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Variation of Black and Brown Carbon in Urban Areas, Bangkok, Thailand during Haze Episode

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Abstract

Currently, Bangkok is a large city with economic growth and various activities. Therefore, it has been experiencing continuous urban air quality problems due to air pollution for many years and its severity is getting worse every year, especially during the haze season which affects the health of the people in the area. The haze in the city contains important aerosol particles, namely Black carbon (BC) and Brown carbon (BrC). Both of these particles affect climate change. BC originates from incomplete combustion of fossil fuels, such as traffic, and BrC originates from incomplete combustion of biomass. Therefore, this research aims to study the changes in BC and BrC during the haze season in the Bangkok area. $PM_{2.5}$ were 24 hours continuously collected by dust monitors (ADR-1500; Thermo Fisher Scientific Inc., Waltham, MA, USA) at high 30, 75 and 110 m above ground level during haze episode (November – December) 2022. BC and BrC wrer analyzed with SootScanTM Model OT21 using the principle of light absorption at 370 and 880 nm, respectively. The average concentration of $PM_{2.5}$ at 30, 75 and 110 m were 16.00 ± 5.40, 28.37 ± 8.99 and 30.48 ± 9.00 µg/m³, respectively and in December the average concentration was 31.24 ± 12.45, 27.33 ± 11.47 and 28.18 ± 10.80 µg/m³, respectively. The results of the study found that BC and BrC changed with altitude. The highest concentration of BC was 8.16 µg/m³ and the highest of BrC was 12.49 µg/m³ and had the strong correlation in the nighttime more than daytime. BC and BrC have the strong correlation was found in the nighttime. BC and BrC were mostly influenced by local sources, especially traffic. This study can be applied as a guideline for sustainable management of BC and BrC.

Keywords: Aerosol; Black Carbon; Brown Carbon; Urban Air Quality; Urban Haze

1. Introduction

Bangkok, the capital of Thailand, is a major urban center known for its dense population, heavy traffic, and industrial activities, making it a hotspot for air pollution. As the center of government, education, and transportation, Bangkok experiences continuous emissions from both human activities and natural processes, leading to the persistent presence of aerosol particles in the atmosphere. Similar to many megacities worldwide, Bangkok faces year-round air pollution challenges, with severe episodes occurring during haze seasons, exacerbating public health concerns (Kanabkaew and Kim Oanh, 2011).

1.1 Variation of PM in Urban Areas

In urban areas, particulate matter (PM), especially $PM_{2.5}$, varies significantly due to differences in traffic density, industrial activities, and meteorological conditions. $PM_{2.5}$ consists of particles smaller than 2.5 microns, making them invisible to the naked

eye but highly dangerous due to their ability to penetrate deep into the respiratory system and bloodstream. Numerous studies have shown that prolonged exposure to $PM_{2.5}$ is linked to respiratory diseases, cardiovascular disorders, and cerebrovascular diseases, contributing to increased morbidity and mortality (Sharma *et al.,* 2020; WHO, 2021). Additionally, during haze seasons, the concentration of $PM_{2.5}$ tends to be significantly higher, resulting in greater exposure to hazardous pollutants (Li *et al.,* 2019). The primary sources of $PM_{2.5}$ in urban areas include vehicular emissions, industrial activities, and biomass combustion, which contribute to air pollution and climate change (Zhang *et al.,* 2020).

1.2 Black Carbon (BC) and Brown Carbon (BrC) Within PM

Carbonaceous aerosols are major components of $PM_{2.5}$, with Black Carbon (BC) and Brown Carbon (BrC) being the two dominant species. These aerosols are mainly emitted from incomplete combustion processes and play a crucial role in atmospheric chemistry and climate forcing (Bond *et al.,* 2013). BC is primarily derived from fossil fuel combustion, such as diesel engines and industrial emissions, and is known for its strong light-absorbing properties across the long-wavelength spectrum. In contrast, BrC originates mainly from biomass burning and absorbs light at shorter wavelengths, contributing to atmospheric warming in different ways (Laskin *et al.,* 2015; Zhang *et al.,* 2017).

Both BC and BrC are not only key contributors to air pollution but also significantly influence radiative forcing. BC, being a strong absorber of solar radiation, contributes to atmospheric heating and cloud formation, which can impact regional climate patterns (Ramanathan & Carmichael, 2008). BrC, although less studied, plays a critical role in altering aerosol optical properties and cloud condensation nuclei activity, making it an important factor in climate studies (Feng *et al.,* 2013).

1.3 Pollution Meteorological Factors Influencing BC and BrC

Meteorological factors strongly influence the dispersion, accumulation, and transformation of BC and BrC in the atmosphere. Key meteorological parameters, such as wind speed, relative humidity, temperature, and boundary layer height, determine the extent to which these pollutants remain suspended in the air. For instance, low wind speeds and stable atmospheric conditions at night facilitate the accumulation of BC and BrC, leading to higher nighttime concentrations compared to daytime (Huang *et al.,* 2020). Additionally, the boundary layer height plays a significant role in pollutant dispersion; a lower boundary layer height at night traps pollutants near the surface, resulting in higher concentrations of BC and BrC (Gani *et al.,* 2019).

Moreover, seasonal variations in meteorological conditions contribute to differences in BC and BrC levels. During winter haze episodes, cold temperatures and high atmospheric stability promote the build-up of pollutants, whereas during the summer, higher wind speeds and convective mixing lead to greater dispersion and lower pollutant concentrations (Ding *et al.,* 2016).

Given the significant health and environmental impacts of BC and BrC, understanding their variation and sources in urban areas is essential for effective air quality management. This study aims to analyze the temporal and spatial variation of BC and BrC in Bangkok, providing insights into their role in urban air pollution and climate change. The findings can serve as a guideline for policymakers to implement effective strategies for reducing emissions, mitigating air pollution, and improving public health.

2. Methodology

2.1 Study site

The study site is the Microclimate and Air Pollutants Monitoring Tower at Kasetsart University (KU Tower). The KU Tower is in the Kasetsart University (13.854529 °N, 100.570012 °E) which represents the urban area. It is surrounded by main road are Phahonyothin Road, Vibhavadi Road and Ngamwongwan Road. In this study was collected in November until December 2022 during haze episode (Figure 1.).

2.2 Sample collection

$PM_{2.5}$ were collected at three heights above the ground level at 30, 75, and 110 m by dust monitors (ADR-1500; Thermo Fisher Scientific Inc., Waltham, MA, USA) (Figure 2.). The monitors were calibrated and their values were compared before the study. The samples were collected on quartz microfiber filters (37 mm in diameter). The filters were pretreated at 550 °C for 1 h to optimize the post-sampling evaluation of the BC and BrC concentrations. The inlet had a cut-off diameter of 2.5 µm and an inflow rate of 1.52 L/min. Collected the sample two times per day, daytime (08:00 AM - 7:00 PM) and nighttime (8:00 PM - 07:00 AM) after $PM_{2.5}$ sampling, the loaded filters were stored in a refrigerator at approximately 4 °C prior to analysis.

2.3 BC and BrC concentration analysis

BC and BrC were analyzed by the Optical Transmiossometer (OT-21, Magee Scientfic), this is instrument that measures the Black Carbon and Brown Carbon content of an aerosol sample collected on a filter. The outside holder was used to measure light attenuation of the sample filter and the inside holder was used for a reference (blank) filter. The transmission intensity of light at Infrared (880 nm) and ultraviolet (370 nm) wavelengths are referred to as BC and BrC respectively. As the light passes through, some of it is absorbed by these particles, and the ratio of transmitted to incident light is used to calculate the concentration of carbon compounds in the dust sample. This process is known as Absorption Attenuation (ATN). (1-3).

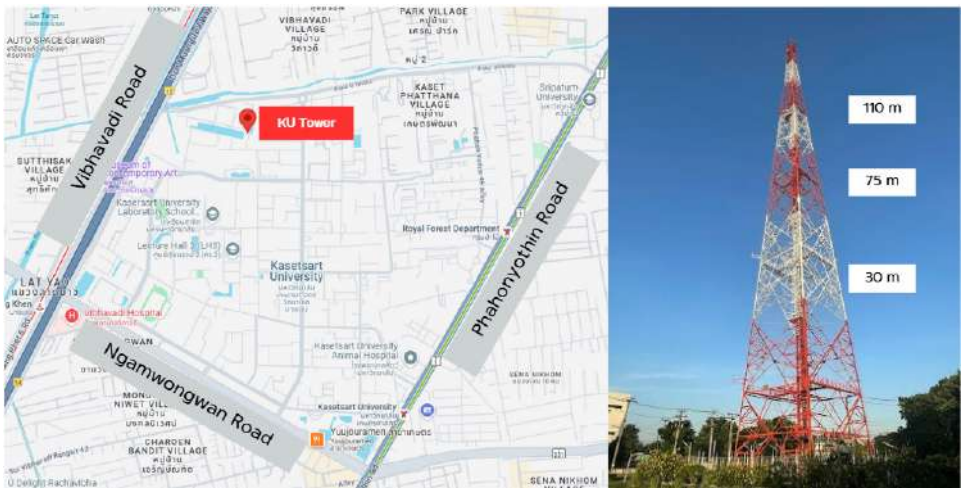

Figure 1. Study area and Microclimate and Air Pollutants Monitoring Tower at Kasetsart University (KU Tower)

Figure 2. The dust monitors (ADR-1500; Thermo Fisher Scientific Inc., Waltham, MA, USA)

The ATN is calculated using equation (1):

$$ATN = 100 \times \ln\left(\frac{Blank\ filter\ transmitted\ intensity}{Sample\ filter\ transmitted\ intensity}\right) \quad (1)$$

The ATN values used in b_{att} is the inverse of megameter, area is area of filter, V_{std} is the air volume at standard conditions.

$$b_{att}\ (Mm^{-1}) = \frac{Area\ (m^2)}{V_{std}\ (m^3)} \times ATN \times 10^4 \quad (2)$$

The ATN values can be used to calculate the concentration of Black Carbon and Brown Carbon using equation (3), where the specific equal to 16.66 m²/g for BC and 39.5 m²/g for BrC. (4)

$$BC\ or\ BrC\ (\mu g\ m^{-3}) = \frac{b_{att}\ (Mm^{-1})}{\sigma_{att}\ (\lambda)\ (m^2\ g^{-1})} \quad (3)$$

3. Results and Discussion

3.1 Concentration of $PM_{2.5}$

The results indicate that the average $PM_{2.5}$ concentrations at heights of 30 m, 75 m, and 110 m were 27.25 ± 19.78 µg/m³, 34.57 ± 16.46 µg/m³, and 34.35 ± 15.42 µg/m³, respectively. Notably, $PM_{2.5}$ concentrations were higher during nighttime compared to daytime. The highest recorded concentration was 88.28 µg/m³ at an altitude of 75 m during a December night.

The average concentrations at 75 m and 110 m varied significantly between daytime and nighttime (Table 1).

Meteorological factors such as relative humidity (RH), temperature (Temp), wind speed (WS), and wind direction (WD) played a crucial role in the variation of $PM_{2.5}$ concentrations (Table 2). Previous studies (e.g., Galindo *et al.,* 2011) have identified wind speed as a key factor influencing atmospheric particulate matter levels. Lower wind speeds tend to reduce the dispersion of pollutants, leading to higher concentrations of $PM_{2.5}$, particularly during stagnant atmospheric conditions. Additionally, increased relative humidity may contribute to particle growth and secondary aerosol formation, further elevating $PM_{2.5}$ levels during haze episodes.

The increase in $PM_{2.5}$ concentration with altitude is likely due to reduced surface deposition, stable atmospheric conditions, local emissions, and limited vertical mixing especially at night. During stable atmospheric conditions, especially at night, the boundary layer tends to be shallower, trapping pollutants at higher altitudes (e.g., 75 m and 110 m). Temperature inversions can prevent vertical dispersion, allowing pollutants to accumulate at mid-level heights rather than dispersing near the surface (Choomanee *et al.,* 2024)

Table 1. Concentration of $PM_{2.5}$, Black carbon and Brown carbon (µg/m³)

Month	Level (m)	Daytime			Nighttime		
		$PM_{2.5}$	BC	BrC	$PM_{2.5}$	BC	BrC
November	30	16.00 ± 5.40	1.01 ± 0.53	1.70 ± 0.50	18.41 ± 12.66	2.59 ± 1.29	3.95 ± 2.11
	75	28.37 ± 8.99	1.84 ± 1.11	2.80 ± 1.11	37.96 ± 15.09	3.01 ± 1.10	4.85 ± 1.61
	110	30.48 ± 9.00	2.29 ± 0.96	3.51 ± 0.88	37.95 ± 15.32	3.36 ± 1.03	5.23 ± 1.55
December	30	31.24 ± 12.45	3.68 ± 0.73	4.50 ± 0.92	48.08 ± 24.01	5.08 ± 1.92	7.76 ± 2.78
	75	27.33 ± 11.47	3.60 ± 1.14	4.58 ± 1.03	43.27 ± 20.72	4.40 ± 1.25	6.47 ± 2.27
	110	28.18 ± 10.80	3.81 ± 0.99	4.74 ± 1.12	40.33 ± 19.86	4.34 ± 1.39	6.68 ± 2.11

Table 2. Average meteorological during the haze episode (November – December 2022)

Month	Height (m)	RH (%)	Temp (°C)	WS (m/s)	WD (degree)
November	30	67.08 ± 15.04	28.61 ± 2.25	1.33 ± 0.60	154.64
	75	68.13 ± 27.78	30.51 ± 10.78	2.13 ± 1.11	152.30
	110	69.82 ± 27.69	30.52 ± 11.30	2.08 ± 1.28	120.41
December	30	59.59 ± 11.36	26.71 ± 2.84	3.85 ± 2.14	143.51
	75	59.14 ± 11.01	26.33 ± 2.74	2.78 ± 1.29	151.92
	110	59.65 ± 11	26.08 ± 2.70	3.04 ± 1.42	92.69

Figure 3 illustrates the temporal variation of $PM_{2.5}$ concentrations at different heights (30 m, 75 m, and 110 m) during November and December 2022. The data show that $PM_{2.5}$ concentrations at 30 m were consistently lower than those at 75 m and 110 m throughout November. Moreover, the concentrations at 75 m and 110 m were highly similar, indicating that pollutants were well-mixed between these two heights.

Additionally, sharp increases and decreases in $PM_{2.5}$ concentrations were observed during certain periods. These fluctuations could be attributed to meteorological influences, such as changes in wind speed, humidity, and temperature, which significantly impact $PM_{2.5}$ levels (Chen *et al.,* 2014). Human activities in urban areas, including vehicular emissions, industrial operations, and biomass burning, also contribute to these variations (Liao *et al.,* 2023). The observed trends underscore the complex interplay between environmental factors and anthropogenic emissions in shaping urban air quality.

3.2 The variation of Black carbon and Brown carbon

The highest Black Carbon (BC) concentrations at 30 m, 75 m, and 110 m were 8.16 μg/m³, 6.48 μg/m³, and 7.17 μg/m³, respectively, all observed during nighttime. Similarly, the highest Brown Carbon (BrC) concentrations at 30 m, 75 m, and 110 m were 12.49 μg/m³, 10.97 μg/m³, and 11.36 μg/m³, respectively (Figure 4).

As shown in Table 1, BC and BrC concentrations were higher at night than during the daytime, following a similar pattern to $PM_{2.5}$ concentrations. In November, the average BC and BrC concentrations increased with altitude. However, in December, the concentrations were more uniform across heights, likely due to similar meteorological conditions that influenced pollutant dispersion.

The BC concentrations observed in this study fall within the range reported for urban areas such as Guangzhou, China (0.6 – 20.5 μg/m³ at 53 m) (Chen *et al.,* 2014) and Shenzhen, China (4.9 ± 1.4 to 6.6 ± 3.6 μg/m³ at 2 – 350 m) (Liang *et al.,* 2022). The elevated BC levels are likely influenced by traffic emissions and long-range transport of pollutants from external sources.

The BrC concentrations in this study were higher than those reported in Beijing, China (0.82 ± 0.44 μg/m³) (Wang *et al.,* 2021), suggesting a significant influence from biomass burning, which is a major source of BrC in urban environments.

3.3 Relationship between BC, BrC mass concentration and $PM_{2.5}$

Figure 5 illustrates a strong correlation between Black Carbon (BC) and Brown Carbon (BrC) concentrations during nighttime, while a weaker correlation was observed during the daytime. This discrepancy may be attributed to better dispersion of aerosol particles due to increased atmospheric mixing during the day.

At nighttime, BrC exhibited a higher correlation than BC at all measured heights: 30 m ($R^2 = 0.72$), 75 m ($R^2 = 0.56$), and 110 m ($R^2 = 0.62$). This suggests that during the night, atmospheric conditions favor the accumulation of BC and BrC, likely due to reduced boundary layer height and weaker wind speeds. The elevated nighttime concentrations indicate contributions from various human activities, including biomass burning, vehicular emissions, and other anthropogenic sources.

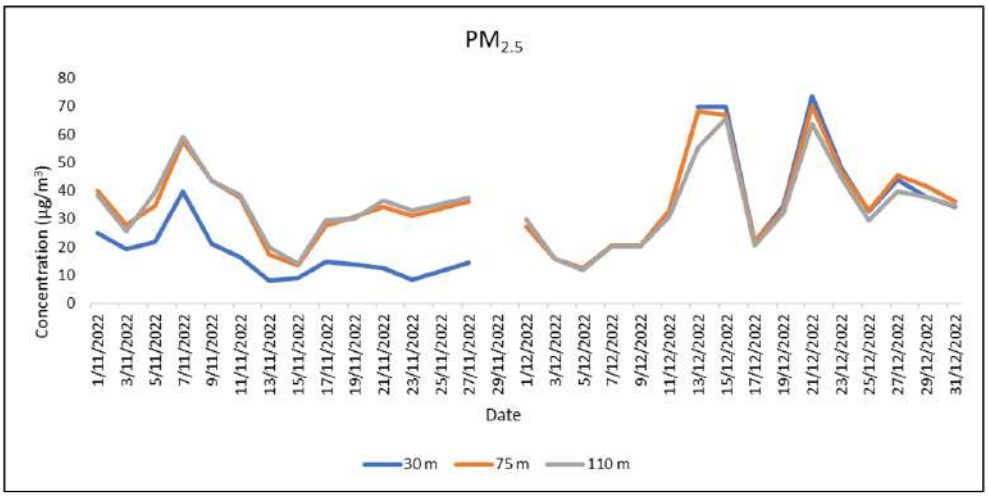

Figure 3. The concentration of $PM_{2.5}$ at height 30, 75 and 110 m

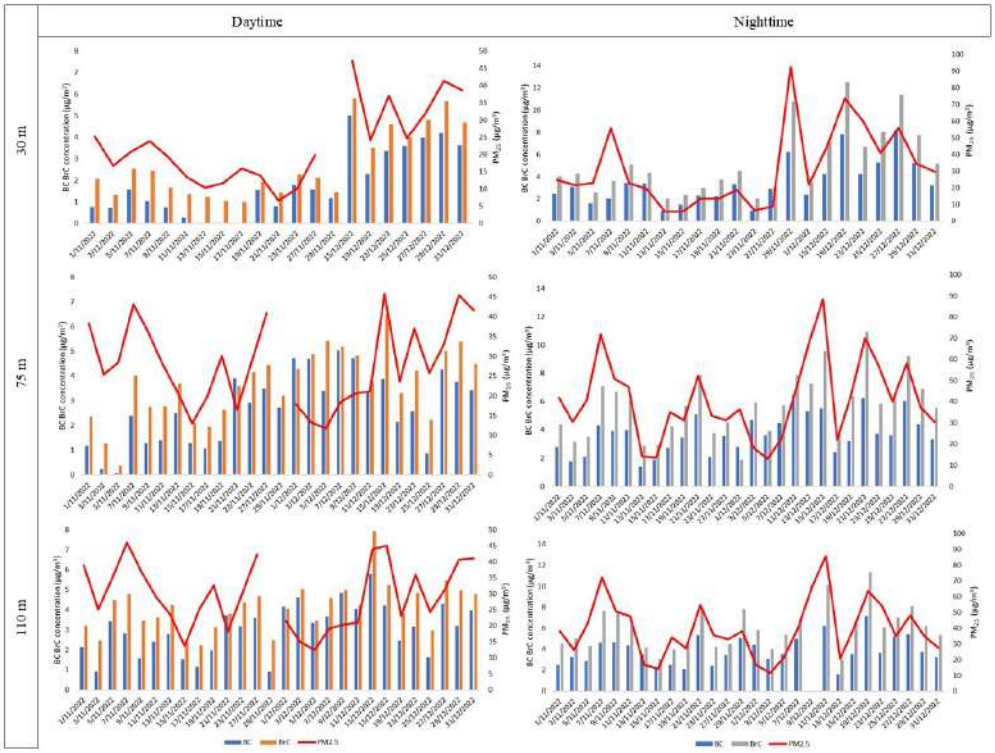

Figure 4. The variation of BC and BrC concentration during the daytime and nighttime at heights of 30 m, 75 m, and 110 m from November 2022 – December 2022.

Black Carbon (BC) and Brown Carbon (BrC) exhibited a strong correlation during both daytime and nighttime (Figure 6). The highest correlation was observed at 110 m during nighttime, with nighttime correlations consistently higher than those during the daytime.

This strong correlation suggests that urban particulate matter originates from common sources, primarily incomplete combustion processes, such as the burning of fossil fuels and biomass (Deng *et al.,* 2020).

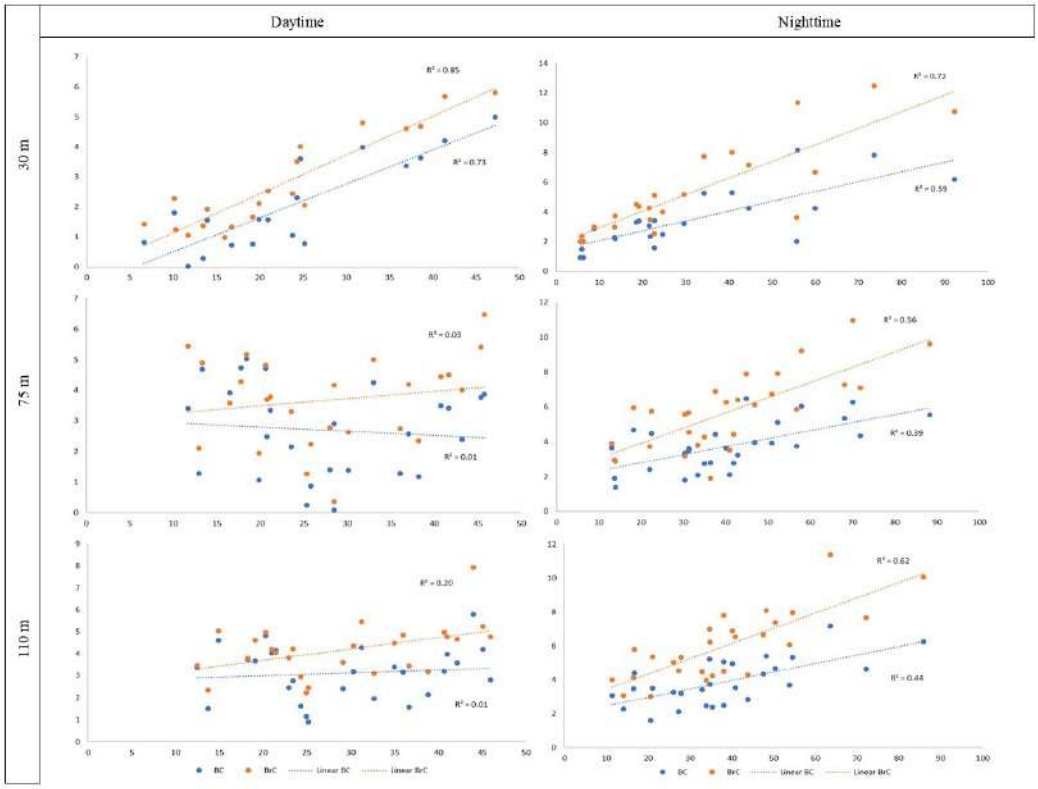

Figure 5. Correlation between BC and BrC mass concentration and $PM_{2.5}$ at the height 30, 75 and 110 m

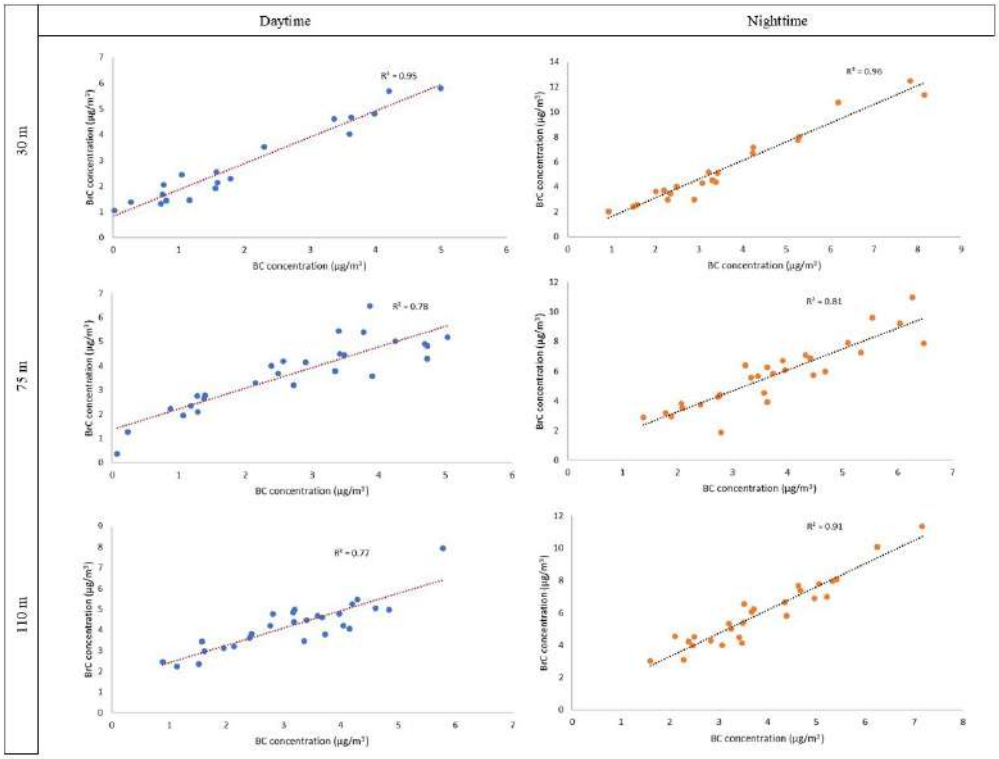

Figure 6. Correlation between BC and BrC mass concentration in 30, 75 and 110 m

4. Conclusion

This study highlights the variation of $PM_{2.5}$, Black Carbon (BC), and Brown Carbon (BrC) concentrations at different altitudes in Bangkok, Thailand, during a haze episode. The highest $PM_{2.5}$ concentration recorded was 88.28 µg/m³, with a clear trend of higher concentrations at 75 m and 110 m compared to 30 m, particularly at night. The results reveal that BC and BrC concentrations were consistently higher during nighttime than daytime, likely due to reduced boundary layer height, lower wind speeds, and emissions from nighttime human activities.

A significant finding of this study is that BrC exhibited the highest concentration (12.49 µg/m³) at 30 m, indicating a strong influence from biomass burning. Additionally, the correlation between BC and BrC was stronger at night, suggesting a common source of emissions, primarily incomplete combustion of fossil fuels and biomass. The elevated concentrations of BC and BrC are concerning, as both pollutants contribute to air pollution, adversely impact human health, and influence atmospheric radiative forcing, potentially altering local climate conditions.

These findings emphasize the urgent need for effective emission reduction strategies, particularly targeting biomass burning and fossil fuel combustion, to mitigate air pollution and improve urban air quality. Future research should focus on source apportionment and long-term monitoring to better understand pollution dynamics and develop sustainable air quality management policies.

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