Original Article

Anthropogenic fine aerosol and black carbon distribution over urban environment

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Abstract

Real-time black carbon (BC) and fine particulate matter (PM) were collected from January to December 2017 with a portable Aethalometer and air sampler in the urban environment of Jamshedpur, India. In the present study, the diurnal and seasonal variations of BC and meteorological variables were analysed. The diurnal variation of BC ranged from 2.1 to 15.5 gm-3, with the lowest concentration during the monsoon season and the highest during the winter season, because in monsoon most of the BC and PM are settled down. The annual mean BC mass concentration was observed at 6.22 ± 3.95 μgm^{-3}. While, fine $PM_{2.5}$ varied from 41.6 to 260.3 μgm-3, with an annual mean of 97.49 ± 63.52 μgm^{-3}. During monsoon, the BC mass concentration shows a value of < 3 μgm^{-3}. Additionally, the percentage contribution of BC in $PM_{2.5}$ was determined to be around 5.06% (winter), 6.32% (summer), 5.20% (monsoon), and 7.21% (post-monsoon). The change in BC concerning different meteorological parameters was systematically studied, in which an exciting inverse relationship was noticed between BC concentration and temperature. The correlation between BC and wind speed was also established as a negative connection during study periods. It also observed a negative correlation with precipitation. Finally, the air back trajectory was analysed using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT), which revealed that the essential campaign of aerosol-bounded air parcels was mostly coming from the western part of India, with some marine air masses also joining from the Bay of Bengal during summer and post-monsoon. Overall study shows that highest BC and $PM_{2.5}$ was observed in the winter season because of mixed layer height (MLH).

Keywords Black carbon · $PM_{2.5}$ · Correlation analysis · Backward trajectory

1 Introduction

The impact of Black Carbon (BC) aerosol on global environmental and climatic change is enormous. BC emissions and poor air quality are mostly caused by expanding urbanisation, increasing industrialization, and related anthropogenic activities. The leading pollutant causes global warming which is a major concern at present across the globe [1, 2]. BC collects short-wave solar radiation and global heat vigorously and shows a key role in the heating and rapid melting of glaciers and snowpack by ambushing the heat within the atmosphere of the Planet [1, 3–5]. BC is generated by partial combustion of fossil fuel, (i.e., gasoline, petrol,) and biomass burning (i.e., crops, peat fires, shrubs, forest wildfires, dry leaves) and biofuels (i.e., wood, dung cakes, waste materials) [6–9]. The BC aerosols have absorbent properties, which directly account for reducing arriving short-wave solar radiation, important to warm the

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troposphere. Tropospheric chemistry, BC, has played a crucial role due to its adsorptive and porous nature. It helps with significant chemical transformations like HNO_3 vapors and converted to NO_2 or NO and oxidation of SO_2 to SO_3 [10], and detection of the ozone layer CO forming [11, 12]. Due to economic development, urbanization, power consumption, industrialization, excessive burning of crop waste, peat fires, and wildfires, the substantial increase in BC concentration levels [13–16]. Around 40 percent of black carbon is emitted by fuel combustion, 40 percent from the open burning of wood, and 20 percent from the burning of biofuels, according to the universal basis [1]. BC is responsible for lung and infectious conditions [17, 18].

In consideration of the factors referred to above, the attenuation observed by the Aethalometer does not truly describe atmospheric BC concentrations. Studies have shown that the detection signal of raw soot particles has risen by 1.6 times under the influence of the connected load, which can be ignored for an aged BC aerosol [19]. The loading condition caused a diffusion deviation of about 10 percent at 880 nm in actual indoor experiments (located at an indoor office next to the road). The absorption cross-section of 532 nm is nearly triple that of the theoretic outcome in the context of large scattering. Furthermore, in cities with extreme dust contamination, the detection of BC would be significantly affected [3]. The reliably retrieved BC concentration was thus closely connected to the optical and component properties of the local aerosol. In this circumstance, it is vital to get the related correction factors for the different geographical features.

BC has fascinated much consideration in the current times due to its wide health effect and climate change which bring us to investigate the concentration of BC in the atmosphere. Characterization of BC is important in South Asian countries mostly India and China, as extensive regional climate effects due to the large population inhabited in these countries [1, 19, 20].

Although BC research has been one of the most important topics of atmospheric research worldwide, it is especially important in South Asia, particularly in China and India, due to the significant regional climate implications. Many authors in the Indian region have reported on the detection of carbonaceous aerosols and their radiative influence, but to the best of our knowledge, this is the first attempt to measure real-time BC and $PM_{2.5}$ in east India. The daily data of BC mass concentrations and $PM_{2.5}$ mass concentrations are critical for generating concepts about BC aerosols and $PM_{2.5}$ particles in the Indian region. This study aims to better understand the relationship between BC and $PM_{2.5}$ in Jamshedpur (India's eastern industrial hub). The study sought to investigate the impact of local climatology on day-to-day variance. We delivered continual ground-based BC evaluations from Jamshedpur. The purpose is to provide a unique and comprehensive explanation of the context and temporal variation of these aerosol characteristics in the study area, as well as the numerous contributing factors. The dispersal mechanism of the BC aerosol is explored using case analysis to demonstrate the associated specific emission sources.

2 Measurements and methods

2.1 Observation site

The study was conducted in Jamshedpur, an industrial city situated in the eastern part of India (Fig. 1). It is coordinated as 22.80°N 86.20°E with an elevation of 135 m above sea level. The city is congested with large number of industries from small to large scale industries. Jamshedpur is also known as 'Tatanagar' due to numerous contributions of J.N. Tata. One of the largest steel industries in the world is Tata steel located here. Jamshedpur is surrounded by large number of industries that could be authorized under AIADA (Adityapur Industrial Area Development Authority). The industry utilizes coal and fuel for generating energy to operate these commercial works. Additionally, the construction of urban roadways, infrastructure build, and movement of vehicles thoroughly run across the city. These anthropogenic activities in the urban and industrial bodies release poor emission sources in the atmosphere. Sampling equipment was located at the National Institute of Technology, Jamshedpur (coordinated as 22.77°N, 86.14°E) due to the proximity of several industries and road junctions in this area. A combination of contaminant discharges from adjacent traffic and together human activity impacts the observation site. The inlet of the instrument is set up on the terrace of the institute building nearby 15 m exceed from ground level. BC and $PM_{2.5}$ were thoroughly monitored from the month of January to December 2017 at the National Institute of Technology Jamshedpur.

The topography of Jamshedpur is a hot and humid climate. It comes under the Chhota Nagpur plateau and belongs to the dharwarian region which is made up of igneous, sedimentary and metamorphic rock. Importantly, it is surrounded by the dense forest of Dalma ranges which continues from west to east. The meteorological parameters such as temperature (temp) (°C), wind speed (WS) (mph), relative humidity (RH) (%), precipitation (prep) (mm), and mixed layer depth (MLD) of the study area were stored from https://www.worldweatheronline.com and www.ifremer.fr/cerweb/deboyer/mld as represented in Table 1. Indian Meteorological Department (IMD) has divided the season into four categories as summer, monsoon, post-monsoon, and winter. The warmer climate was recorded during the month of September (29.47 ± 1.33 °C)

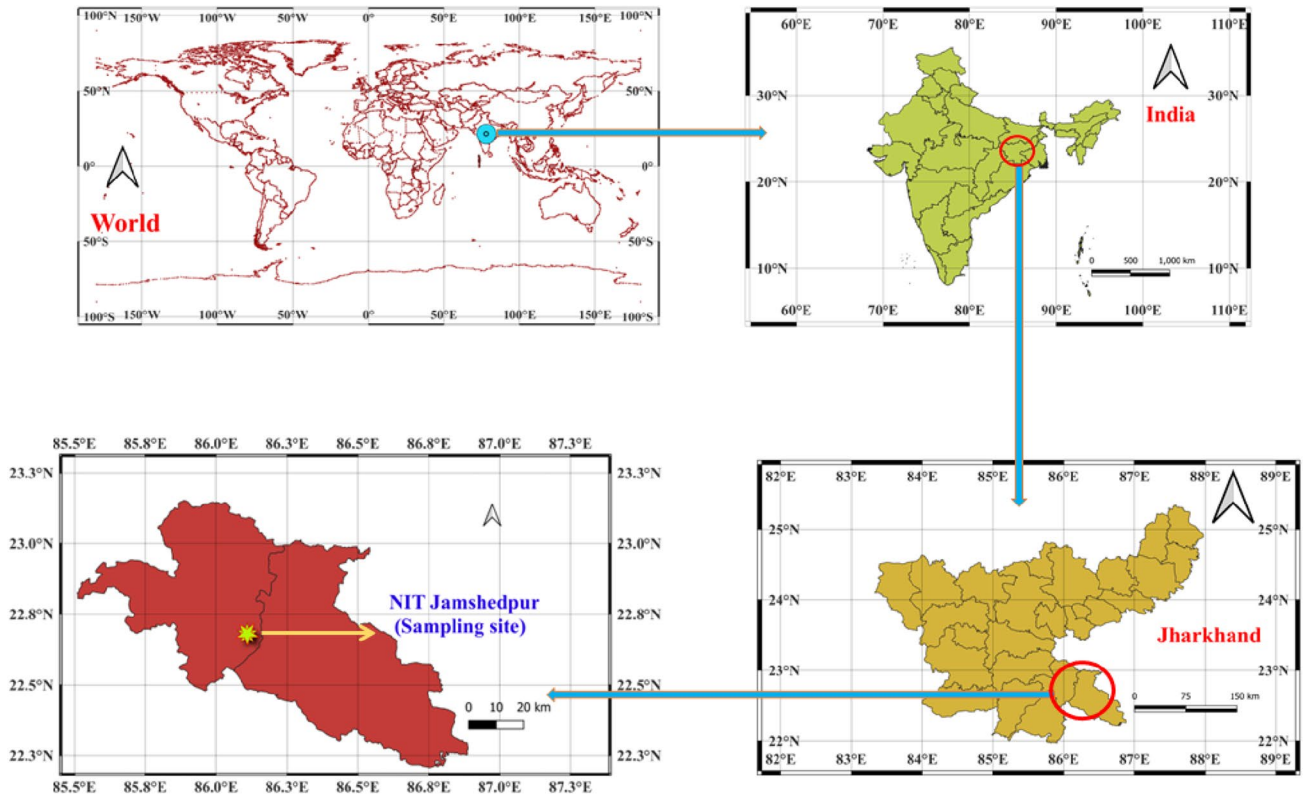

Fig. 1 Map of sampling location

Table 1 Metrological parameter data during the sampling period

Sampling period (2017)	MLDs (m)	Temp (°C)	Wind speed (m/s)	Humidity (%)	Precipitation (m)
January	214.7	19.6	1.6	54.53	0
February	320.9	23.3	2.1	45.25	0
March	458.9	27.4	3.6	41.69	12
April	759.2	32.9	5.7	44.70	24
May	872.4	32.0	5.9	29.77	434.7
June	843.3	31.4	5.8	64.60	93.4
July	614.8	28.6	3.9	79.69	718.6
August	532.7	29.0	3.1	77.58	436.6
September	421.4	29.7	2.0	73.30	256
October	309.7	27.7	2.0	71.90	150.4
November	290.7	22.9	1.9	60.83	2.6
December	214.0	20.0	1.1	57.40	0.3

whereas the colder weather was recorded in the month of December (19.87 ± 1.67 °C).

2.2 Measurement of black carbon mass concentration

Aethalometer is the first instrument that shows the optical properties of aerosol components in real-time. Monitoring of BC was performed from January to December 2017. The aerosol is deposited at 7 different wavelengths (370, 470, 520, 590, 660, 880, and 950 nm) with the help of a handy aethalometer (Model: AE-42; Magee Scientific, USA). The maximum concentration of BC is found at 880 nm, as it is the primary absorber at this wavelength (supplementary aerosol has minimum deposition) [21]. Ambient air particles are entering through the inlet pump at a flow

rate of 5 LPM, deposited on a quartz filter. A high-intensity LED (light-emitting-diode) is passed into the deposited sample of the filter spot at 880 nm. The attenuated light is calculated in linear proportion to the volume of aerosol-bounded BC collected on the filter tap. Inspections were done every 5 min intervals and reported regularly. The attenuation cross-section was calibrated before the campaign to achieve the greatest precision needed for the site by using a comparative approach among BC and EC (elemental carbon) from the thermal optical method. Data obtained during dust operations were filtered and removed from BC calculations in order to avoid exposure to other absorbent materials such as minerals and dirt aerosols. In the databases ensuring data validation, we have also manually omitted unsound measurements. In order to reduce the variability resulting from equipment noise, flow rate, sensor reaction, exciting standards, etc., the useful data were then summed up to an interval resolution of 1 h for the subsequent tests. Aethalometer is an advanced instrument for quantifying BC as related to other methods like particle soot absorption photometer, thermal oxidation/reflectance, coefficient of haze tape sample, etc. [22].

2.3 Measurement of $PM_{2.5}$

Daily $PM_{2.5}$ concentrations were collected along with BC from January to December 2017, representing all four seasons as discussed earlier with BC. It was monitored by using a Partisol air sampler (Model 2000 H, Thermo Electron Corporation, USA). The sampler was built-in with a $PM_{2.5}$ cyclone (Model PQ200, BGI Inc, Waltham, MA, USA) and after that weighted with 47 mmquartz fiber filters and controlled at a flow rate of 15.7 Lmin–1 for 24 h per day (started from 08:00 LT same day and stop at 08:00 LT next day). Throughout the sampling, a total of 84 samples containing $PM_{2.5}$ were obtained, and 10 samples operating as blank samples were also gathered. The aerosol-deposited filters were initially dried at 750 °Cfor 4 h and some test was done for checking a strategic distance from carbon-based impurities.

3 Result and discussions

3.1 Variation of BC and $PM_{2.5}$ aerosols over Jamshedpur

Trends in monthly mean BC mass concentration and $PM_{2.5}$ has disclosed in Fig. 2. The annual mean concentration of BC was observed around $6.22 \pm 3.95\ \mu gm^{-3}$. It varied in the range of 2.1 to 15.5 μgm^{-3} and minimum concentration was found in monsoon and maximum in the winter season. The order of BC mass concentration is practiced as winter > post-monsoon > summer > monsoon. The daily variation of BC in Jamshedpur as shown in Fig. 3, was attributed due to the change in day-to-day aerosols formed from the backgrounds and migrated after distant locations, local sites, and even the indigenous areas. The season variation of BC concentration was collected in winter ($10.38 \pm 4.09\ \mu gm^{-3}$), post-monsoon ($7.82 \pm 3.35\ \mu gm^{-3}$), summer ($4.12 \pm 1.10\ \mu gm^{-3}$), and monsoon ($2.56 \pm 0.25\ \mu gm^{-3}$). BC concentration in the winter season was almost 5 times greater compared to monsoon and 2 times greater in summer. This might be examined that the larger concentration in winter happened due to the mixing of the atmospheric layer in cold weather. Also, The predominant contamination of man-made activities i.e., vehicular emission, industrial activity, coal combustion, and wood burning, leads to the larger emission of BC.

$PM_{2.5}$ is assured to most aerial particles which are hazardous to health [23] and causes visibility issue in the atmosphere. The annual mean concentration of $PM_{2.5}$ was examined around $97.49 \pm 63.52\ \mu gm^{-3}$ which varied from 41.6 to 260.3 μgm^{-3}. It was seen least concentration during monsoon and a larger concentration during the winter season. Similarly, the order of $PM_{2.5\ was}$ found as winter > post-monsoon > summer > monsoon. The seasonal mean concentration of $PM_{2.5}$ was observed around $167.14 \pm 73.03\ \mu gm^{-3}$ in winter, $108.40 \pm 65.31\ \mu gm^{-3}$ in post-monsoon, $65.23 \pm 7.73\ \mu gm^{-3}$ in summer, and $49.20 \pm 4.27\ \mu gm^{-3}$ in monsoon. The concentration of $PM_{2.5}$ in winter was noticed around 3.5 times greater than in monsoon, and 2.5 times higher than in summer.

The Monthly mean concentration of BC and $PM_{2.5}$ vs Temp and MLD are depicted in Fig. 2. We have seen an inverse relation between MLD and Temperature with both aerosols. It found a minimum concentration of aerosol and maximum MLD during the Monsoon periods. It was noticed that the BC mass concentrations started rising in October ($8.2 \pm 0.44\ \mu gm^{-3}$) and maximum in winter (Table 2). BC concentrations varied by at least six-fold, from a lower concentration of 2.37 ± 0.14 (August) to $14.74 \pm 0.55\ \mu gm^{-3}$ (December) during the yearly course of the study. At the time of the study, BC's maximum concentration was noticed on 31st December (15.5 μgm^{-3}). This might happen due to the New Year celebrations, public gatherings, more vehicular movement, and the bursting of crackers. Daily variation BC mass concentrations and $PM_{2.5}$ concentration was found extreme in the pre-afternoon time from 07:00 to 08:00 and post-afternoon time from 17:00 to 18:00 IST (Indian Standard Time), which is clearly shown in Fig. 4. This might be observed because of the high traffic load in that region and also the temperature fluctuation during sunrise and sunset.

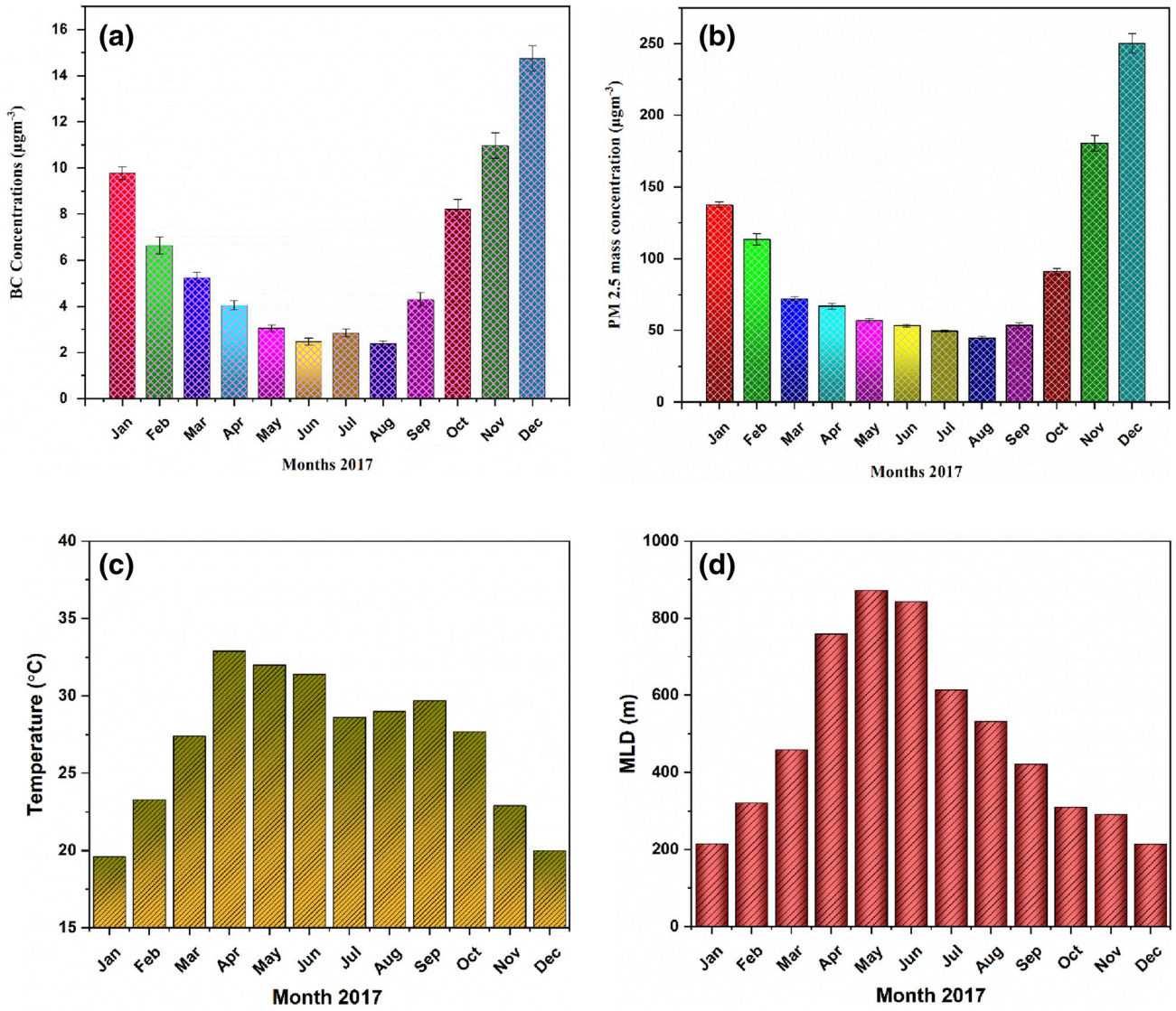

Fig. 2 Monthly mean concentration of BC and $PM_{2.5}$ vs Temp abd MLD at Jamshedpur

3.2 BC mass concentrations in other Indian and global geographical areas

Measurement of mean BC mass concentrations from present study sites to different parts of India and other different land locks in the world has been explained in this research which is recorded in Table 3. The mean BC reported at Jamshedpur has analogous behavior as noticed at Delhi, India (6.64 μgm^{-3}) [24], Srinagar, India (6.06 μgm^{-3}) [25], and also with Sao Paulo, Brazil (7.6 μgm^{-3}) [26]. But it has relatively observed half of that in Xi'an', China (14.7 μgm^{-3}) [27], and roughly twice that found in China (annual average across the country, 3.5 μgm^{-3}) [28], three and a half with BC concentration at Lahore, Pakistan (21.7 μgm^{-3}) [29]. Also, other cities of India like Dehradun (3.85 μgm^{-3}) [30], and Pune (4.1 μgm^{-3}) [31] have observed lower BC mass concentrations in comparison to Jamshedpur. Some Indian cities observed higher monthly mean concentrations of BC like Kharagpur (16.5 μgm^{-3}) [32], Agra (20.6 μgm^{-3}) [31], Panchgaon, NCR Delhi (7.2 μgm^{-3}) [33], and Kolkata (35 μgm^{-3}) [34], in contrast to Jamshedpur.

3.3 Source identification of air-borne particulate matter at Jamshedpur

BC source profile has been divided into two types (a) Anthropogenic activities, like biomass burning, and domestic applications such as the burning of fossil fuel, and other forms of pollution from vehicles and factories, etc. (b) Natural activities, like volcanic outbreaks, emissions of VOCs from plants, forest fires, etc. BC aerosol has

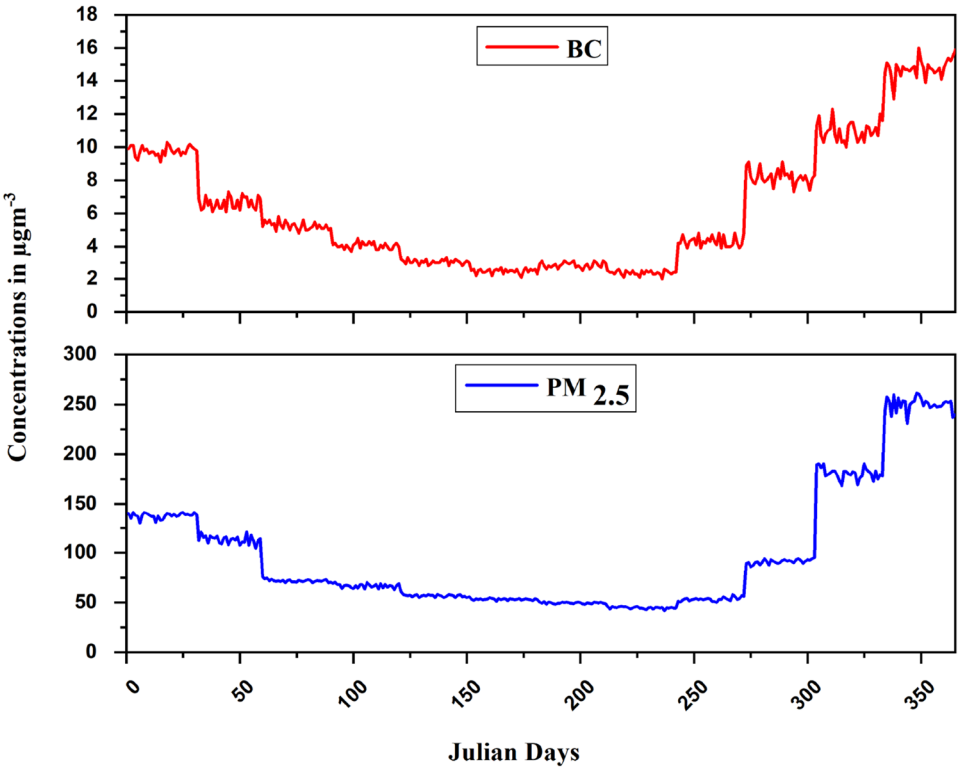

Fig. 3 Daily (Julian days) mass concentration of BC and $PM_{2.5}$ from 1st January to 31st December 2017

Table 2 Monthly means mass concentrations of BC and $PM_{2.5}$ concentration (μgm^{-3}) in Jamshedpur during study 2017

Months	BC Concentration (μgm^{-3})		$PM_{2.5}$ Concentration (μgm^{-3})	
	Mean	SD	Mean	SD
January	9.77	0.28	137.68	1.84
February	6.63	0.37	113.44	4.02
March	5.25	0.24	72.04	1.4
April	4.05	0.19	66.77	2.12
May	3.05	0.14	56.88	1.35
June	2.47	0.15	53.29	0.79
July	2.85	0.17	49.55	0.74
August	2.37	0.14	44.77	1.04
September	4.3	0.3	53.42	1.93
October	8.2	0.44	91.19	2.26
November	10.97	0.56	180.6	5.56
December	14.74	0.55	250.3	6.73

the property of long-range transport in the air due to its small size and chemically inert nature [35]. The Air back trajectory has analysed to movements and pathways of air particles and identified the possible generating sources. These are planned at variations in altitudes up to 3000 m from the target locations. Trajectories are calculated by computation of separate trajectories which are comparable to four distinct periods. The backward trajectory was applied to ascertain the dispersal of sources to the receptor (detector) site of air-bone particles in Jamshedpur. The trajectory data for the distinct season were calculated and formulated with the help of METEX (Meteorological Data Explorer) developed by CGER (Centre for Global Environmental Research) Japan and the graph was plotted by Igor software.

The back trajectory analysis explained that the air masses originating from different sources across all four seasons are shown in Fig. 5. In the winter season, the air masses were mostly coming from northeastern countries such as Iran and Afghanistan. Some of them were also noticed in the central part of India. In summer, incoming air parcels were spotted from the northeast and some fresh marine air masses were also observed from the Bay of Bengal and the Indian Ocean. But in the monsoon season, most of the air-bone particles were coming from the Arabian Sea, and it might be salt aerosols particle that originates from seawater. In post-monsoon, air pollutants were coming from mixed directions like the north, east, and some central parts of India. Some marine air particles were also coming from the Arabian Sea and the Bay of Bengal.

3.4 Climatic consequence of black carbon

Coal combustion is India's major and cheapest source of energy, meeting 76% of our daily demands [36]. The

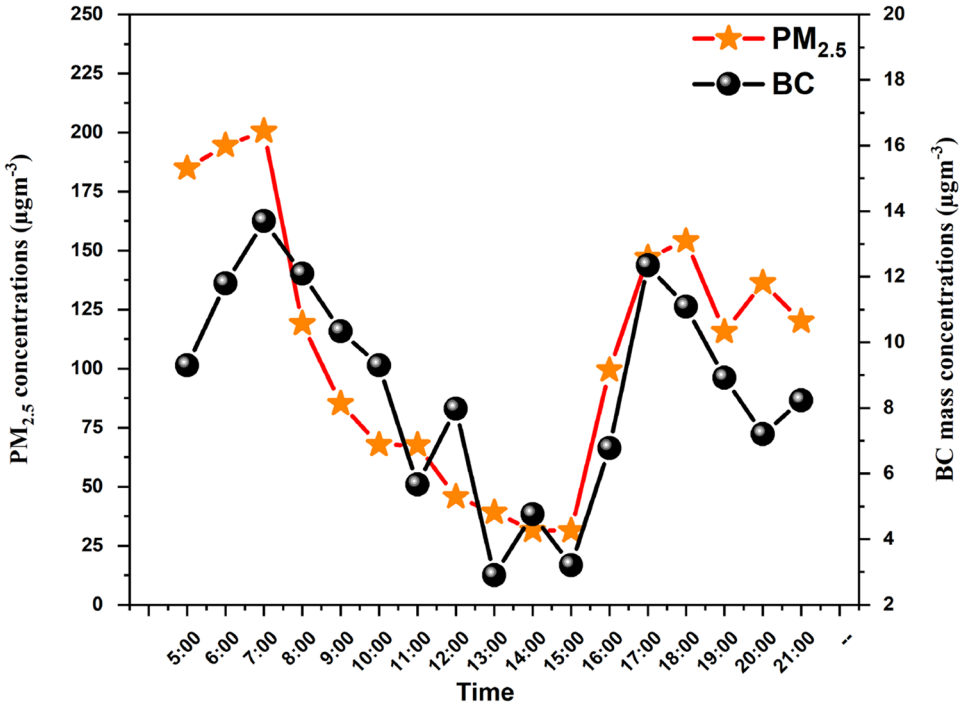

Fig. 4 Diurnal variation of BC and $PM_{2.5}$ mass concentration

Table 3 Comparison of BC mass concentration measured at some of the stations over India and World

Place	Location	BC Concentration (μgm^{-3})	References
Paris, France	Urban	14	Ruellan and Cachier (2001)
Sao Paulo, Brazil	Urban	7.6	Castanho and Artaxo (2001) [27]
Bangalore, India	Urban	4.2	Babu and Moorthy (2002) [41]
Delhi, India	Urban, Mega-city	29	Ganguly et al. (2006)
Pune, India	Urban	4.1	Safai et al. (2007) [32]
Kharagpur, India	Semi-urban	16.5	Nair et al. (2007) [33]
Lahore, Pakistan	Urban	21.7	Husain et al. (2007) [30]
Agra, India	Urban	20.6	Safai et al. (2007) [32]
Kolkata, India	Urban, Mega-city	35	Verma et at. (2013) [35]
Delhi, India	Urban	6.64	Tiwari et al. (2013) [25]
Jamshedpur, India	Urban	6.22	Present study

incomplete combustion of low-grade coal generates primary air pollutants such as BC that affect the global climate terribly. The monthly variation of meteorological parameters like temperature, wind speed (WS), mixed layer depths (MLD), and relative humidity (RH) over Jamshedpur is shown in Fig. 6. To understand the climatic effect on exposure to BC, a statistical analysis is studied to correlate the BC mass concentrations with the various meteorological parameters like temperature, WS, RH, and precipitation over Jamshedpur during 2017. The monthly average temperature was observed in the range of 8 to 43 °C. It has observed a negative relationship (r = – 0.86) between temperature and concentration of BC. In Xi'an (China), the local resident consumed approximately 40% of coal burning over total carbon emission during winter [37]. BC also observed an overall negative correlation with the WS (r = – 0.74), and different seasons contribute to a variety of correlations with BC i.e., summer (r = – 0.92) and post-monsoon (r = – 0.81) having WS as 1.97 and 5.07 m/s respectively. On the contrary, a non-considerable negative correlation was found during monsoon (r = – 0.03) periods when the corresponding WS was higher (4.27 m/s). However, a positive correlation was observed during winter (r = 0.38) at lower WS (1.6 m/s). Conclusions are relatable with other studies reported in Delhi [24, 39], and in Ahmedabad [38], excluding the winter study.

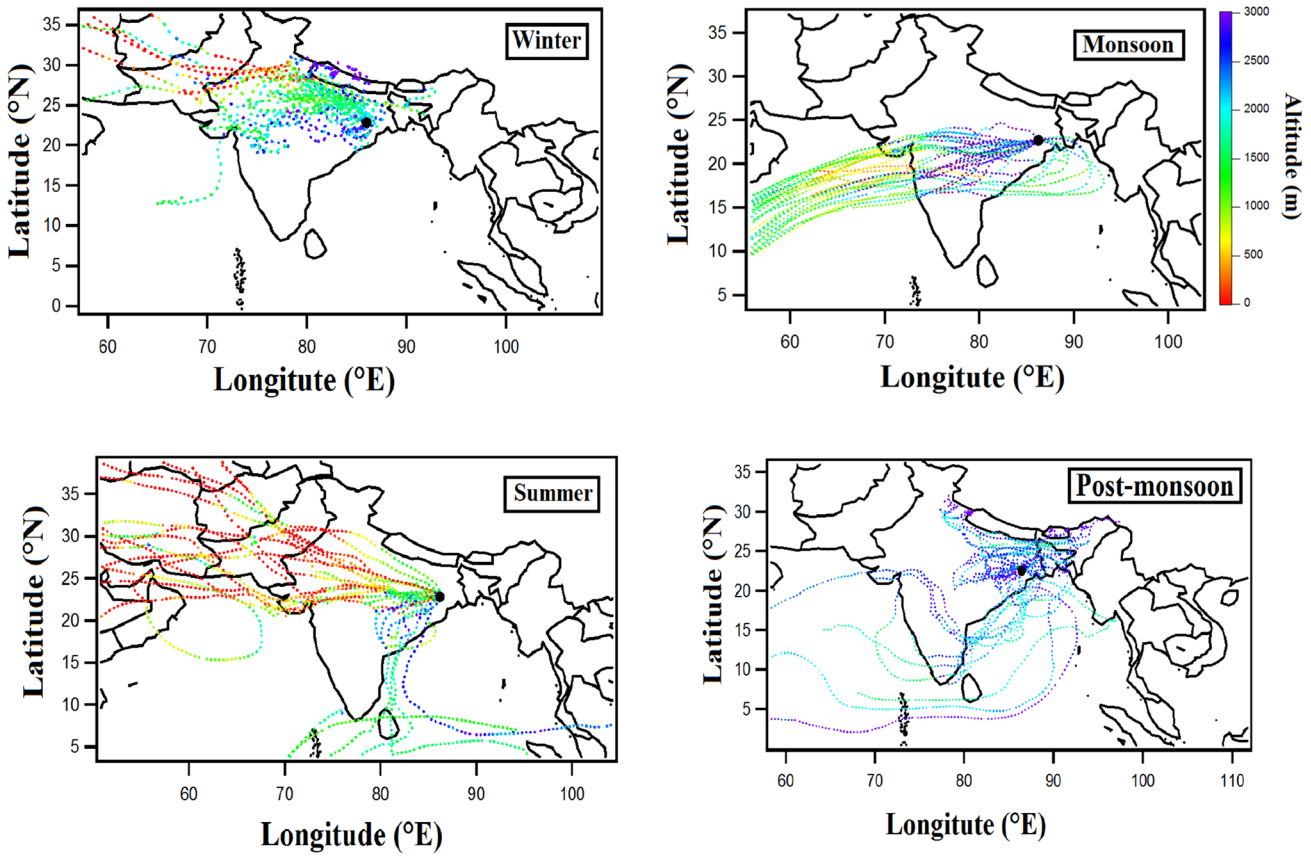

Fig. 5: 10-days back-trajectory analysis of the air masses at receiving point Jamshedpur during 2017

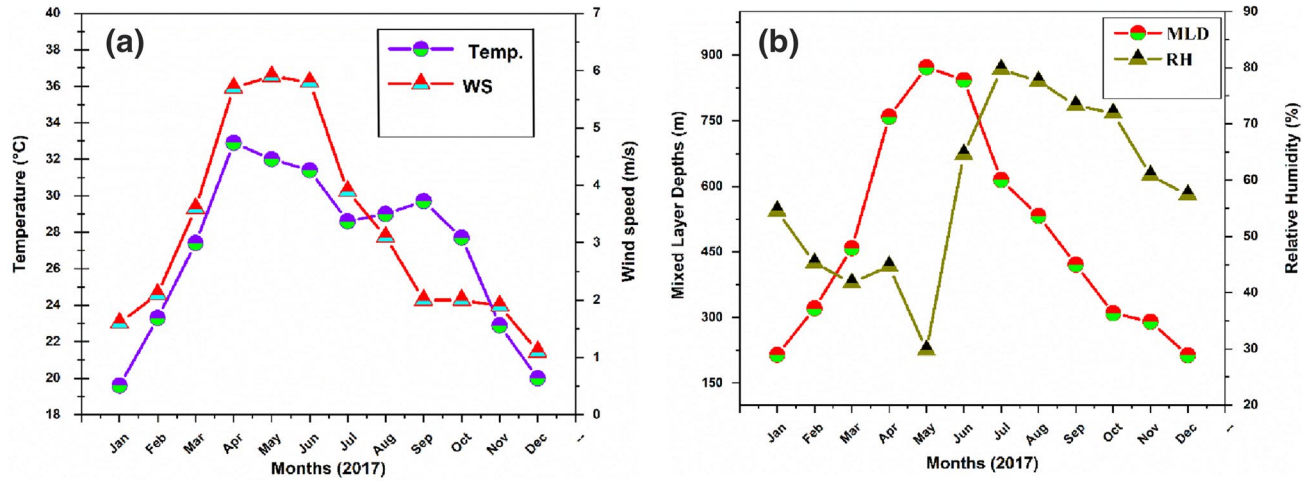

Fig. 6 Monthly variation of meteorological parameters **a** temperature (Temp.) vs wind speed (WS); **b** mixed layer depths (MLD) vs relative humidity (RH) over Jamshedpur in 2017

In eastern India, the highest rainfall appeared after summer from the month of July to October. Total rainfall during the monsoon season in 2017 was 1248.6 mm. The rainfall was recorded highest in the month of July (718.6 mm). Pearson Correlation analysed a negative result between BC mass concentration with rainfall (r = − 0.59). Consequences are persistent with other investigations described in Ahmedabad i.e., r = − 0.35

[38] in western India, and Trivandrum i.e., r = – 0.74 in southern India [40].

4 Conclusion

Throughout the study, measurements of BC and $PM_{2.5}$ were collected at Jamshedpur, an urban location in eastern India. The annual BC and $PM_{2.5}$ concentration (mean ± standard deviation) was found about 6.22 ± 3.95 and 97.49 ± 63.52 μgm^{-3} respectively. $PM_{2.5}$ levels were noticed around 2.5 times greater than the National Ambient Air Quality Standards (NAAQS) standards of 40 μgm^{-3} [41]. BC varies over the study site from a lower concentration of 2.56 ± 0.25 μgm^{-3} during monsoon to a higher 10.38 ± 4.09 μgm^{-3} during the winter season. In the case of $PM_{2.5}$, concentration varies observed lower (49.20 ± 4.27 μgm^{-3}) during monsoon and higher (167.14 ± 73.03 μgm^{-3}) in winter. This might happen due to heavy rainfall (1248.6 mm) in the monsoon and it could wash out the maximum air-borne particulates from the atmosphere. Since BC is a subgroup of $PM_{2.5}$, it contributes to the intensity of suspended $PM_{2.5}$.The reported % BC present in $PM_{2.5}$ was around 5.06% in winter, 6.32% in summer, 5.20% in monsoon, and 7.21% in course of post-monsoon in the monthly range of 4.63% (in June) to 9% (in October). The Correlation of BC with different meteorological parameters such as temperature, WS, RH, and precipitation was analysed, and observed a noticeable change. The negative correlation (r = – 0.86) between temperature and black carbon was noticed, implying that with an increase in temperature, the BC concentration decreases and vice-versa. Similarly, BC was negatively correlated with the WS (r = – 0.74) at the time of the study, having relatively more significant in summer (r = – 0.92) and post-monsoon (r = -0.81) seasons with respective WS as 1.97 and 5.07 m/s. Also, a negligible negative relation was noticed during monsoon (r = – 0.03) at high WS of 4.27 m/s. However, an exciting positive correlation was observed during winter (r = 0.38) at lower WS of 1.6 m/s. A negative correlation was analysed between concentration BC and precipitation during the study period (r = – 0.59).

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Author contributions TKS: Sampling, analysis and measurements, DKM: measurements and data results, BA: Supervisor, training, editing, writing, and management of measurements, AK and RJ: Project management, Editing and software.

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Data availability Data will be made available on reasonable request.

Declarations

Conflict of interest On behalf of all authors, there is no conflict of interest.

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