International Journal of Environmental Science and Technology
https://doi.org/10.1007/s13762-024-06302-3

SHORT COMMUNICATION

The influence of meteorological factors on wintertime black carbon and $PM_{2.5}$ pollution in Dhaka, Bangladesh

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Received: 22 August 2024 / Revised: 21 October 2024 / Accepted: 25 December 2024

Abstract

This study focuses on the alarming levels of black carbon (BC) and fine particulate matter ($PM_{2.5}$) pollution during winter in Dhaka, Bangladesh. The study period was chosen to coincide with the cold wave period during winter when temperatures were at their lowest. The average concentration of BC (24.2 μgm^{-3}) and $PM_{2.5}$ (73.2 μgm^{-3}) in Dhaka, the capital city, were measured and found to surpass national air quality standards and WHO guidelines. The study period had two distinct parts: a high pollution (HP) period from January 23–25, 2024, and a low pollution (LP) period from January 12–15, 2024. During the HP period, the average BC and $PM_{2.5}$ concentrations were 60 and 36% higher than the overall study period average. On the other hand, during the LP period, the average BC and $PM_{2.5}$ concentrations declined by about 30 and 26%, respectively, compared to the overall study period averages. High concentrations of BC (> 10 μgm^{-3}) were detected daily, indicating significant pollution levels during the winter season. Distinct diurnal patterns were observed during the HP period. Specifically, the concentration of BC significantly increased during the night, in contrast to the mild diurnal patterns observed in the LP period. Moreover, both $PM_{2.5}$ and BC concentrations exhibited a statistically significant negative correlation with key meteorological parameters, including wind speed, wind direction, and visibility. This study highlights the critical role of meteorological factors in managing air pollution, which has broader implications for environmental sustainability.

Keywords Air-pollution · Particulate matter · Black carbon · Diurnal variation · Indo-Gangetic plain

Introduction

Black carbon (BC) aerosol originates from incomplete fuel combustion and holds significant importance in atmospheric dynamics due to its potential influences on climate and human health (Petzold et al. 2013; Liu et al. 2016). BC absorbs solar radiation within the visible spectrum, thus significantly driving global warming (Jacobson 2010; Bond et al. 2013). Apart from its role in influencing climate, it is also linked to various respiratory disorders and poses risks to cardiovascular health (Jansen et al. 2005; Suglia et al. 2008b, a). These BC aerosols are integral constituents of $PM_{2.5}$, which denotes fine particles with a diameter smaller than 2.5 µm. They can exert considerable effects on both human health and the surrounding environment.

Given the profound effects of BC and $PM_{2.5}$ on air quality, climate dynamics, and public health, it is crucial to investigate its sources to develop effective mitigation strategies thoroughly (Budhavant et al. 2015; Liu et al. 2018; Dasari et al. 2019). BC has come under increased scrutiny due to its small particle size, inert chemical properties, and remarkable ability to absorb radiation (Bond et al. 2013; Budhavant et al. 2020; Nair et al. 2023). These characteristics, coupled with the rising levels of BC emissions, underscore the necessity of closely monitoring these aerosols across diverse South Asian locations (Gawhane et al. 2019; Dasari et al. 2020; Nair et al. 2024). Such monitoring efforts are essential for comprehensively understanding and addressing the

Editorial responsibility: M.F. Yassin.

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Published online: 04 January 2025

complex challenges of $PM_{2.5}$ and BC pollution (Bibi et al. 2017; Budhavant et al. 2018, 2023).

Automotive emissions, specifically diesel engines, residential heating, biomass burning, and industrial activities, are human-caused sources of atmospheric BC (Budhavant et al. 2015; Singh et al. 2018a; Dasari et al. 2020). In contrast, forest fires and volcanic emissions are natural sources (Singh et al. 2018c; Budhavant et al. 2023). The transportation of fine particles over long distances may contribute to the amplification of BC concentrations in urban regions, which are already subject to the impact of local urban emissions (Aruna et al. 2013; Ji et al. 2019; Liu et al. 2019).

Dhaka, the capital city of Bangladesh, grapples with elevated air pollution levels attributed to substantial urban development, expanding vehicular traffic, and a growing industrial sector (Pavel et al. 2021a). Dhaka city faces challenges from transboundary air pollution, as emissions from neighboring regions worsen the city's air quality further (Zaman et al. 2021b, a). Several investigations have explored air pollution in Bangladesh (e.g., Salam et al. 2003; Pavel et al. 2020; Pavel et al. 2021b, 2023; Zaman et al. 2022; Azam et al. 2023; Hossain et al. 2023; Hossen et al. 2023; Roy et al. 2023; Islam et al. 2024; Kamal et al. 2024; Nayeem et al. 2024); However, a limited number of these studies have focused specifically on BC pollution. Salam et al. (2021) explored the combustion sources of BC in high-loading winter during 2013/14 using dual carbon isotope and reported high concentration (13 ± 6 μgm^{-3}) in Dhaka. Similar concentrations (11.2 ± 9.8 μgm^{-3}) were reported by Begum et al. (2013) in a study conducted from January 2007 to February 2009. Another study conducted in the brick kilns found very high concentrations of BC 16.6 ± 7.1 μgm^{-3}) in Dhaka (Haque et al. 2018).

It's crucial to highlight the existing gap in comprehensive research explicitly focusing on the relationship between BC and $PM_{2.5}$ (fine particulate matter) during high pollution periods, particularly in distinguishing between haze and non-haze conditions. However, this study aims to address this research gap by thoroughly examining the high pollution period, specifically in January, and investigating the meteorological factors that influence BC concentrations. Consequently, the outcomes of this study will furnish policymakers and stakeholders with invaluable insights, facilitating the formulation of efficacious mitigation strategies targeted at curbing atmospheric BC levels.

Materials and methods

Site description

Dhaka City, Bangladesh, has a warm and humid climate that is influenced by seasonal pattern of pre-monsoon, monsoon, post-monsoon, and winter seasons, which often result in heavy precipitation and tropical cyclones. Based on historical climate data, the average temperature in Bangladesh is around 26 °C, with fluctuations ranging from 15 to 34 °C throughout the year. With an average of approximately 2,200 mm of rainfall per year, Bangladesh is known for its high precipitation levels, contributing to its reputation as one of the wettest countries in the world (Pavel et al. 2021a). This study period was chosen as the country experienced a cold wave, and the temperature was at its lowest between December and January during the winter.

The study was conducted at the Department of Chemistry, University of Dhaka (23.73°N, 90.39°E, Fig. 1), in the heart of Dhaka city on Mukarrom Hossian Khandakar (MHK). Two busy highways, Chankharpul Road (0.5 km) and Shahbag Road (1.1 km), are near MHK Bhaban. The TSC Station, a bustling metro station, is approximately 0.3 km away. The sampling site is exposed to emissions from various sources, which include buses, lorries, private cars, and non-motorized vehicles. Although there are no major industrial enterprises in the vicinity, smaller chemical and other companies are situated within a distance of 2–3 km in old Dhaka. Despite being located in an institutional area, several large construction projects are nearby, namely high-rise buildings and metro rail development. The sampling was conducted in the ambient atmosphere to capture the area's environmental conditions accurately.

Instrumentations

BC mass concentration was continuously monitored through the use of a dual-spot Aethalometer (Model AE-33, Magee Scientific, USA), operating at a flow rate of 5 L/min and providing a time resolution of 1 min (Fig. 2 and Fig. 3). The device measures BC levels at the surface level at seven different wavelengths (370, 470, 525, 590, 660, 880, and 950 nm). Measurements at 880 nm are commonly used as BC aerosols strongly absorb at this wavelength (Hansen et al. 1984; Prasad et al. 2018; Shen et al. 2021). Aethalometer was placed on the 3rd floor of the MHK Bhaban, DU at around 10 m from the ground level. The device collected BC data between January 8 and 27, 2024. The instrument user manual was followed to examine the data for discrepancies and errors carefully. The screened data was analyzed to calculate hourly and daily averages for this research. Information regarding the instrument and sampling methodologies has been delineated in numerous studies (Sandradewi et al. 2008; Drinovec et al. 2015; Prasad et al. 2018).

$PM_{2.5}$ data was collected using a BlueSky™ sensor manufactured by TSI Incorporated, USA. The device was installed on the third floor in close proximity to the Aethalometer. The sensors utilize a Sensirion sensor (SPS 30) and employ the light scattering principle to measure $PM_{2.5}$ concentration

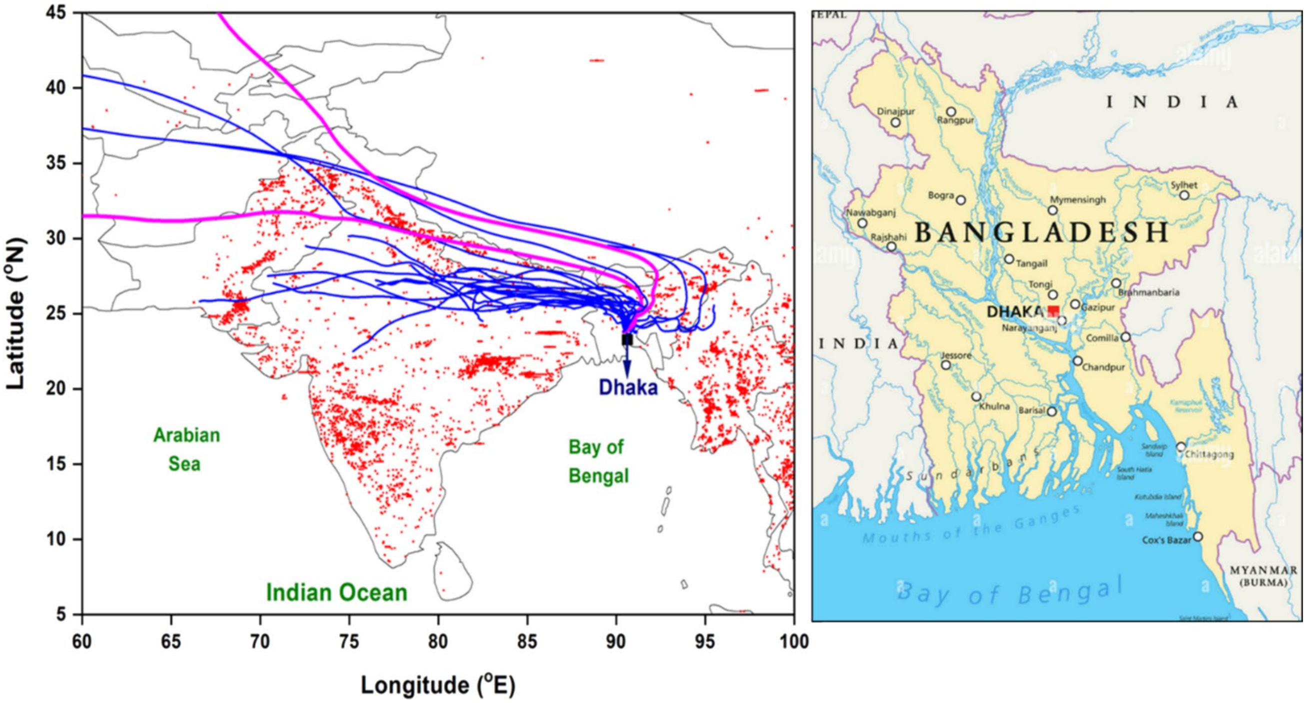

Fig. 1 Daily 120 h of air mass back trajectories ending at Dhaka at 100 m are indicated by pink (High pollution period, January 24–25, 2024) and blue lines for the rest of the period. The MODIS/Aqua sensors have detected fire activities indicated by red spots. The right-side panel displays a map of Bangladesh

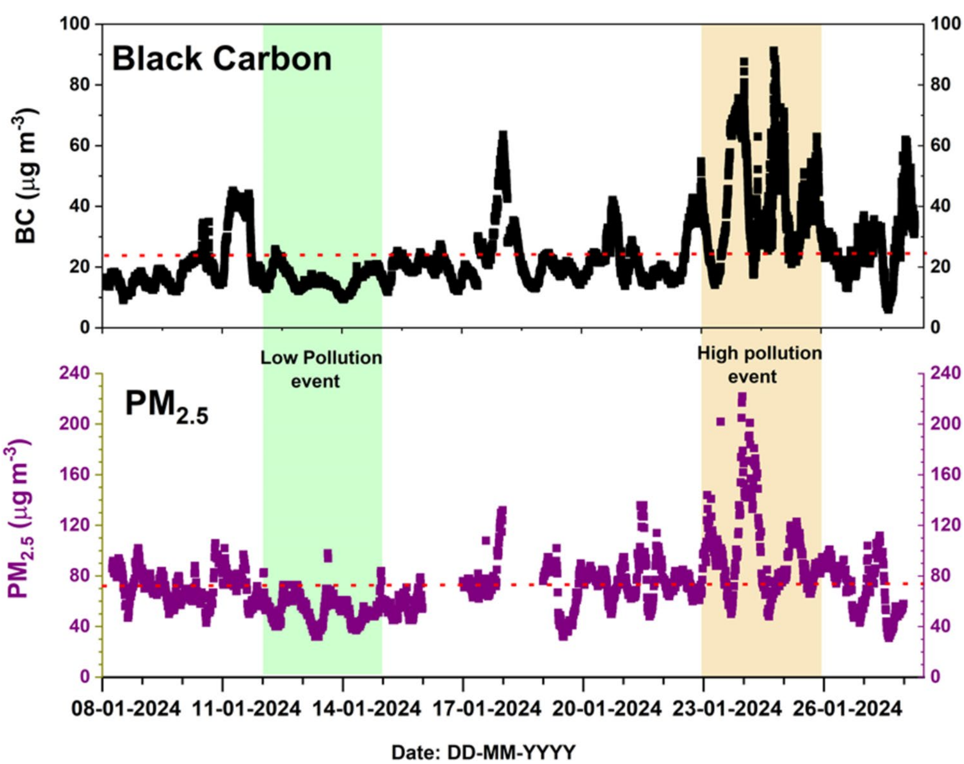

Fig. 2 Temporal variation of BC and $PM_{2.5}$ concentration in Dhaka from January 8 to 27, 2024. The vertical color columns indicate low and high pollution events. The red dotted horizontal line depicts the average values of the measured species

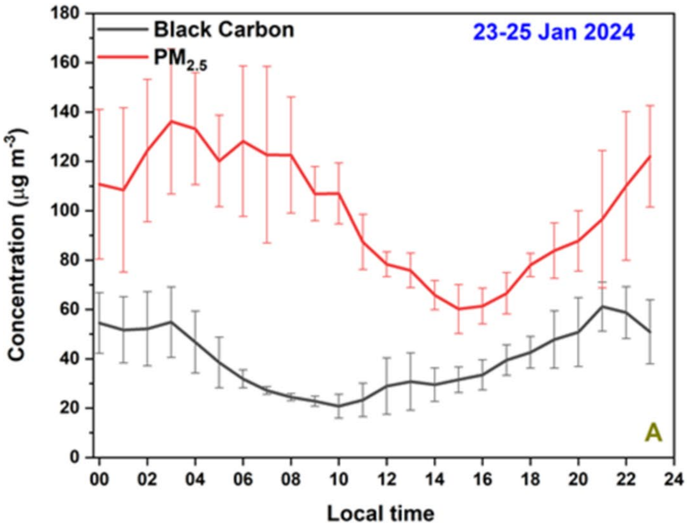

Fig. 3 The changes in black carbon and $PM_{2.5}$ levels during high and low pollution periods in Dhaka. The standard deviation is shown as a vertical bar

(Gao et al. 2015). The sensor is designed to measure aerosol concentrations within the range of 0–1000 μg/m³. It exhibits a counting efficiency of 50% at 0.3 μm and 98% at 0.5 μm, ensuring an accuracy of ± 10% for concentrations between 100 and 1000 μg/m³. With optimal performance parameters, it operates effectively within a humidity range of 0–95% (non-condensing) and a temperature range of − 10 to 60 °C, making it well-suited for our study, where relative humidity (RH) typically fluctuates between 65 and 90%.

It is crucial to recognize that elevated levels of RH can influence the accuracy of PM sensors that use light scattering. Previous research has underscored how RH affects $PM_{2.5}$ measurements, particularly indicating that scattering increases at higher humidity levels (Lee et al. 2021; Chang et al. 2023; Borhani et al. 2024). Daily $PM_{2.5}$ data was also collected from January 8–27, 2024. Meteorological parameters like temperature, RH, windspeed, wind direction, visibility, and pressure were collected from https://www.visualcrossing.com (Fig. 4). The weather station is approximately 5 km from MHK Bhaban, DU.

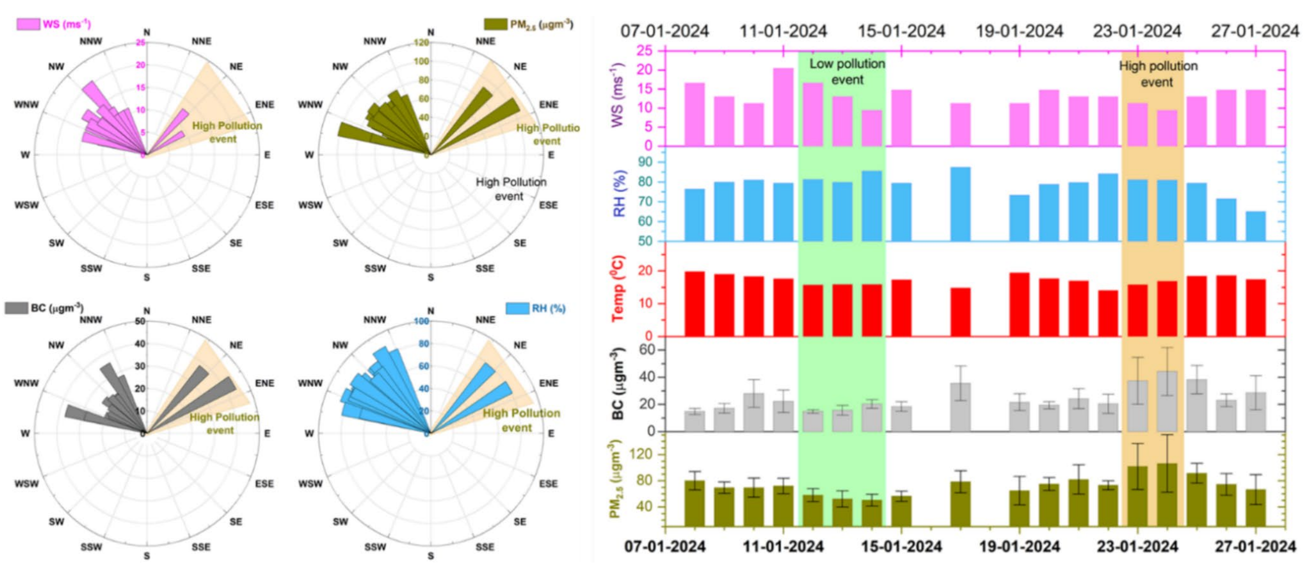

Fig. 4 Illustrates the wind roses for various parameters measured at Dhaka during the sampling period. The right-side panels display the daily average of $PM_{2.5}$, BC, and meteorological parameters. The vertical color panels on the left indicate the low and high pollution events observed in Dhaka, Bangladesh

Air mass back trajectories and statistical analysis

The NOAA HYSPLIT model is utilized to determine the three-dimensional trajectories of air that arrived at the Dhaka measuring site over five days (Fig. 1). These trajectories are calculated using data from the National Weather Service's National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS, 1 degree). They help identify where pollutants originate and how they travel to a specific location. This information is crucial in determining the regional contribution of contaminants at different altitudes. The study used Pearson correlation analysis to investigate the association between meteorological parameters with BC and $PM_{2.5}$ concentrations. Furthermore, Student's t-tests determined the significance ($p<0.05$) of mean differences in BC concentration among these parameters.

Results and discussion

Temporal variation of BC and $PM_{2.5}$

The study aims to analyze the changes in BC and $PM_{2.5}$ over time, focusing on identifying patterns and trends in their temporal variation (Fig. 2). The average concentration of BC was 24.6 ± 8.8 μgm^{-3}, with a range of 14.8–44.2 μgm^{-3}. The findings showed high BC concentrations (> 10 μgm^{-3}) daily, indicating significant pollution levels during the winter season. Table 1 provides data from other South Asian studies to compare the results. For instance, Bano et al. (2011) conducted observations during the winter of 2006 in Delhi, India, utilizing the aethalometer AE 42, revealing a significantly high concentration of BC at 25.5 μgm^{-3}. Similarly, Vaishya et al. (2017) documented a substantial BC concentration of 19 ± 14 μgm^{-3} in Gorakhpur, India, during winter, spanning from August 2013 to July 2015. The trend of heightened BC levels persisted in Agra, as Song et al. (2013) indicated, with a recorded concentration of 20.6 μgm^{-3}. However, contrasting results emerged from studies conducted in other South Asian regions. Joshi et al. (2016) found substantially lower BC levels of 7.9 ± 5.2 μgm^{-3} in Pantnagar, India. Safai et al. (2008) observed a range of 10.5 to 17.4 μgm^{-3} for BC during December 2004 in Agra, underscoring variability within the same city over different periods. Across the border in Pakistan, Bibi et al. (2017) documented a relatively lower BC concentration of 12.5 μgm^{-3} in Karachi. Similarly, studies in Dhaka, Bangladesh, revealed comparatively lower BC levels: Salam et al. (2021) reported concentrations of 13 ± 6 μgm^{-3}, while Begum et al. (2013) found levels of 11.2 ± 9.8 μgm^{-3}.

Throughout the study duration, the mean daily $PM_{2.5}$ concentration varied from 50.4 to 106.3 μgm^{-3}, averaging at 73.4 ± 15.4 μgm^{-3}. This average value exceeds the national ambient air quality standards (NAAQS) set for Bangladesh, which is 65 μgm^{-3} daily. About 77.8% of days during the study period exceeded this limit. Furthermore, the $PM_{2.5}$ level was five times higher than the daily guidelines set by the World Health Organization (WHO-2021) for $PM_{2.5}$ (15 μgm^{-3}) (Organization 2021). Memhood et al. (2018) found similar trends in Islamabad, Pakistan, with a $PM_{2.5}$ concentration of 69.97 μgm^{-3} in 2017. They highlighted the winter season as the most polluted. Conversely, Rengarajan et al. (2011) reported a lower average $PM_{2.5}$ concentration of 55.7 μgm^{-3} in Ahmedabad, India. However, higher $PM_{2.5}$ concentrations have also been observed across South Asia. Lv et al. (2019) recorded a $PM_{2.5}$ concentration of 97.3 μgm^{-3} in Islamabad during winter 2017, indicating

Table 1 Black carbon (BC) and $PM_{2.5}$ (μgm^{-3}) from various studies conducted in South Asia

Study	City/Region	Period	$PM_{2.5}$ (μgm^{-3})	BC (μgm^{-3})
Present study (2024)	Dhaka, Bangladesh	January 8 to 27, 2024	73 ± 15	25 ± 9
Bano et al., (2011)	Delhi, India	January, 2006- January, 2007		26
Joshi et al., (2016)	Pantnagar, India	2009–2012		8 ± 5
Safai et al., (2008)	Agra, India	December, 2004		11–17
Vaishya et al., (2017)	Gorakhpur, India	August, 2013- July, 2015		19
Bibi et al., (2017)	Karachi, Pakistan	2006–2008		13
Ramachandran and Kedia, (2010)	Ahmedabad, India	2008		12 ± 3
Salam et al., (2021)	Dhaka, Bangladesh	December, 2013- February, 2014		13 ± 6
Begum et al., (2013)	Dhaka, Bangladesh	January 2007, February, 2009	37 ± 26	11 ± 10
Pavel et al., (2021a, b)	Dhaka, Bangladesh	2003–2019	89 ± 10	
Lv et al., (2019)	Islamabad, Pakistan	2016–2017	97	
Mehmood et al., (2018)	Islamabad, Pakistan	2017	70	
Rengarajan et al., (2011)	Ahmedabad, India	December 2006– January 2007	56	
Singh et al., (2021)	Delhi, India	April, 2012- March, 2013	208 ± 44	

significant regional pollution levels. Similarly, Singh et al. (2021) reported exceptionally high $PM_{2.5}$ concentrations in Delhi, reaching 208 ± 44 μgm^{-3}, highlighting the severity of pollution episodes in the Indian capital. Pavel et al. (2021a) utilized reanalysis model data to report a $PM_{2.5}$ concentration of 87 ± 10 μgm^{-3} in Dhaka, Bangladesh.

The variations of BC and $PM_{2.5}$ concentrations in Dhaka for the study period are shown in Fig. 2. The figure depicts two distinct periods: a high pollution (HP) period observed from January 23–25, 2024, and a low pollution (LP) period from January 12–15, 2024. During the HP period, the mean BC concentration was 39.9 ± 3.8 μgm^{-3}, while the mean $PM_{2.5}$ concentration was 99.8 ± 7.6 μgm^{-3}. These values represent an increase of approximately 60% for BC and 36% for $PM_{2.5}$ compared to the average values for the whole study period. Conversely, during the LP period, the average BC concentration was 17.3 ± 2.5 μgm^{-3}, and the mean $PM_{2.5}$ concentration was 54.2 ± 3.5 μgm^{-3}, indicating a decrease of around 30% for BC and 26% for $PM_{2.5}$ compared to the overall study period averages. During the HP period, the ratio of BC to $PM_{2.5}$ was approximately 40%, compared to around 30% during the LP period. These ratios are significantly higher than those reported in studies from countries like India, Korea, and Japan, where BC/$PM_{2.5}$ ratios typically range from 5 to 30% (Cha et al. 2019; Gawhane et al. 2019; Krishna et al. 2019; Mori et al. 2020). These findings clearly indicate substantial fluctuations in air pollution levels in Dhaka, with significantly higher concentrations of BC and $PM_{2.5}$ during the HP period compared to the LP period. The markedly higher BC/$PM_{2.5}$ ratios observed in Dhaka, relative to other regions, emphasize the urgent need for improved air quality management in Bangladesh.

Diurnal variation of BC and $PM_{2.5}$

BC concentration in the atmosphere in the daytime and nighttime is substantially affected by human activities, such as the intensity of source emissions, surface meteorological parameters, and mixing height, as well as by natural factors, such as solar heat and the density of the boundary layer (Liu et al. 2018; Prasad et al. 2018). Two distinct diurnal BC and $PM_{2.5}$ concentration patterns were observed at Dhaka (Fig. 3). During the HP period, BC concentration in Dhaka showed a clear diurnal pattern, with levels gradually decreasing from late at night until reaching their lowest point at 10 am (20.8 μgm^{-3}). Afterward, there was a steady rise in concentrations, peaking at 9 pm (61.1 μgm^{-3}), and BC concentrations were consistently higher during nighttime compared to daytime. This increase in nighttime concentrations was due to low temperatures and reduced wind speeds (Fig. 4), facilitating pollutant accumulation. Nighttime high BC concentrations were also reported in Korea (Lee et al. 2016) and Japan (Yoshikado 2018). On the other hand, during the day, the intensification of solar heat and the densification of the boundary layer promoted pollutant dispersion, leading to a reduction in BC concentration. A similar phenomenon was observed by Bibi et al. (2017) and Singh et al. (2018b), who stated that solar heat and boundary densification caused the intensification of the convective mixing layer, leading to enhanced vertical mixing and pollutant dispersion. The intensity of solar heat and the density of the boundary layer are the primary factors that promote the dispersion of pollutants during the day. During the LP, the period of low pollution, mild diurnal variation was observed, with a minimum at 2 am (14.4 μgm^{-3}) and a maximum at 6 pm (19.5 μgm^{-3}). The reason for this mild variation is that the intensity of source emissions is low during the LP, leading to lower pollutant concentrations. This explains that the complex diurnal variation in BC concentration is influenced by humans and nature. Effective strategies to mitigate air pollution's adverse environmental effects and explore potential links with public health through future studies are crucial.

Source Identification of Pollutants

This study found that BC (25 ± 9 μgm^{-3}) accounted for about 34% of the $PM_{2.5}$ (73 ± 15 μgm^{-3}) loadings in Dhaka. BC and $PM_{2.5}$ levels had a strong positive correlation ($r = 0.76$), indicating a possible common source. The study by Salam et al. (2021) exhibited that in the intense winter period of 2013/14, 44 ± 1% of BC came from biomass combustion, while the remaining portion came from fossil combustion. We studied the daily air-mass back trajectories arriving at Dhaka to detect the origins of long-range pollution. During the HP period, most air-mass routes came from India in the west, as shown in Fig. 1. This reveals the negative impact of transboundary air pollution on the environment in Dhaka. We also analyzed regional meteorological information and found that the wind direction during the sampling period differed from the rest. It was coming from the northeast instead of the northwest, as shown in Fig. 4. This demonstrates the severity of the effect of transboundary air pollution during the HP period.

Previous studies from Bangladesh have conducted cluster trajectory analyses to detect the source regions and potential air-mass transport (Dasari et al. 2019; Zaman et al. 2021a; de Foy et al. 2024; Nair et al. 2024). During the LP period, the level of BC and $PM_{2.5}$ was mainly dominated by local sources due to meteorological conditions. However, during the HP period, contributions from regional pollution sources became more prominent (Fig. 4). Figures 2 and 4

Table 2 The relationship between $PM_{2.5}$ and BC concentration with meteorological parameters (Temperature, Relative humidity, Windspeed, Wind direction, Visibility, and Pressure) from January 8 to 27, 2024 in Dhaka, Bangladesh. Correlations higher than 0.5 are highlighted in bold

	$PM_{2.5}$	BC	Temperature	Humidity	Windspeed	Wind Direction	Visibility	Pressure
$PM_{2.5}$	1.00	**0.78**	0.06	0.06	−0.21	**−0.60**	−0.46	0.38
BC	**0.78**	1.00	−0.15	0.10	**−0.49**	**−0.66**	−0.42	0.23
Temperature	0.06	−0.15	1.00	**−0.58**	0.23	−0.10	0.38	0.18
Humidity	0.06	0.1	**−0.58**	1.00	−0.33	−0.04	**−0.77**	**−0.56**
Windspeed	−0.21	**−0.49**	0.23	−0.33	1.00	0.27	0.34	0.22
Wind Direction	**−0.60**	**−0.66**	−0.1	−0.04	0.27	1.00	0.29	−0.36
Visibility	−0.46	−0.42	0.38	**−0.77**	0.34	0.29	1.00	0.18
Pressure	0.38	0.23	0.18	**−0.56**	0.22	−0.36	0.18	1.00

provide a comparative analysis of the levels of $PM_{2.5}$ and BC throughout both the HP and LP periods. The data reveals an important observation: the concentrations of both pollutants were almost twice as high during the HP period compared to the LP period. This highlights the need for urgent action to tackle the issue of declining air quality in Dhaka as well as the surrounding regions.

Table 2 reveals the relationship between BC and $PM_{2.5}$ alongside meteorological parameters measured simultaneously. The table highlights that BC has a significant negative correlation ($p < 0.05$) with windspeed, wind direction, and visibility. This result aligns with earlier research conducted in different regions, suggesting that BC produced locally tends to accumulate under low wind speed conditions (Cao et al. 2009). Conversely, high wind speeds reduce airborne particulate levels by enhancing vertical dispersion. At high wind speeds, a decrease in particulate concentrations is observed close to specific point or line sources, attributed to dilution effects at the source. Wind direction is also a vital parameter for reducing BC (Cao et al. 2009), and a strong correlation of −0.66 implies that the sampling site is significantly impacted by both local and regional transported air pollution in the west direction (Guo et al. 2015). Visibility is another crucial parameter affecting urban air quality (Watson 2002). A negative correlation (−0.42) between visibility and BC was also observed in India (Tiwari et al. 2013) and Pakistan (Bibi et al. 2017) in the winter season.

The temperature, RH, and pressure remained relatively consistent throughout both the HP and LP periods. However, there were notable variations in wind speed and visibility. During the LP period, the wind speed reached 6.18 kph, and visibility expanded to 2.25 km, surpassing respective measurements during the HP period, which were recorded at 2.81 kph and 1.67 km. The significant decrease in wind speed during the HP period resulted in stagnant pollution and higher concentration levels. To mitigate the profound health consequences of BC and other aerosol pollution in Dhaka, mitigation efforts must focus on controlling local traffic, regional-scale biomass, and agricultural burning.

Conclusion

Dhaka is currently grappling with a severe issue of air pollution. It fails to meet the national and WHO standards for BC and $PM_{2.5}$ pollution. This study discovered that BC accounted for around 34% of the $PM_{2.5}$ loadings in Dhaka. BC and $PM_{2.5}$ levels demonstrated a robust positive correlation, suggesting a potential common origin. During the high pollution period, unique diurnal patterns were observed. The BC concentration increased considerably at night, in contrast to the mild diurnal patterns observed during the low pollution period. Moreover, $PM_{2.5}$ and BC concentrations have a negative correlation ($p < 0.05$) with crucial meteorological parameters, such as wind speed, wind direction, and visibility. These results indicate that meteorological conditions play a substantial role in determining the levels of particulate matter in the air, particularly during periods of heightened pollution. Therefore, policymakers and urban planners may need to consider these meteorological factors when designing and implementing interventions to mitigate the detrimental effects of air pollution in the city.

Acknowledgements Authors greatly acknowledge the support from Örjan Gustafsson and Joakim Romson, Stockholm University, Sweden to supply Aethalomater to perform the study in Dhaka, Bangladesh.

Author contributions Shahid Uz Zaman—Conceptualization, Methodology, Validation, Formal analysis, Data management, Writing—original draft, review & editing; Krishnakant Budhavant- Formal analysis; Data management; Writing—review & editing; Abdus Salam—Writing—review & editing, Conceptualization, Methodology; Supervision.

Funding The authors received no external funding.

Data availability Data will be shared upon request.

Declarations

Conflict of interest The authors state that they have no known conflicting interest that might have influenced the research presented in this study.

Ethical approval Not Applicable.

Consent to participate Not Applicable.

Consent to publish All authors read and approved the final manuscript to publish.

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