AMBIENT PM_{10} AND $PM_{2.5}$ CONCENTRATIONS AT DIFFERENT HIGH TRAFFIC-RELATED STREET CONFIGURATIONS IN BANGKOK, THAILAND

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Abstract. This study investigated the potential exposure levels of PM_{10} and $PM_{2.5}$ at two different road configuration sites in Bangkok, Thailand: covered and open roadside areas. One hundred samples were collected together with the meteorological data: temperature, relative humidity, wind speeds, and solar radiation. Spearman rank correlation was used to analyze the relationships between these factors, and PM_{10} and $PM_{2.5}$ levels at different roadside areas. The PM_{10} and $PM_{2.5}$ levels at the covered area were 1.72 and 1.60 times more than those levels at open area were. The mean levels were found to be 154.59 and 94.42 μg/m^3 at the covered areas, and 89.43 and 58.69 μg/m^3 at the open areas. These results suggested that a higher potential risk for workers, such as street vendors, was the exposure to particulate matters at the covered areas compared to open areas. Wind speeds and relative humidity were significantly negative-related influencing factors on PM_{10} and $PM_{2.5}$ levels at the open area, but not significantly related for the covered areas.

Keywords: air pollution, particulate matter, PM_{10}, $PM_{2.5}$, open roadside area, covered area, Bangkok

INTRODUCTION

Particulate matter consists of microscopic pollutant particles found worldwide, particularly in urban areas where traffic is a major source of their spread (Pfeffer, 1994; Ross *et al*, 2011; Padro-Martinez *et al*, 2012). Particulate matter, especially inhalable particulate matter with a diameter smaller than 10 microns (PM_{10}), has been shown to have strongly adverse effects on the respiratory tract. The effects of inhalable particulate matter depend on the diameter; smaller diameter particulate does more damage to the respiratory tract than higher diameter does. Previous studies show that PM_{10} levels are significantly associated with adverse health effects and daily mortality (Brunekreef and Forsberg, 2005; Janssen *et al*, 2013; Patel *et al*, 2013).

Inhalable particulate consists of coarse particulate ($PM_{2.5-10}$) and fine particulate (<$PM_{2.5}$), and these mostly originate from traffic emissions. Exhaust emissions (emitted from tailpipes) mainly consist of coarse particulate, and non-exhaust emissions (from other vehicle parts

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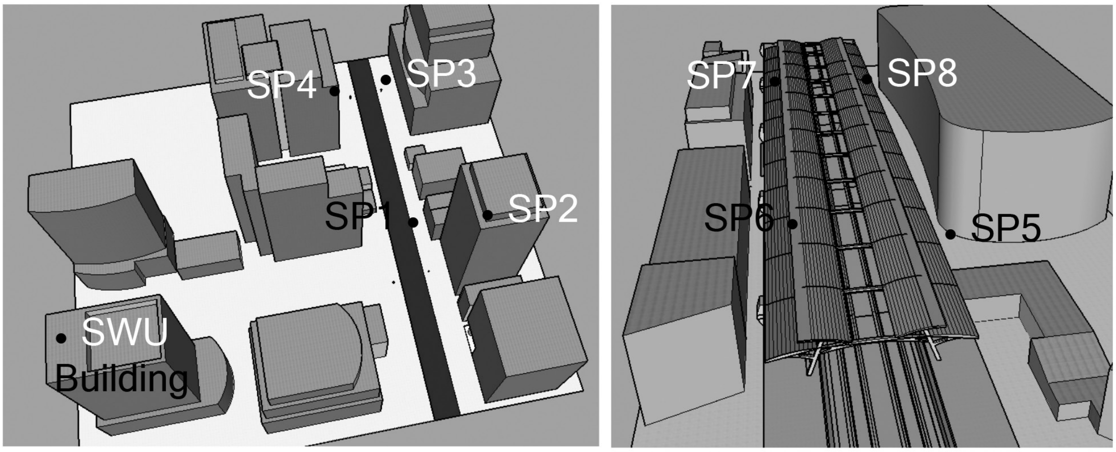

Fig 1–The sampling points with different street configurations. The open area: Asoke-Montri Road (left) and the covered area: Sukhumvit Road (right), with eight sampling points: SP1, SP2, SP3, and SP4 in open areas; and SP5, SP6, SP7, and SP8 in covered areas.

such as brakes, tires, or clutch) consist of fine particulate (Luhana *et al*, 2004). Urban areas that have traffic problems or lower traffic flow speeds will therefore have higher inhalable particulate levels. In addition, surrounding building structures, so called 'street canyons,' also affect particulate dispersion (Zhou and Levy, 2008; Gokhale, 2011).

Bangkok, the capital of Thailand, is a city with an intractable traffic problem. Urbanization patterns and government policies have resulted in high numbers of automobiles. In 2012, registered automobiles in Bangkok exceed 7.1 million and increased to 8.2 million in 2013 (DLT, 2014). The Bangkok road infrastructure is complex, and some street areas are covered by tunnel-like sky train platforms that lead to poor ventilation. Therefore, inhalable particulate levels at different areas may differ, and some tunnel-like areas may have increased levels with negative health effects.

Our investigation measured roadside PM_{10} and $PM_{2.5}$ levels for different street configurations: covered and open areas. Meteorological conditions consisting of wind speed, relative humidity, temperature, and solar intensity were also measured and used for correlation analysis to understand the inhalable particulate exposure risk in humans, in both covered areas under sky train platforms and open areas.

MATERIALS AND METHODS

Sampling sites

Bangkok has a South Asian monsoon-influenced climate with tropical wet and dry seasons. The city's Sukhumvit area was selected as the study site, because it has serious traffic congestion. This area is located in a commercial office-building zone, and many street vendors are located on the roadsides. The PM_{10} and $PM_{2.5}$ samples were obtained from a covered and an open area at Sukhumvit Road, under the Skytrain platform and Asoke-Montri Road, respectively.

In both areas, eight sampling points were set up at varying building structure types (Fig 1): street segment with no buildings (SP1), street segment with buildings on one side (SP2), and street segments with buildings on both left and right sides (SP3-SP8). The building structure at the sampling points would be represented by quantitative values with the heights of the building on the roadside and the road-width ratio (H/W ratio). The H/W ratio on SP1 to SP8 was 0.00, 2.14, 3.21, 3.86, 0.24, 0.61, 0.60, and 1.20, respectively.

$PM_{2.5\text{-}10}$ and $PM_{2.5}$ samples were collected with PTFE filters using a Personal Modular Impactor® (PMI) (SKC: Eighty Four, PA) connected to personal air pump (SKC) with the airflow rate of 3 l/min for 8 hours. The $PM_{2.5\text{-}10}$ and $PM_{2.5}$ concentrations were determined by gravimetric method using ultra-microbalance, UMX2® (Mettler Toledo: Columbus, OH), with a readability 0.0001mg. The particulate samples were collected for 7 days during 1-15 May at the covered areas and 15-31 October 2013 for the open areas.

The sampling equipment was installed on traffic signs at roadsides, approximately 1.6 m height from the ground, which represented the breathing zone of a person, and 1 m from the curb. The sampling was performed twice daily from 05:00 AM to 01:00 PM and 01:00 PM to 09:00 PM. At each sampling site (covered and open areas), four samples were collected for each sampling period (56 samples).

Mobile meteorological stations with data logging recorded the meteorological conditions during the sampling periods. The cup-type anemometer AM4257SD® (Lutron: Taipei, Taiwan), and temperature and humidity meter, TM-305U (Tenmars; Taipei, Taiwan) was used for measuring wind speed, temperature, and relative humidity, respectively. The mobile meteorological station was installed at 3 m from the ground, because the meteorological condition data on ground level would be taken to investigate how they related to particulate matter concentration. Nevertheless, a 3 m-height installation was followed according to recommendations of the Urban Meteorological Measuring Guidance of the World Meteorological Organization (Oke, 2006).

Analysis of correlation between $PM_{2.5\text{-}10}$ and PM_{10} and influencing factors

The Spearman rank correlation was used to test the associations between $PM_{2.5\text{-}10}$ and PM_{10} concentrations and the four influencing factors: wind speed (ms^{-1}), relative humidity (%), temperature (^{o}C) at three meters above ground near sampling points, and solar intensity (Wm^{-2}) at the rooftop of Srinakharinwirot University (SWU) building.

RESULTS

Table 1 describes the PM_{10} and $PM_{2.5}$ levels at the eight sampling points in the covered and open areas. The results indicate that PM_{10} and $PM_{2.5}$ levels were significantly higher by 1.73 and 1.61 times ($p<0.001$) in the covered areas compared to the open areas. In the covered areas, PM_{10} and $PM_{2.5}$ levels at SP5, SP6, SP7, and SP8 did not differ significantly ($p>0.05$). However, in the open areas, PM_{10} and $PM_{2.5}$ levels at SP1, SP2, SP3, and SP4 exhibited significant differences ($p=0.016$ and 0.014).

The levels at SP1 did not differ significantly with SP2 ($p>0.05$) but did so with SP3 and SP4 ($p=0.039$ and 0.005). PM_{10} and $PM_{2.5}$ levels at SP2 did not differ significantly with SP3 ($p>0.05$) but did so with SP4 ($p=0.019$ and 0.021). Finally, the levels at SP3 did not differ significantly with SP4 ($p>0.05$).

The PM_{10} and $PM_{2.5}$ levels at morning time (05:00 AM-01:00 PM) were higher than

Table 1
The mean (SD) of PM_{10} and $PM_{2.5}$ level at study areas.

Sampling points	PM_{10}			$PM_{2.5}$		
	5AM-1PM	1PM-9PM	Mean	5AM-1PM	1PM-9PM	Mean
SP1	76.05 (19.19)	68.38 (22.63)	72.22 (20.55)[a]	54.48 (16.27)	38.31 (12.02)	46.40 (16.10)[a]
SP2	87.67 (26.72)	69.68 (16.57)	78.67 (23.21)[a,b]	56.27 (13.08)	44.17 (7.06)	50.22 (11.89)[a,b]
SP3	107.03 (29.24)	89.62 (47.32)	98.33 (38.85)[b,c]	70.22 (20.33)	64.21 (37.39)	67.21 (29.08)[b,c]
SP4	115.31 (50.40)	101.66 (35.04)	108.49 (42.30)[c]	71.98 (34.50)	69.89 (26.94)	70.93 (29.75)[c]
Mean	96.52 (35.27)	82.33 (33.85)	89.43 (34.99)	63.24 (22.76)	54.14 (26.39)	58.69 (24.84)
SP5	181.38 (59.39)	146.92 (75.97)	162.58 (67.98)[d]	105.92 (30.46)	86.34 (36.84)	95.35 (33.94)[d]
SP6	127.97 (53.59)	138.38 (59.30)	132.72 (53.59)[d]	81.29 (31.12)	81.20 (25.62)	81.25 (27.33)[d]
SP7	169.75 (80.04)	159.44 (73.54)	164.60 (73.48)[d]	113.07 (52.40)	91.20 (35.28)	102.14 (44.09)[d]
SP8	175.49 (75.23)	140.28 (41.02)	157.88 (60.07)[d]	95.77 (32.59)	101.46 (18.23)	98.62 (25.04)[d]
Mean	162.30 (66.63)	146.88 (61.03)	154.59 (63.63)	98.84 (37.73)	89.99 (29.34)	94.42 (33.70)

[a, b, c,] and [d] are non-significant signs in pair wise comparison.

Table 2
The mean (SD) of meteorological factors value.

Factors	Open areas			Covered area		
	5AM-1PM	1PM-9PM	Mean	5AM-1PM	1PM-9PM	Mean
WS (m s^{-1})	0.69 (0.21)	0.80 (0.45)	0.75 (0.34)	0.45 (0.08)	0.44 (0.09)	0.45 (0.08)
RH (%)	50.74 (14.79)	58.88 (18.34)	54.81 (16.56)	56.91 (9.39)	51.32 (8.75)	54.12 (9.13)
TM (ºC)	34.44 (2.80)	32.87 (3.82)	33.66 (3.32)	32.76 (2.86)	33.08 (2.41)	32.92 (2.53)
SI (W m^{-2})	879.93 (92.73)	554.40 (65.41)	717.17 (185.67)	918.44 (97.99)	669.91 (155.59)	794.17 (179.48)

WS, wind speeds; RH, relative humidity; TM, temperature; SI, solar intensity.

the afternoon (01:00 PM-09:00 PM), but they did not differ significantly ($p>0.05$).

Correlation between PM_{10} and $PM_{2.5}$ level with affecting factors

The four meteorological factors in this study that were recorded included wind speed (WS), relative humidity (RH), temperature (TM), and solar intensity (SI) (Table 2). The indicators of mean wind speed, temperature, and humidity at open area were slightly higher than the covered areas were. The comparison of mean values between open and covered areas found no significant differences with relative humidity, temperature, and solar intensity factors, but the average wind speed at open areas was slightly significantly higher than covered areas ($p<0.05$). The mean meteorological factors at 05:00 AM-01:00 PM did not differ compared with 01:00 PM-09:00 PM, except the mean solar intensity in afternoon was lower than before 12:00 PM.

The correlation coefficient between the PM_{10} and $PM_{2.5}$ average levels from four sampling points for each area (SP1-

Table 3
Spearman rank correlation coefficient of PM_{10} and $PM_{2.5}$ with the affecting factors.

Factors	Correlation coefficient of PM_{10}		Correlation coefficient of $PM_{2.5}$	
	Covered area	Open area	Covered area	Open area
Wind speeds (ms^{-1})	0.266	-0.639[a]	0.277	-0.650[a]
Relative humidity (%)	0.126	-0.538[a]	0.070	-0.626[a]
Temperature (°C)	-0.280	0.260	-0.210	0.488
Solar intensity (Wm^{-2})	0.350	0.455	0.357	0.336

[a]Correlation is significant at 0.05 level (1-tailed).

SP4 in open areas and SP5-SP8 in covered areas) and four influencing factors were analyzed from 14 samples of each area (Table 3). From the analysis results, no factors were correlated with the PM at the covered area, while some factors were influential at the open area, such as wind speed and relative humidity.

DISCUSSION

These study results indicate that the dominant particulate in both areas was fine particulate. The $PM_{2.5}$:PM_{10} was 0.6, approximately in agreement with previous research for the dominant particulate matter and their $PM_{2.5}$:PM_{10} ratio in urban areas (Eeftens *et al*, 2012). The comparison found that PM_{10} and $PM_{2.5}$ levels in the covered areas were higher than in the open areas.

The PM_{10} and $PM_{2.5}$ levels in the open areas were significantly affected by the 'street canyon' structure. The particulate concentrations at SP1 (H/W ratio=0.00) were lowest and continually higher at SP2, SP3, and SP4 (H/W ratios: 2.14, 3.21, and 3.86, respectively). These results support models where particulate levels at high-H/W ratio roadsides are significantly higher than at low-H/W ratio roadsides (Lee and Park, 1994). However, particulate levels were not significantly affected by H/W ratio in the covered area, because the structure was already tunnel-like. Wind speeds at rooftop level create an increased circulation at ground level, but this effect may not occur to the same extent at covered areas.

Wind speed has long been recognized as an important influencing factor on concentrations of particulate pollutants (Harrison *et al*, 2001). In our study, wind speed was found to be negatively correlated with PM_{10} and $PM_{2.5}$ in open areas and positively correlated in covered areas. This supports the dilution effect, which states that decreasing particulate levels will be related to increased wind velocity (Pateraki *et al*, 2012). The wind speed may be non-significantly related with PM_{10} and $PM_{2.5}$ in the covered area, but it still showed positively correlated coefficient with particulates. They were possibly so correlated, because the covered structure contained particulate that would otherwise had been dispersed and diluted by the wind.

In a previous study, Jason and Bruce (2006) studied fugitive dust emission rates in a wind tunnel. Their results suggested that wind velocity affects the volume of dust emission. The wind keeps the dust in a tunnel circulating, rather than settling on the ground, thereby increasing the number of particles in the air. The covered area in this study is similar to a wind tunnel. The wind turbulence may isolate PM_{10} and $PM_{2.5}$ in the covered area, and greater wind speeds increase turbulence and thereby airborne particulate concentration.

Particulate pollutant levels are affected by solar intensity and temperature factors, because they play a role in fine particulate mass formation (Vassilakos, 2007). The particulate matter increases when temperature and solar radiation increase, but this study did not show a significant relation (p>0.05). However, this study found a positive relation between solar intensity, and PM_{10} and $PM_{2.5}$ in both areas, but conversely suggested a negative correlation between temperature and particulate matters at the covered areas. This result is similar with a previous study that found a negative correlation between temperature and particulate because of co-influencing factors (Vellingiri *et al*, 2014).

The significant negative correlation was found between particulates and relative humidity relationship at open areas. This result is similar to a previous study (Akyuz and Cabuk, 2009) that also found a similar negative correlation. The atmospheric particulate may be removed by relative humidity and so diminish the re-suspended particle (Hien *et al*, 2002). However, the correlation showed a non-significant relation between particulates and relative humidity relationship at covered areas. The data showed that the correlation coefficient of particulates and relative humidity at covered area was much lower (0.126 and 0.070), suggesting that the relative humidity values at covered areas were not very different (SD=9.13) because the building structure may influence relative humidity to stabilize.

The concentrations of PM_{10} and $PM_{2.5}$ in the studied roadside areas are generally high. A previous study in the Netherlands of the short-term impact of PM_{10} and $PM_{2.5,}$ reviewed the effects of particulate matter as related to mortality (Janssen *et al*, 2013). WHO has recommended that people were informed if the daily PM_{10} levels exceed 50 μg m^{-3} and warned they were seriously affected if the PM_{10} levels exceed 80 μg m^{-3} (WHO, 2005). In addition, WHO advised an additional threshold of 25 μg m^{-3} for daily $PM_{2.5}$, while the setting a $PM_{2.5}$ threshold for being informed (30 μg m^{-3}) and for being warned (50 μg m^{-3}) has been discussed in France (Haut Conseil de la Sante Publique, 2012). However, the WHO guideline for the PM_{10} level is for a 24-hour average, which is a different period from this study data.

The hourly mean trigger concentration was developed to state about air pollution information of particulate matter, indicating that a period of moderate, high, or very high air pollution may be taking place or likely to happen soon (Health Protection Agency, 2011). Regarding this study results, the 8-hour average was considerable to be comparable with a trigger concentration, because each 8-hour sampling period represented peak concentration of particulate matters during a day, and the value would not much differ from hourly average concentration. Comparing the results with hourly mean trigger concentration, PM_{10} and $PM_{2.5}$ were 89.43 μg m^{-3} and 58.69 μg m^{-3}, respectively, at open areas, which was classified as moderate air pollution. Covered-area levels of 154.59 μg m^{-3} and 94.42 μg m^{-3}, respectively, were determined as high air pollution.

These results indicated that there was a possible risk for human health, especially for people who work at the covered areas, such as street vendors. Therefore, we recommend to further study particulate exposure assessment and related hazard air pollutants to determine the health risk of people who live or work in these areas.

ACKNOWLEDGEMENTS

The author would like to thank the Srinakarinwirot University and the Traffic and Transportation Department, Bangkok Metropolitan Administration for providing locations for the installation of air sampling units and meteorological measurement devices.

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