ROADSIDE PM2.5 AND BTEX AIR QUALITY IN HO CHI MINH CITY AND INVERSE MODELING FOR VEHICLE EMISSION FACTOR

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ABSTRACT: The roadside PM2.5 and BTEX pollutions were monitored in relation to traffic volume at a typical urban street in Ho Chi Minh City (HCMC), Vietnam. The 24-h PM2.5 concentration was 53 – 129 μg/m^3 while 8-h PM2.5 concentration was 50 – 170 μg/m^3. The hourly levels of benzene, toluene, ethylbenzene, m,p-xylenes and o-xylene vary between 6 – 53, 14 – 170, 3 – 24, 5 – 59, and 2 - 21 μg/m^3, respectively, within a day. During the daytime higher concentrations were observed on weekdays than weekend but the opposite was observed at the nighttime and early morning when weekend had higher concentrations. This corresponds to the variations in traffic volume between weekdays and weekend. Pollution levels measured within 30 m from the traffic lane were found to reduce with increasing downwind distance. Principal component analysis (PCA) was applied to the set of air pollution concentration and traffic volume data which revealed that diesel fueled vehicles (truck and bus) were associated with PM2.5 while gasoline fueled vehicles (motorcycle, car, and delivery tricycle) were linked to BTEX. Vans were associated with both PM2.5 and BTEX as they use both diesel and gasoline fuels.

Inverse CALINE4 modeling produced the average emission factors of PM2.5, benzene, toluene, ethylbenzene, m,p-xylenes, and o-xylene for the whole street fleet of 38 ± 3.9; 23 ± 4.3; 74 ± 14.8; 8 ± 1.3; 28 ± 9.5; and 9 ± 2.5 mg/vehicle.km which correspond to hourly fleet emission ranges during a day of 141 – 388; 18 – 435; 52 – 1493; 6 – 131; 18 – 655; and 6 - 194 g/km.hour, respectively. Solving the multilinear equation system constructed based on the hourly fleet emission and fleet composition was revealed that the gasoline fueled vehicles had lower PM2.5 emission factor but higher benzene, toluene, ethylbenzene, m,p-xylenes, and o-xylene emission factors than the diesel fueled vehicles. The corresponding emission factors for gasoline fueled vehicles were 25 ± 2.4; 22 ± 0.1; 68 ± 0.3; 8 ± 0.1; 22 ± 0.1; and 8 ± 0.1 mg/vehicle.km, respectively, while for diesel fueled vehicles the emission factors were 388 ± 164.0; 17 ± 5.3; 61 ± 22.2; 4 ± 3.3; 20 ± 5.5; and 5 ± 2.9 mg/vehicle.km, respectively.

INTRODUCTION

Transport sector has become an increasing source that causes serious adverse effects on air quality in Ho Chi Minh City (HCMC), the largest city in Vietnam. A rapid growth in vehicle number has been observed during the last decade. Large fleet of cheap and over-aged motorcycles, poor vehicle maintenance, and low quality fuels contribute significantly to the pollution level in the city. Good understanding vehicle emission and the consequent roadside air pollution is a first step toward traffic air pollution management.

Many efforts have been put forward to estimate vehicle emission factor. Chassis dynamometer test is the direct way to obtain it but requires complicated monitoring equipment to simulate the on-road conditions. Though this method would not produce the real "on road" emission factor, it is normally a preferred test method for vehicle emission regulation purpose (Kim Oanh et al., 2008). Other methods used include the tunnel method or inverse modeling approach that calculate emission factor based on data collected by a specially designed monitoring program. The methods look promise since they can reflect the on road situation, ability in large number of vehicle estimation and a cost – effective. Different types of line source models can be used for the purpose which should be selected based on road configuration. CALINE4 model, developed by the California Department of Transportation, is applied to characterize air pollution in open streets, using the Gaussian diffusion equation and mixing zone concept. The inverse modeling capacity of this model for vehicle emission factor determination was shown by several researchers (Gramotnev et al., 2003, Kawashima et al., 2006).

This study has been designed to characterize the roadside air pollution in HCMC in relation to traffic volume. An open street that represents average traffic flow in the city was selected for the monitoring and CALINE4 inverse modeling. The focus was toxic air pollutants including

PM2.5 and BTEX (benzene, toluene, ethylbenzene, and xylenes).

METHODOLOGY

Monitoring design

Monitoring program was conducted at Hoang Van Thu Street, Ho Chi Minh City. This two lane street, 20 m in width, was selected as it is a typical urban street which has average vehicle speed, and traffic volume in the city. The street characteristic is suitable for CALINE4 application (open street, street direction nearly perpendicular to prevalent winds). PM2.5 and BTEX measurements were conducted during one month (from 10 December 2007 to 7 January 2008) simultaneously with meteorological parameters, and traffic volume. The sketch of monitoring site is shown in Figure 1.

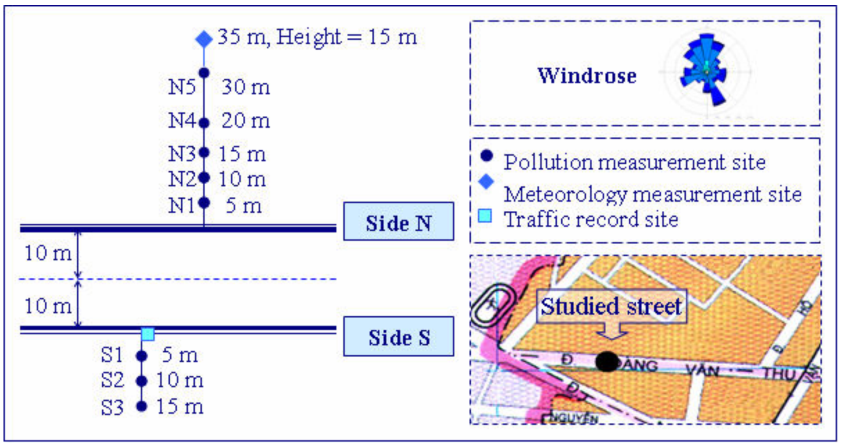

Figure 1 Sampling site

PM2.5 samples were collected using a Minivol portable air sampler while BTEX samples were collected by SKC–coconut shell charcoal tubes. All samples were taken at 2 m above the ground. In the laboratory, PM2.5 mass measurement was done using a microbalance in a temperature and relative humidity controlled environment (22 ± 2°C and 39 ± 3%). BTEX concentrations were quantified by a GC-FID followed NIOSH method 1501 (NIOSH, 2003). Traffic was recorded using a video camera then hourly traffic volume was counted manually. Meteorological parameters were recorded on the top of 15 meter height building located at the distance of 35 meters from the roadside. Data, which was collected for every 10 minutes consisting of wind direction, wind speed and ambient temperature, was used to determine hourly average parameters following the Yamartino method (Yamartino, 1984).

Air pollution and traffic relationship analysis

Pollutant concentrations attributed by traffic emission and traffic composition were analyzed together to find the relationship. The principal component analysis (PCA) was used for the multivariate data set consisting of 8 hours average PM2.5, BTEX concentrations and traffic volumes which are separated into motorcycle, car, van, bus and truck, and delivery tricycle.

Composite emission factor calculation using inverse modeling

CALINE4 model gives the direct proportion of emission factor to the predicted concentration (Benson, 1989) that leads to the following equation.

$$\frac{e_{Estimated}}{e_{Modeled}} = \frac{C_{Measured-N} - C_{Background}}{C_{Traffic-N,Modeled}} = \frac{C_{Measured-S} - C_{Background}}{C_{Traffic-S,Modeled}} \quad (1)$$

Where $e_{Estimated}$ is the estimated composite emission factor; $e_{Modeled}$ is the arbitrary emission factor reloaded into CALINE4 model; $C_{Traffic\text{-}N,Modeled}$ is the traffic concentration estimated by CALINE4 model at side N; $C_{Traffic\text{-}S,Modeled}$ is the traffic concentration estimated by CALINE4 model at side S; $C_{Measured\text{-}N}$ is the concentration measured at side N; $C_{Measured\text{-}S}$ is the concentration measured at side S; $C_{Background}$ is the background concentration. When the wind is highly variable or wind direction is nearly parallel to the street direction, background concentration is hardly to be measured. In this case, the study was developed a calculation equation for background concentration as follow.

$$C_{Background} = \frac{\alpha C_{Measured-S} - C_{Measured-N}}{\alpha - 1} \quad (2)$$

Where α is the ratio of $C_{Traffic\text{-}N,Modeled}$ to $C_{Traffic\text{-}S,Modeled}$. Note that when traffic concentration calculated by CALINE4 model is equal to zero, background concentration is equal to measurement concentration.

Once running CALINE4 with arbitrary emission factor, $e_{Modeled}$, and background concentration, $C_{Background}$, of zero, predicted concentration at two receptors, $C_{Traffic\text{-}N,Modeled}$ and $C_{Traffic\text{-}S,Modeled}$, are obtained. Thus background concentration, $C_{Background}$, is estimated by Eq (2). And composite emission factor, $e_{Estimated}$, is estimated by Eq (1).

Emission factor calculation for individual vehicle categories

Fleet emission is the sum of individual vehicle categories emissions (Kawashima et al., 2006; Palmgren et al., 1999) that gives a chance for calculating their own emission factor.

$$Q = N_{GV}.E_{GV} + N_{DV}.E_{DV} \quad (3)$$

Where Q *is the* hourly fleet emission; $N_{GV,DV}$ is the hourly traffic volume of gasoline, diesel fueled vehicle; $E_{GV,DV}$ is the emission factor of gasoline, diesel fueled vehicle. From the monitoring data, a system of Eq (3) was constructed. This equation system was solved by using multilinear regression analysis to obtain the emission factors of gasoline and diesel fueled vehicles.

RESULTS AND DISCUSSIONS

PM 2.5 roadside concentration

The average 8h-PM2.5 concentrations were 134 μg/m^3 for weekdays and 114 μg/m^3 for weekend. The diurnal variation (Figure 2) shows that weekdays had higher concentration than weekend but not in the nighttime and early morning (22 p.m. – 6 a.m.). At this time, weekend had higher concentrations due to the higher traffic volume as recorded. Especially the higher number of truck, truck is the main source of PM2.5 among vehicles, contributed strongly to the high concentration.

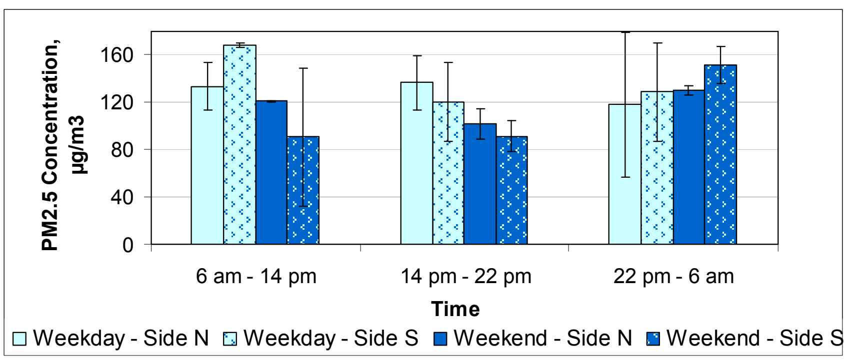

Figure 2 8h-PM2.5 Diurnal variations

The 24h-PM2.5 concentrations reduced gradually along downwind distance. They were 88 ± 7, 83 ± 8, and 78 ± 10 μg/m^3 for the distances of 10, 20, and 30 m from the traffic lane in the North roadside, respectively. Figure 3 shows the 24h-PM2.5 concentrations during monitoring period. These obtained 24h-PM2.5 concentrations are all higher than the 24 hours limit level of US EPA standard, 35 μg/m^3 and indeed the WHO guideline, 25 μg/m^3.

Comparing with some Asian cities (Table 1), the 24h-PM2.5 pollution level in HCMC is somewhat similar to that in Ha Noi, Bangkok and Hong Kong. Note that the sampling site in this study represents the average traffic condition in HCMC and not the high congestion streets as the others.

BTEX roadside concentrations

Hourly BTEX concentrations were correlated to traffic volume (Figure 4). On weekdays, the diurnal concentration ranges were 6 – 53, 18 – 170, 3 – 24, 5 – 59, and 2 – 21 μg/m^3 for benzene, toluene, ethylbenzene, m,p-xylenes, and o-xylene, respectively. On weekend, the ranges were 8 – 34, 14 – 122, 3 – 12, 5 – 34, and 2 – 12 μg/m^3 for benzene, toluene, ethylbenzene, m,p-xylenes, and o-xylene, respectively.

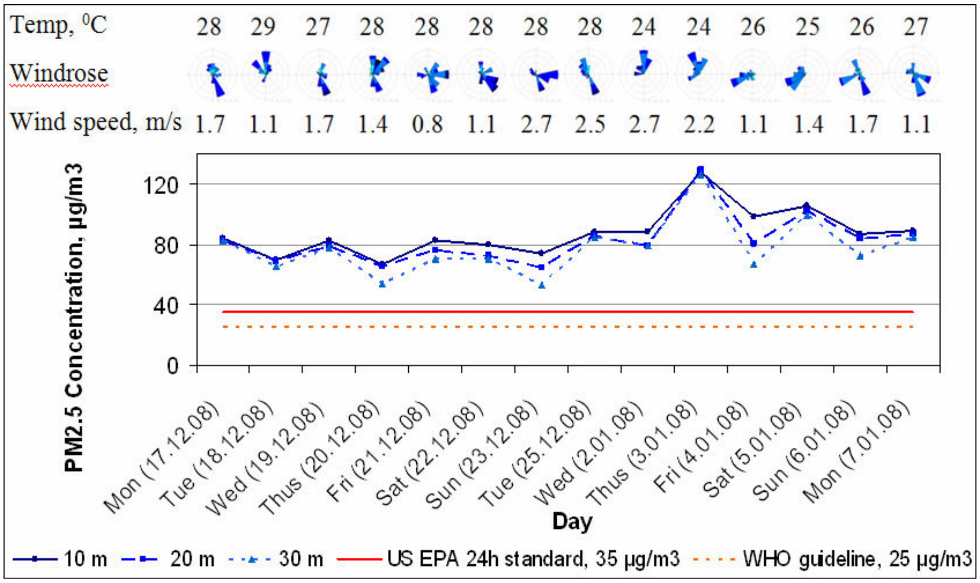

Figure 3 24h-PM2.5 Concentrations during the monitoring period

Table 1 24h-PM2.5 Concentration in comparison to that of other studies, µg/m^3

Study	24h-PM2.5 concentration
This study (Average traffic condition in the city)	82 ± 17 (range: 53 – 129)
Hai, 2007 (Urban mixed site, Ha Noi, Viet Nam)	42 - 134
Chuersuwan et al., 2008 (Din Daeng station - High traffic impact site, Bangkok, Thailand)	69 ± 29
Chan et al., 2001 (Urban commercial and residential site - High traffic during working hour, Hong Kong)	73 ± 5

Similar to PM2.5, in the daytime, weekdays is observed to have higher concentrations than weekend. But in the nighttime and early morning, weekend had higher concentrations that corresponds to higher traffic volume. Among BTEX, toluene and xylene had the concentrations under Vietnam Standard which were 500 µg/m^3 for toluene and 1000 µg/m^3 for xylene. Most benzene concentrations in the daytime exceeded the standard of 22 µg/m^3. Especially, at peak hours (7 a.m., 11 a.m., and 18 p.m.), the level were around 2 times higher than the standard.

Comparing with BTEX concentrations in some Asian Cities (Table 2), for toluene, ethylbenzene, m,p-xylenes, and o-xylene, the results in this study are in the range of others studies since the sampling street in this study is not a hot spot like the others as mention earlier. Nevertheless, the maximum benzene concentration in this study was about 2.2 times higher than that in Bangkok. It is also higher than the level reported in a study in Mong Kok, Hong Kong. The problem of high benzene concentration might result from the high benzene content in the unleaded gasoline fuel used in the city at present.

At peak hours, BTEX concentrations along downwind distance reduced with further distance from the roadside which indicates the effect of traffic emission contribution (Figure 5). Approximately, the concentrations were reduced 15% for each 5 m downwind further from the roadside.

Relationship between air pollution and traffic

PCA resulted in three principal components as shown in Table 3. In the first component, all BTEX compounds and vehicles including motorcycle, car, van, and delivery tricycle were combined in one group. These are mostly gasoline fueled vehicles thus have a strong association with the BTEX level. Gasoline fuel is known to emit high amount of VOCs but not significant amount of particle. On the other hand, diesel fuel produces far lower emission of VOCs and higher emission of particle than does gasoline fuel. It explains why truck and bus were not present in this group and fall into the third component in relation to PM2.5. Van uses both gasoline and diesel fuels thus it also associated with PM2.5 in the second component.

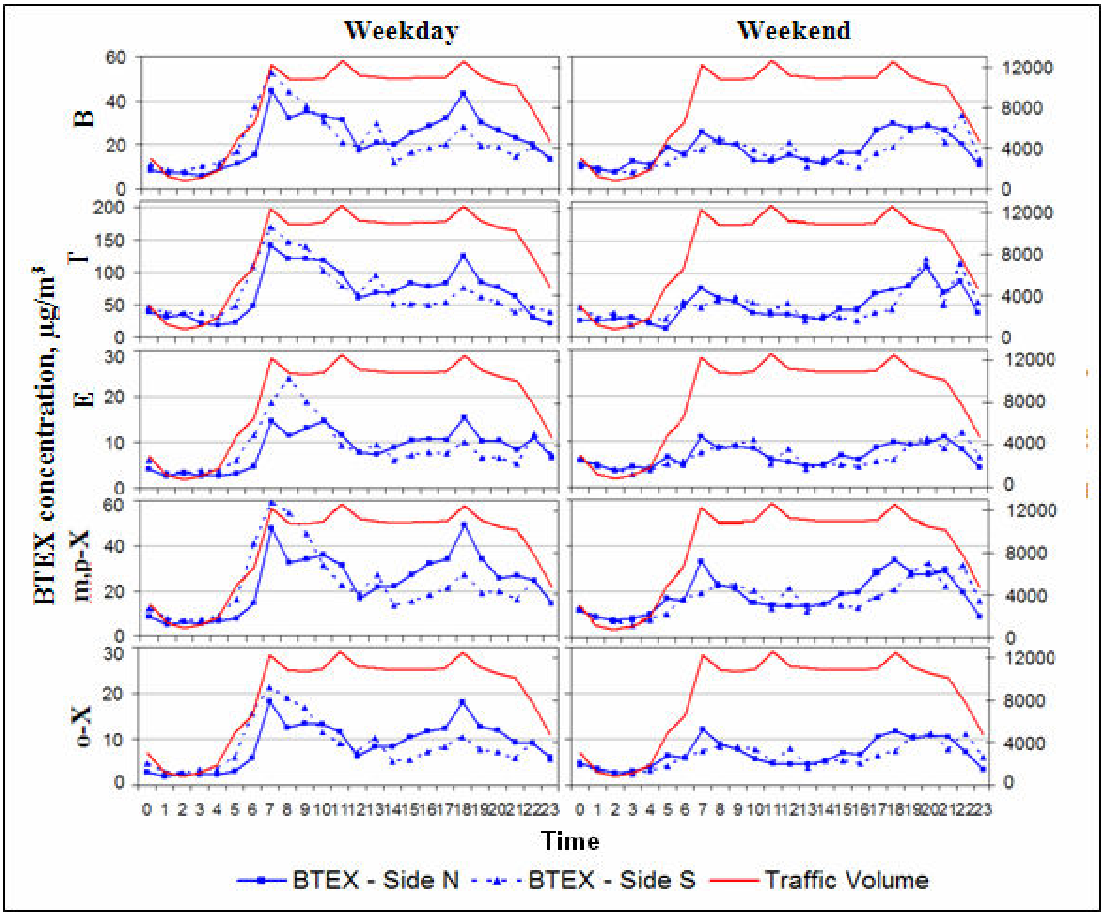

Figure 4 BTEX Diurnal Variations

Table 2 BTEX Concentrations in comparison to those of other studies, µg/m^3

Study	BTEX concentrations				
	Benzene	**Toluene**	**Ethyl-benzene**	**m,p-Xylene**	**o-Xylene**
This study (Average traffic condition)	6 – 53	14 –170	3 – 24	5 – 59	2 - 21
Truc and Kim Oanh, 2007 (Truong Chinh Street, Ha Noi, Viet Nam – High traffic volume)	65	62	15	43	22
Keprasertsup et al., 2003 (High traffic volume intersection, Bangkok, Thailand)	8 – 24	71 –128	4 – 31	14 – 149	
Lee et al., 2002 (Heavy traffic area, Mong Kok, Hongkong)	15 ± 23	137 ± 195	12 ± 19	22 ± 37	11 ± 15

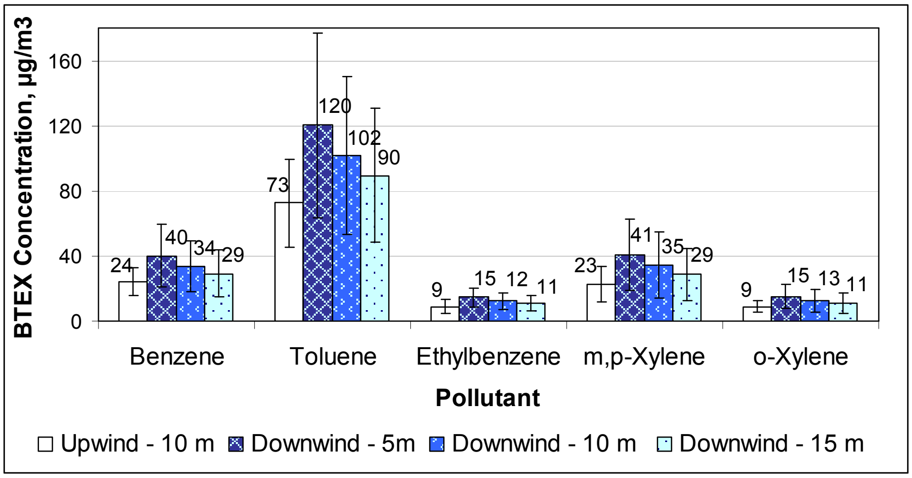

Figure 5 BTEX concentrations along downwind distance at peak hours

Table 3 Component matrix for 8 hour average data

Variable	Component 1	Component 2	Component 3	Communality
PM2.5	0.028	**0.701**	**0.612**	0.867
Benzene	**0.921**	-0.149	0.279	0.948
Toluene	**0.840**	0.089	0.500	0.964
Ethylbenzene	**0.586**	-0.739	-0.039	0.891
m,p_xylene	**0.804**	-0.581	0.062	0.988
o_xylene	**0.898**	-0.303	0.225	0.949
Motorcycle	**0.844**	0.438	-0.265	0.975
Car	**0.882**	0.296	-0.301	0.956
Van	**0.563**	**0.694**	-0.302	0.890
Bus and truck	-.386	0.183	**0.461**	0.395
Delivery tricycle	**0.919**	0.286	-0.094	0.935
% of variance	55.9	21.6	11.2	

Composite emission factor and hourly fleet emission

Using inverse modeling, the average PM2.5 composite emission factor was obtained to be 38 mg/vehicle.km. In the night time and early morning, emission factor was higher than that in the daytime due to the higher truck fraction (5.1%) comparing to that of the daytime (1.4%) (Figure 6a). The average BTEX composite emission factors were 23, 74, 8, 28, and 9 mg/vehicle.km for benzene, toluene, ethylbenzene, m,p-xylenes, and o-xylene, respectively. It was revealed that at peak hours, emission factors were significantly high, around 1.6 times higher than that at non-peak hours (Figure 6b). The result looks rational by the fact that when the street is crowded, vehicles could not go smoothly. Vehicle engine produces higher emission while decelerating and accelerating, especially with poor maintained vehicles.

Hourly fleet emissions were calculated as products of composite emission factors and vehicle density. They varied between 141 – 388, 18 – 435, 52 – 1493, 6 – 131, 18 – 655, and 6 - 194 g/km.hour for PM2.5, benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene, respectively during a day.

Emission factors for individual vehicle categories

Since emission factor is influenced by many factors (vehicle age and maintenance level, engine technology, fuel quality, driving condition …) it varies from area to area. Difference in determination methods also induces the difference in emission factor. The results obtained in this study however look agreeable with other studies.

The emission factors for gasoline and diesel fueled vehicles were calculated based on the hourly fleet emission and fleet composition. The results are presented in Table 4 together with those of other studies. Gasoline fueled vehicles had high BTEX emission factors but low PM2.5 emission factor comparing to diesel fueled vehicles.

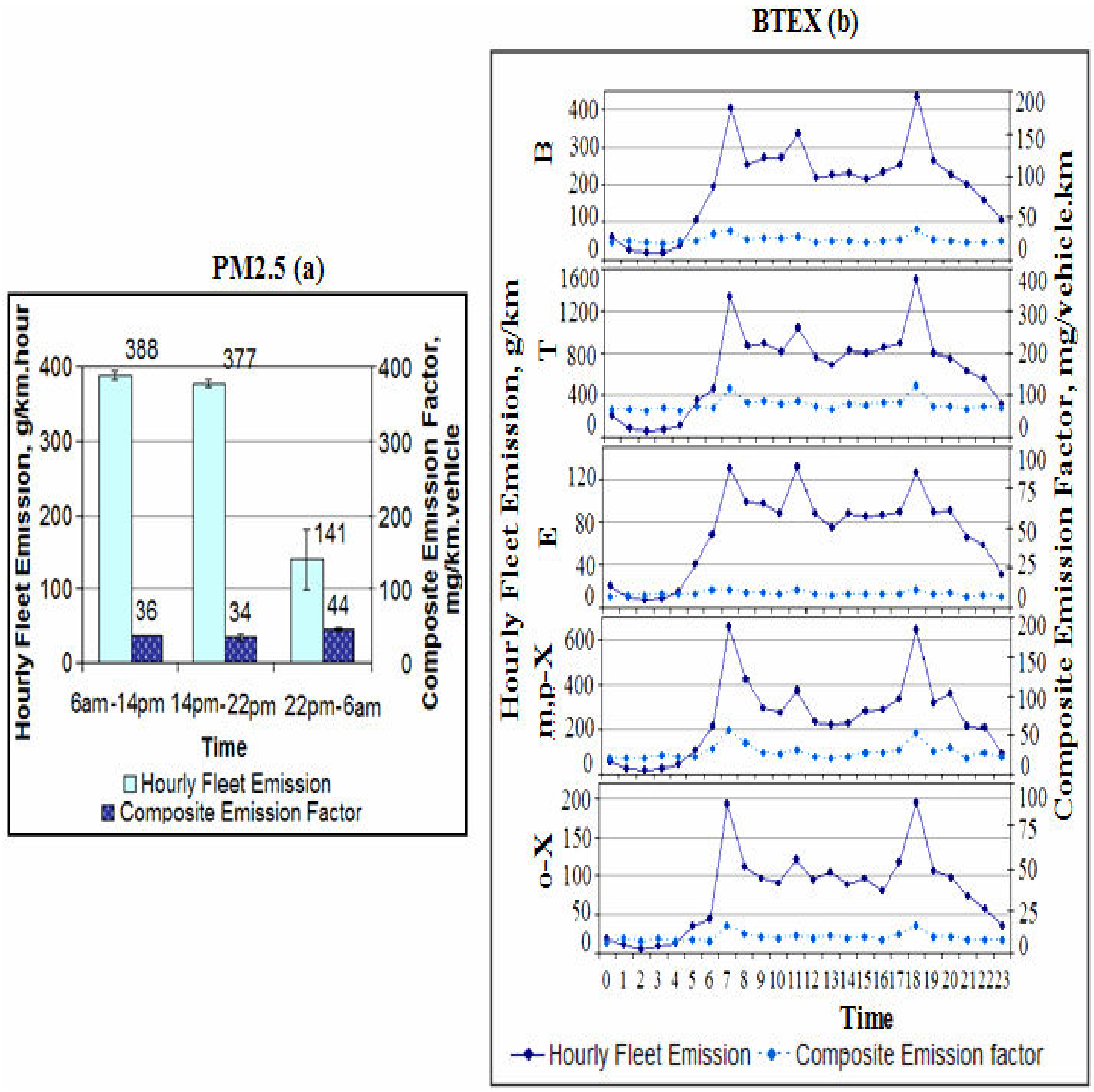

Figure 6 Diurnal composite emission factor and hourly fleet emission trends

Table 4 Emission factors of individual vehicle categories in comparison to those of other studies, mg/vehicle.km

Pollutant	This study	AIT-UIUC (Thai-land)	Onoglu, and Atimtay, 2005 (Turkey)	Gertler et al., 2002 (USA)	Cheng et al., 2006 (Hong Kong)	Gomes, 2001 (Ger-many)	Sagebiel et al., 1995(USA) Fort McHenry Tunnel	Sagebiel et al., 1995(USA) Tusca-rora tunnel
	Inverse modeling	Chassis dynamometer		Tunnel method				
Gasoline fueled vehicles								
PM2.5	25±2.4	-	-	14±13	-	-		-
Benzene	22±0.1	-	32±18	-	-	19.9±5.8	14.8±1.1	-
Toluene	68±0.3	-	55±51	-	-	36.6±10.7	29.0±2.6	-
Ethylbenzene	8±0.1	-	8±7	-	-	10.9±3.0	7.0±1.4	-
p,m_xylenes	22±0.1	-	49±47	-	-	9.2±3.1	23.9±4.9	-
o-xylene	8±0.1	-	14±14	-	-	8.4±2.2	8.8±1.6	-

Table 4 Emission factors of individual vehicle categories in comparison to those of other studies, mg/vehicle.km (cont.)

Pollutant	This study	AIT-UIUC (Thai-land)	Onoglu, and Atimtay, 2005 (Turkey)	Gertler et al., 2002 (USA)	Cheng et al., 2006 (Hong Kong)	Gomes, 2001 (Ger-many)	Sagebiel et al., 1995(USA)	
							Fort McHenry Tunnel	Tusca-rora tunnel
	Inverse modeling	Chassis dynamometer		Tunnel method				
Diesel fueled vehicles								
PM2.5	388±164.0	230±120	-	135±18	257±31	-	-	
Benzene	17±5.3	-	-	-	-	-	12.0±5.7	8.5±3.1
Toluene	61±22.2	-	-	-	-	-	17.6±13.7	14.8±7.7
Ethylbenzene	4±3.3	-	-	-	-	-	10.7±7.5	2.5±1.7
p,m_xylenes	20±5.5	-	-	-	-	-	41.4±25.8	10.7±7.2
o-xylene	5±2.9	-	-	-	-	-	14.1±8.6	4.3±2.9

CONCLUSIONS

Roadside air pollution in HCMC and traffic have close relation. PM2.5 appears to associate with diesel fueled vehicles while BTEX appear to associate with gasoline fueled vehicles which reflects the fact that diesel engines produce large amount of particulates, while gasoline engines produce large amount of hydrocarbons.

Inverse modeling method generated the reasonable emission factors. The obtained hourly fleet emissions and emission factors in this study can directly use for emission inventory in HCMC. The use should be with caution since inverse modeling method is site specific. Thus the application is suitable for the streets which have similar characteristics to that of this study (open street, quite free flowing).

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