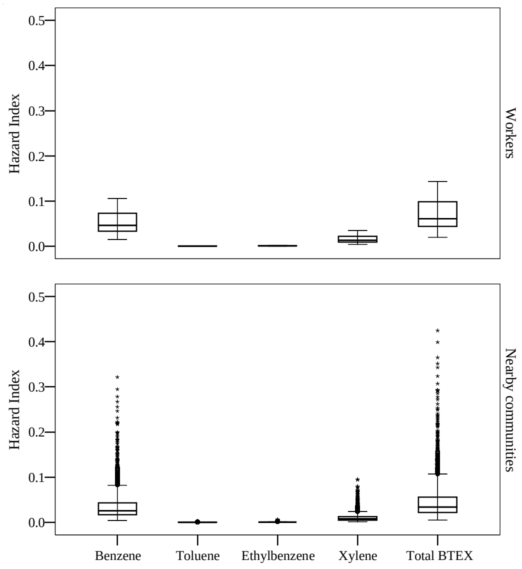

Figure 9. Box plot of health risk to on site workers and nearby communities.

In case of nearby communities, the BTEX concentrations for lifetime exposure which give hazard index equal to 1.0 were 0.87, 141.94, 29.40 and 2.94 g/m^3 whereas the maximum annual concentrations of BTEX in 2007 from the AERMOD model were only 0.4028, 0.6473,0.2800 and 0.4438 g/m^3. These results suggested that the dispersive transport of BTEX to nearby communities were at low level. Figure 10 shows the risk map of VOC exposure at the site and nearby communities.

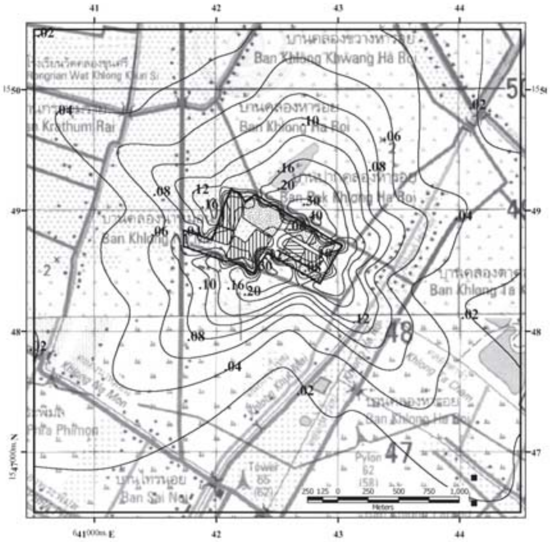

Figure 10. Risk map of VOC exposure

Conclusions

Methane and VOCs emission and distribution from solid waste disposal activities at Nonthaburi municipal solid waste disposal site were studied. Methane and VOCs emission rate was found highest from solid waste pile with cover soil during wet season and dry season respectively. VOCs were found contaminated in various waste components. The distribution of VOCs in ambient air within the site and surrounding communities were determined by direct measurement and AERMOD model. The concentration of VOCs distribution varies seasonally. Nevertheless, health risks to the workers within the site and nearby communities were at low level as determined by hazard index.

Acknowledgments

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