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Vertical Distribution of Black Carbon and Health Risk Assessment of Particulate Matter in Bangkok

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Abstract

This study undertakes a comprehensive analysis of the distribution and health implications of particulate matter (PM), with a specific focus on $PM_{2.5}$, in the urban atmosphere of Bangkok. $PM_{2.5}$ is a critical concern for both environmental and public health, particularly in urban settings where sources such as vehicular emissions, fuel combustion, and various human activities are ubiquitous. The research involved the collection of particulate matter samples at three distinct heights (30, 75, and 110 meters) at the Microclimate and Air Pollution Monitoring Station, Faculty of Environment, Kasetsart University. The sampling was conducted over two periods each day: 8:00 a.m. to 7:00 p.m. (daytime) and 8:00 p.m. to 7:00 a.m. (nighttime). The health impact evaluation, focusing on the inhalation of $PM_{2.5}$ and associated black carbon exposure, revealed a Hazard Quotient (HQ) value of less than 1, suggesting no significant non-carcinogenic health effects for both adults and children. However, the assessment highlighted a substantial risk of cancer among children, underscoring the need for stringent regulatory measures. The average $PM_{2.5}$ concentrations in the atmosphere exceeded the standard values set by Thai regulatory authorities, with the highest levels observed at the 110-meter height. Analysis of the soot-EC to Char-EC ratios indicated that near-surface particulate matter is predominantly derived from combustion sources, such as fossil fuels and industrial emissions. This study emphasizes the importance of understanding the distribution and sources of particulate matter in urban environments to develop effective strategies for managing air pollution and mitigating its health impacts. Therefore, policy interventions should prioritize the reduction of emissions from combustion activities and industrial processes to enhance the overall air quality and health of the urban population.

Keywords: Black carbon; Health risk assessment; $PM_{2.5}$; Source apportionment

1. Introduction

Air pollution, particularly the presence of fine particulate matter ($PM_{2.5}$), has become a significant environmental and public health concern in urban areas worldwide, including Bangkok, the capital of Thailand. $PM_{2.5}$, defined as particulate matter with a diameter of less than 2.5 microns, can penetrate deep into the lungs and even enter the bloodstream, causing severe respiratory and cardiovascular problems.(Feng *et al.,* 2016)

Bangkok, known for its heavy traffic congestion, numerous construction sites, and industrial activities, is plagued by high levels of $PM_{2.5}$. The primary sources of $PM_{2.5}$ in Bangkok include vehicle emissions, construction dust, and the open burning of agricultural waste (Ahmad *et al.,* 2022). These activities, especially during the haze season, exacerbate the air pollution problem, leading to $PM_{2.5}$ concentrations that often exceed the World Health Organization (WHO) guidelines.(Organization, 2021)

One of the critical components of $PM_{2.5}$ is black carbon (BC), a highly light-absorbing material formed by the incomplete combustion of fossil fuels, biofuels, and biomass(Viidanoja *et al.,* 2002). Black carbon is a major constituent of soot and is emitted directly into the atmosphere in the form of $PM_{2.5}$. Black carbon originates from various sources, including diesel engines, industrial emissions, and the burning of solid fuels like coal and wood. In urban settings, diesel vehicles and industrial activities are significant contributors to black carbon emissions(Pani *et al.,* 2020).

The health impacts of $PM_{2.5}$ exposure are profound. Short-term exposure can cause irritation of the eyes, nose, and throat, as well as respiratory problems such as coughing, wheezing, and shortness of breath. Long-term exposure is linked to chronic respiratory diseases like asthma and chronic obstructive pulmonary disease (COPD), cardiovascular diseases including myocardial infarction, hypertension, and strokes, and even lung cancer, particularly in vulnerable populations such as the elderly, children, and those with chronic health conditions(Amnuaylojaroen and Parasin, 2024; Kloog *et al.,* 2013). For instance, exposure to black carbon can increase the risk of respiratory and cardiovascular problems in pregnant women and their fetuses, and can lead to adverse birth outcomes such as low birth weight and preterm delivery(Janssen *et al.,* 2011).

This study aims to (1) study the sources of black carbon in the Bangkok area, (2) investigate the health risks, and assess the health impacts of exposure to black carbon, and identify effective strategies for managing these sources to mitigate the adverse health impacts.

2. Methodology

2.1 Study location and sample collection

For the monitoring of $PM_{2.5}$ and meteorological data, measurements were taken and collected at three distinct heights: 30, 75, and 110 meters above ground level at the Microclimate and Air Pollution Monitoring Station (KU Tower), Faculty of Environment, Kasetsart University, Bangkok. The map of the sampling location is provided in Figure 1

$PM_{2.5}$ was collected from January - February 2021 (Haze period) from 8.00 a.m. - 7.00 p.m. (daytime) using an Area Dust Monitor (ADR) 1500

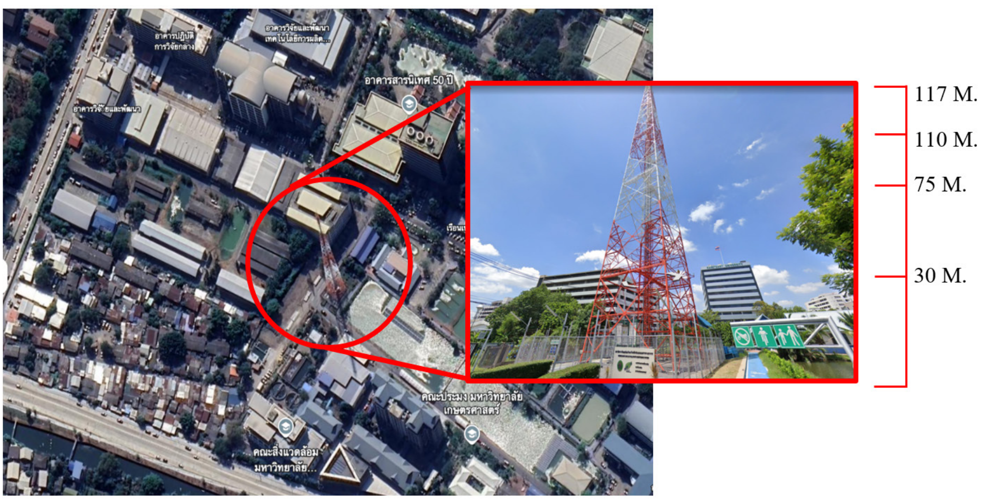

Figure 1. The Location of Microclimate and air pollution monitoring station, Faculty of Environment Kasetsart University (KU Tower) (Latitude: 13.85441782894868, Longitude: 100.56999967462087)

(Thermo Fisher scientific Inc.) by the light scattering method. $PM_{2.5}$ particles were collected on quartz microfiber filters (37 mm.). Following sampling, the collected filters were stored in a refrigerator at about 4 °C in preparation for subsequent analysis.

2.2 Carbonaceous Analysis

The carbonaceous analysis was carbon composition evaluated in $PM_{2.5}$. The organic carbon (OC) and elemental carbon (EC) were conducted utilizing a Thermal/Optical Reflectance (TOR) method (Sunset laboratory carbon analyzer). To measure OC EC and black carbon (BC), the filter sample was cut to a size of 1.5 cm^2. In this study, we focused on EC was measured at 550 ºC. The thermograms of EC reference materials showed that activation energy is lower for Char- than soot-EC. Low-temperature EC1 (550 ºC in a 98% He/2% O_2 atmosphere) is more abundant for char samples. Diesel and n-hexane soot samples exhibit similar EC2 (700 ºC in a 98% He/2% O_2 atmosphere) peaks, while carbon black samples peak at both EC2 and EC3 (800 ºC in a 98% He/2% O_2 atmosphere). The pyrolyzed carbon fraction (OP) was a laser-monitored optical pyrolyzed carbon. The total EC (EC_{total}) was calculated by EC1 + EC2 + EC3 - OP. Char-EC as EC1-OP and Soot-EC as EC2 + EC3 (Han *et al.,* 2007).

2.3 Health Risk Assessment

Exposure to automobile exhaust (diesel combustion emissions) is classified as "carcinogenic to humans (group 1) by the International Agency for Research on Cancer (IARC) which leads to the development of lung cancer in the future. (Benbrahim-Tallaa *et al.,* 2012). Therefore, the objective of this study was to conduct a health risk assessment of black carbon in $PM_{2.5}$ particulate matter, focusing on the inhalation exposure risk assessment, which encompasses the evaluation of Chronic Daily Intake (CDI), Hazard Quotient (HQ), and Carcinogenic Risk (CR) in both children and adults. The calculation of CDI was shown in Table 1

Chronic Daily Intake (CDI) is used to estimate long-term exposure to toxic substances over a prolonged period, which could be a lifetime or a significant portion of a lifetime. Factors used in calculating CDI, including concentration of BC (C) (mg/m³), inhalation hate (IR) (adult 20 m3/day and children = 10 m³/day), exposure frequency (EF) (350 days/year), exposure duration (ED) (approximately 30 years), body weight (BW) (adult 70 kg. and children = 20 kg.), and average time (AT) (350 days/year x 70 years or 25,550 days for adult and children) (U.S.EPA, 2009).

The Hazard Quotient (HQ) is a risk assessment to evaluate the potential for non-cancer health hazards resulting from exposure to a contaminant or chemical substance. The HQ is calculated as the ratio of the potential exposure to a substance and the level at which no adverse effects are expected or the reference concentration (RfC) by the USEPA is defined for BC as $5x10^{-3}$ (mg/m³). HQ value is < 1 as no non-carcinogenic risk and HQ value is > 1 as non-carcinogenic risk. (Li *et al.,* 2013; U.S.EPA, 2009).

The carcinogenic risk (CR) level is calculated from the exposure to black carbon in $PM_{2.5}$ and the Cancer Slope Factor (CSF) values for inhalation toxicity, BC or soot of 1.1 (1.1 mg/kg/day)-1 (Lin et al., 2019). According to criteria set by the New York State Department of Health classified cancer risk to (1) $CR \geq 10^{-1}$ (very high), (2) $10^{-3} \leq CR < 10^{-1}$ (high), (3) $10^{-4} < CR \leq 10^{-3}$ (moderate), (4) $10^{-6} < CR \leq 10^{-4}$ (low), and (5) $CR \leq 10^{-6}$ (extremely low) (D.O.H, 2012).

3. Results and Discussion

3.1 $PM_{2.5}$ Concentration and Meteorological data

Figure 2 summarizes the mean mass concentration of $PM_{2.5}$ from January to February 2021 (Haze period) in the daytime. The average concentration at 30 m., 75 m., and 110 m. were 48.67 ± 25.07 µg/m³, 44.89 ± 25.12 µg/m³, and 50.24 ± 27.29 µg/m³, respectively. The results of the study found that the average concentration of $PM_{2.5}$ at all levels exceeded the standard value of Thailand at 37.5 μg/m^3. From January to February 2021, average $PM_{2.5}$ concentrations were found to increase with height during the haze period due to the influence of urban activities from traffic, fuel combustion is the main source of $PM_{2.5}$ emissions, including the influence of oxidation by VOCs and chemical oxidation to secondary organic aerosols (SOA) in the daytime (Hao *et al.,* 2020). That is consistent with the study of the vertical distribution of $PM_{2.5}$ in the urban area of the current study (Roostaei *et al.,* 2024).

Table 1. The table shows the calculation formulas of Chronic Daily Intake (CDI), Hazard Quotient (HQ), and Carcinogenic Risk (CR) and parameters.

Parameter	Equation	Factors
Chronic Daily Intake (CDI) (mg/kg−day)	$CDI = \frac{C \times IR \times EF \times ED}{(BW \times AT)}$	C : Concentration of BC (mg/m^3) IR : Inhalation Rate (m^3/day) EF : Exposure frequency (days/year) ED : Exposure duration (years) EW: Body Weight (kg.) AT : Average time (days)
Hazard Quotient (HQ)	$HQ = \frac{CDI}{RFC}$	RFC : Reference dose for inhalation toxicity of diesel exhaust particulate (5x10^{-3} mg/m^3) (OEHHA, 1998 and Feng *et al.*, 2019)
Carcinogenic Risk (CR)	$CR = CDI \times CSF$	CRF : Cancer slope factor (1.1 mg/kg/day)$^{-1}$ (US.EPA, 2000)

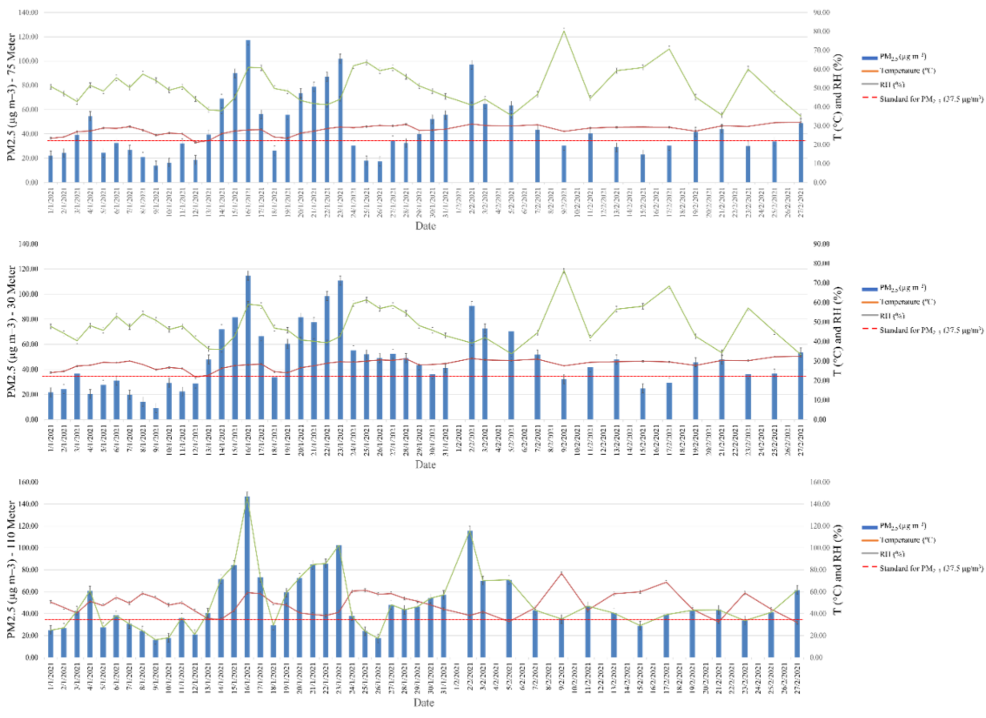

Figure 2. The average concentration level of $PM_{2.5}$ and Meteorological data in the study

The average of meteorological data such as wind speed, wind direction, air temperature, and relative humidity are shown in Table 3. The average air temperature across all three altitude levels ranged from 27 ºC to 28 ºC, while relative humidity was recorded between 47% and 50% RH. The average wind speed increases with height, correlating with the concentration of dust particles. This phenomenon may be influenced by various factors, including the proximity of dust sources that can release particles directly at elevated altitudes or nearby pollution sources, such as elevated expressways. Additionally, the accumulation of dust in the atmosphere may exhibit characteristics associated with stable atmospheric layers and air mass movement, potentially influenced by temperature inversion effects (Buchunde *et al.,* 2019; Hu *et al.,* 2020).

3.2 Carbonaceous Concentration of $PM_{2.5}$

The ratio of elemental carbon (EC) in $PM_{2.5}$ constitutes approximately 20% of the total concentration of $PM_{2.5}$. This indicates that the sources of particulate matter in the area are likely associated with combustion-related activities, including emissions from diesel vehicles, the use of fossil fuels, biomass burning, and industrial combustion processes.

In addition, Soot-EC and Char-EC ratios were crucial tools for identifying the sources of particulate matter. These ratios enable the differentiation of various types of carbonaceous materials based on their origins and combustion processes. As indicated in the accompanying table, near-surface particulate matter is predominantly derived from high-temperature combustion sources, including emissions from traffic and industrial facilities (Han *et al.,* 2007). In the previous study (winter season), the ratio of char-EC/soot-EC was 3.1 ± 2.2, representing particulate matter from the combustion of biomass fuels(Mishra & Kulshrestha, 2021). In another study were reported to be 4.8 ± 2.2 for biomass burning, 5.4 ± 2.8 for biofuel burning, 1.3 ± 0.8 for coal combustion, and 0.6 ± 0.4 for vehicular emissions (Han et al., 2010; Kumar *et al.,* 2021; Pani *et al.,* 2019; Ram *et al.,* 2012).

3.3 Health risk assessment

The health impact assessment of black carbon exposure from inhalation of $PM_{2.5}$. Table 5 presents the predicted non-cancer risk (HQ) and carcinogenic risk (CR) levels of black carbon exposure. All high levels and no non-carcinogenic effects of black carbon in $PM_{2.5}$ (HQ < 1) in both adults and children. However, the assessment identified a high risk of cancer in children.

Table 3. Meteorological data during the haze period at three high levels

Level (m.)	30	75	110
Wind Speed (m/s)	2.10 ± 0.87	8.56 ± 1.05	3.03 ± 1.11
Temperature (°C)	28.34 ± 2.43	27.83 ± 2.49	27.56 ± 2.51
RH (%)	47.93 ± 9.32	50.34 ± 9.55	48.70 ± 9.89
Wind direction (Deg.)	2.10 ± 0.87	130.90 ± 71.51	128.94 ± 50.68

Table 4. Vertical variation of $PM_{2.5}$ in urban area in Bangkok (Mean and standard deviations)

Level (m.)	30	75	110
$PM_{2.5}$ (μg/m^3)	48.67 ± 25.07	44.89 ± 25.12	50.24 ± 27.29
Total EC (μg/m^3)	9.06 ± 4.29	9.25 ± 4.76	8.65 ± 4.18
Total EC/$PM_{2.5}$	0.21 ± 0.09	0.24 ± 0.15	0.20 ± 0.11
soot-EC(μg/m^3)	6.40 ± 3.15	6.57 ± 3.73	6.01 ± 2.83
Char-EC (μg/m^3)	2.67 ± 1.61	2.68 ± 2.08	2.64 ± 1.80
soot-EC/Char-EC	3.81 ± 6.82	2.55 ± 2.34	2.86 ± 1.68

Table 5. Predicted non-cancer risk (HQ) and Carcinogenic Risk (CR) level of black carbon in this study

Level	Parameter	Adult	Children
30 m.	CDI (mg/kg-day)	7.5E−05	1.32E−03
	HQ	0.08	0.26
	CR	7.8E10-5	1.43E-03
75 m.	CDI (mg/kg-day)	7.7E-05	1.32E−03
	HQ	0.08	0.26
	CR	8.5E-05	1.43E-03
110 m.	CDI (mg/kg-day)	7.06E-05	1.2E−03
	HQ	0.01	0.24
	CR	7.7E-05	1.32E-03

In the previous study at the subway platform, HQ values were lower in adults and children (HQ < 1). While the level of cancer risk from BC ranges from 1.93 to 1.98 times for PM10 (< 10^{-6}) (Roy *et al.,* 2024). The EPA considers cancer risk below the threshold of one case per million (10^{-6}) to be insignificant, whereas risks beyond one in 10,000 (10^{-4}) are considered significant enough for measures to reduce $PM_{2.5}$ problems and guidelines to reduce health impacts.

4. Conclusion

During haze episodes, the average concentration of $PM_{2.5}$ in the atmosphere during the daytime exceeded the standard value set by Thailand (37.5 µg/m³). Notably, $PM_{2.5}$ particles exhibited the highest average concentration at a vertical height of 110 meters (~50 µg/m³), followed by concentrations measured at 75 meters and 30 meters, respectively. Analysis of the Soot-EC to Char-EC ratio values indicates that near-surface particulate matter is primarily derived from the combustion of fossil fuels, engine emissions, and industrial processes. The children are 17 times more likely than adults to develop cancer from exposure to inhaled black carbon. Studies have shown that long-term exposure to black carbon, a component of fine particulate matter produced primarily from fossil fuel combustion, is linked to various health issues, including respiratory diseases and cancer. Specifically, black carbon has been classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC), highlighting its potential role in increasing cancer risk among vulnerable populations such as children.

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