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Source apportionment and short-term variation of Black Carbon and $PM_{2.5}$ during Diwali Festivals over an industrial city in India

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Abstract

Fireworks play an important role in impacting the quality of air, which is experienced in the Diwali festival, where majority of population celebrate the festival with burning of crackers and oil lamps. The investigation is taken to challenge the variability, source apportionment of Black Carbon (BC) and $PM_{2.5}$ during Diwali Festivals in 2020 and 2021 over an industrial city. This monitoring was conducted during two Diwali periods (DP1 and DP2), in which observations were made for 4 consecutive days i.e., Before-Diwali, Diwali, Chota-Diwali, After-Diwali. The level of BC ranged from 2.15 to 136.9$\mu g\ m^{-3}$ and 2.5 to 185.6$\mu g\ m^{-3}$ in DP1 and DP2 respectively. The concentration of BC in DP1 was found to be lower compared to DP2 due to less pre-suspended particulate matter after the first Covid19 waves. Likewise, there was a reduced concentration of $PM_{2.5}$ at DP1 varied from 15.4 to 281.4$\mu g\ m^{-3}$ as compared to DP2 ranged from 17.6 to 322.3$\mu g\ m^{-3}$. The average BC was found to be 7.1, 14.38, 13.5, and 9.1$\mu g\ m^{-3}$ in DP1 whereas 8.5, 17.4, 15.5 and 11.9$\mu g\ m^{-3}$ in DP2 during consecutive days respectively. The source apportionment of BC_{BB} and BC_{FF} ratio was observed 39:61 and 46:54 in DP1 and DP2 respectively which indicates the larger bursting of crackers in DP2.

Keywords: Black Carbon (BC), $PM_{2.5}$, Aethalometer, Source Apportionment, Diwali Period, Air quality.

Introduction

The world is facing a drastic change in the environment due to rapid industrialization, metropolitan expansion of cities, creation of infrastructure etc. Along with this, fireworks also play a significant role in contributing to the concentration of air-borne Particulate matter in the atmosphere which have been done on the occasions of festivals like Diwali, Dussehra, Christmas etc. It is also performed in some other occasions like wedding, election, cricket match, film shooting. India is a country where Diwali is celebrated on a large scale, mainly falling between October and November. The festival of lights is celebrated at night with oil lamps and firecrackers that add a feeling of light, noise, smoke and release harmful gases to the environment. On this auspicious occasion, people burst firecrackers, which increases particulate matter in the environment and reduces visibility[1]. Along with particulate matter, other gaseous pollutants like CO, SO_2, NO_x, ozone are also emitted[2]. These activities emit PM_{10}, $PM_{2.5}$, Black Carbon as well as other pollutants.

Black Carbon (BC) mainly generated by partial burning of fuel /gasoline stuff and solid biomass which contains very short lifespan of 4 to 14 days,. BC is extensively known for its adverse health and climatic effects[3-7]. BC Aerosol can scatter and absorb solar radiation that may be treated as one of principal pollutant to impact the earth radiation budget. BC may also undergo catalytic oxidation which converts SO_2 to Sulphate and results in the depletion of Ozone in the atmosphere[8].

In the Indo-Gangetic-Plains (IGP) region, the BC aerosol enhanced due to the more anthropogenic activities in the Northern Himalayan region[9,10]. The IGP region experienced the dense foggy, smog and haze like situation in the atmosphere. It also affect the clouds by varying the size distribution, optical properties, chemical configuration, and number density of the Cloud Condensation Nuclei (CCN) population[4,11]. It can easily transport to longer distance of remote locations due to its very small size. Lots of studies have shown that anthropogenic activity increases BC which deposits into glaciers, reduce ice volume, and melts earlier than expected[12,13]. Air bounded with BC can influence various parameters i.e., visibility, precipitation, surface temperature, regional climate, and hydrological cycles[14].

Due to one of the key properties, i.e., small size which is 30 times smaller than human hair (≤ 2.5 µm), BC can penetrate human body through respiration. On Long-term exposure to BC, cause serious environmental risk factor that affects human health such as lung cancer, insomnia, heart disease, asthma, bronchitis and respiratory tract disfunction[15-20]. The Lancet report revealed that in 2019, there were approximately 1.67 million deaths due to air pollution in India, which was 17.8% of the total deaths in the country that year[21].

However, there were changes in the concentrations of air pollutants during the COVID19 pandemic. This plays a major role in influencing the concentration of BC aerosols during Diwali festival.

In the first wave, a huge decline was seen in the concentration of pollutants while in the second wave a slight increase was perceived during event times. Here through research, we have discussed the comparison of concentration levels of BC aerosols in Diwali period after the impact of COVID19. We have presented ground measurements of BC concentrations with the help of Aethalometer and comparing all the data in Two Diwali Periods i.e., DP1 (Diwali Period 1) and DP2 (Diwali Period 2). Also, we have run a mini volume air sampler for the daily measurement of $PM_{2.5}$ concentration. In DP1, the data was recorded from 13^{th} to 16^{th} November 2020. Whereas in the DP2, the data was analyzed from 3^{rd} to 6^{th} November 2021. The concentration was compared for 4 days consecutive days i.e., Before Diwali (BD), Diwali1 (D 1), Diwali 2 (D 2), After Diwali (A D) Days.

Comparable fluctuations were observed in black carbon concentrations, which were detected through real-time data. In the previous study, it was observed that short-term concentrations of particulate matter increased during the Diwali festival[22]. The burning of crackers and fireworks are the cause for reproductive deficiencies like premature birth[23]. The ambient air samples were collected from a site in the two Diwali Periods on an hourly basis. The source apportionment of BC can also be determined either coming from fossil fuel (FF) or biomass burning (BB), which is determined with the help of an aethalometer. We also plotted the graph for the surface mass concentration of BC by the help of Giovanni NASA satellite model at different height.

Sampling location and Meteorology: The measurement of Black Carbon and $PM_{2.5}$ was done at National Institute of Technology, Jamshedpur as shown in Figure-1. The sampling point is located in Jamshedpur, an industrial city of Jharkhand (coordinates as $22^0$80'N Longitude and $86^0$20'E Latitude), having an area of around 224 km^2. The population of the Urban agglomerates of Jamshedpur is roughly around 1,339,438. It is the headquarter of East Singhhum district, which shares the border with Odisha and West Bengal. The sampling city is situated at the south of Swarnrekha and Kharkai river which witnesses the merger of the two rivers at a point named "Domuhani or River meet". The sample was collected from terrace of National Institute of Technology, Adityapur-2, Jamshedpur. Adityapur is one of the largest industrial areas in India which consists of around 1300 plus units of MSME. The loaded emission of Particulate matter occurs due to these dense industrial belts.

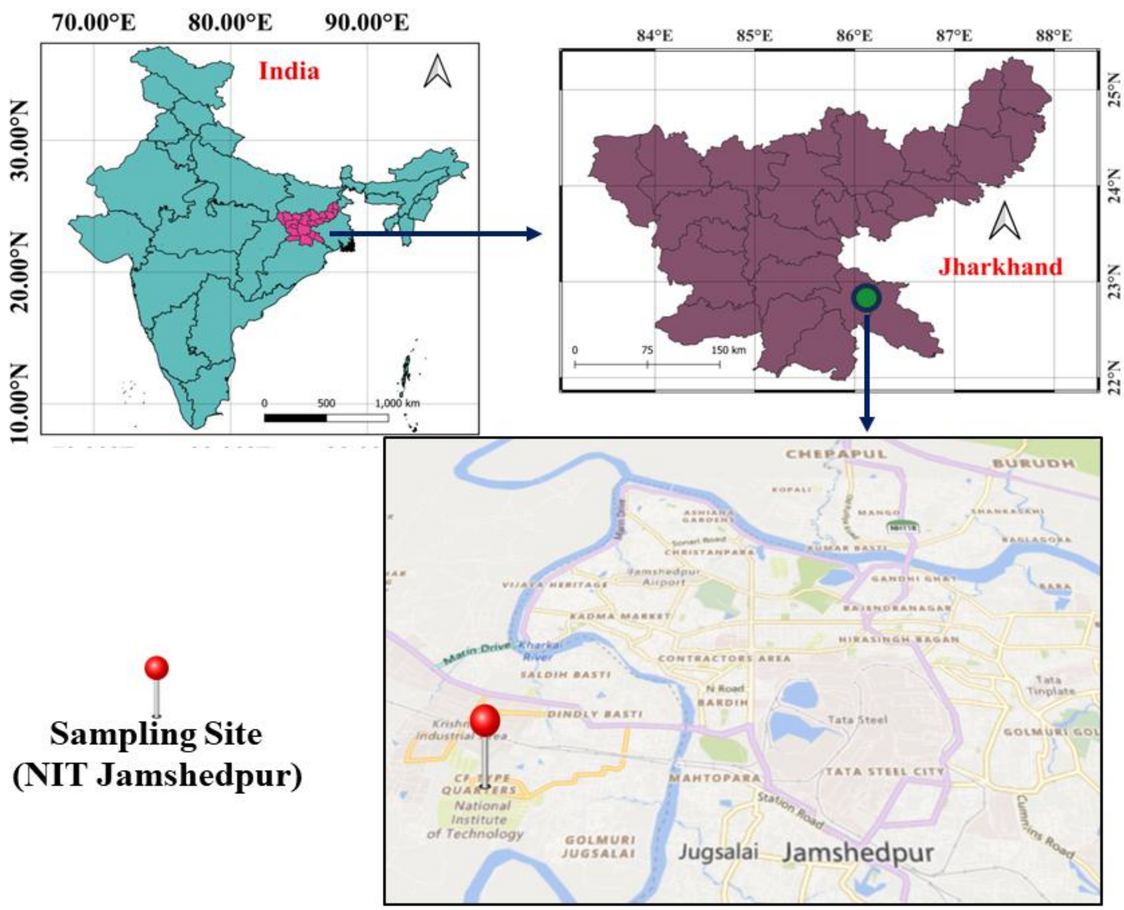

Figure-1: Study site to examine the BC concentration.

The climate of Jamshedpur is influenced by cloud burst winds and seasonal nature, i.e., it is majorly classified into four seasons i.e., pre-monsoon (March to May), monsoon (June to September), post monsoon (October to November) and winter (December to February). Whereas, it has a tropically humid climate. The monsoon transports moisture and heat, mainly from the south-eastern monsoon of the Bay of Bengal, and to a lesser extent from the western and north-eastern monsoons. These monsoon winds are the important transporter of mineral dusts and salts. The south-east monsoon brings cool and dry air to the city, with temperatures ranging from a minimum of 10.3°C to a maximum of 40.3°C, with an average ambient temperature of 25.8°C and monthly average relative humidity ranging from 12.9% to 99.8% is 67.6%. The average meteorological parameters during the study period were taken from them. The meteorological variables which were noted that influencing the concentration of Black Carbon Aerosols as Temperature in °C, Wind Speed in km/h, Relative Humidity in %.

During the present study, the average temperature in DP1 recorded as 26.6, 26, 26.87 and 26.75°C with a ranged from 22 to 31°C. Whereas during the DP2, it was raised from 18 to 32 °C with an average temperature of 24.25, 23.62, 23.75 and 23.12°C in B D, D 1, D 2, and A D Day respectively as shown in Table-1. The average Relative Humidity was noted as 57.125, 69, 69 and 60.75 % in DP1. In DP2, average RH was noted as 72.25, 70.5, 68.125 and 64.25%. The mean Wind Speed was to be ranged from 4.37 to 5.25 km/h in DP1 and 2.75 to 8.5 m/h in DP2. Aerosol particle height is observed to be predominantly low in mixed layer height (MLH) during the month of November to January. MLH indicates the study of the dispersion of aerosols in the atmosphere. Temporary disturbances that occur during different weather conditions bring atmospheric pollutants closer to the Earth.

Table-1: Meteorological parameters data of Diwali Periods.

	DP1 (μgm^{-3})			DP2 (μgm^{-3})		
	Temp (℃)	RH (%)	WS (km/h)	Temp (℃)	RH (%)	WS (km/h)
B D	26.6	57.125	5.25	24.25	72.25	2.75
D 1	26	69	5.12	23.62	70.5	8.5
D 2	26.87	69	4.37	23.75	68.125	4.5
A D	26.75	69.75	4.37	23.12	64.25	5.5

Where: Before Diwali = B D, Diwali = D 1, Chota Diwali = D 2, After Diwali = A D, Temp = Temperature (°C), RH = Relative Humidity (%), W S = Wind Speed (km/h).

Methodology

Measurement of BC: The Aethalometer (Model No: AE-33, Magee Scientific, Berkeley, USA) was taken for the monitoring of real time analysis of BC on frequent intervals. The air inlet chamber is set up in the terrace of an academic building at National Institute of Technology, Jamshedpur. The instrument works on a principle based on the measurement of an absorbed light beam transmitted through a filter on which a consistent drag of aerosol is dropped. The instrument calibrates to provide continuous observations at 7 wavelength patterns at 370, 470, 520, 590, 660, 880 and 950nm. Light-absorbing aerosol particles generally absorb in these wavelengths, but the maximum concentration of BC is seen at 880 nm because others have insignificant absorption[24,25]. It has a 2.5µm sized aerosol inlet with a flow rate of 5 $Lmin^{-1}$ and a reading interval of 1 min on using TFE-coated glass fiber filter (T60A20)[25]. The working model of instrument was intended to calculate sources of BC from either fossil fuel or biomass burning[26].

Measurement of $PM_{2.5}$: Like BC emissions, $PM_{2.5}$ concentrations were also collected on regular basis. The $PM_{2.5}$ was examined utilizing a mini volume air sampler (Model No. Envirotech APM 550, India).

The particulate matter was deposited in the 47mm PTFE filters enclosed in the sampler by keeping flow time of 16.5 L/min for 24 hours during the Diwali event on consecutive days during both periods. For determination of $PM_{2.5}$, before inserting the PTFE filter in the sampler, the weight was measured before and after deposition of particulate matter. A digital weighing balance with single pan top (VWR, Model no: VWR1611–2263 and Weighing Chamber L × W × H: 162 × 171 × 225 mm) was being used to weigh the PTFE filters.

Source Apportionment of BC: The aethalometer model can measure the ATN by BC particles on the filter and then calculate light absorption coefficient of BC (β_{abs}) at distinct wavelengths. The calculation from ATN to β_{abs} is as follows:

$$\beta_{atn}=\frac{S\times(\frac{\Delta ATN}{100})}{Fin\Delta t} \quad (1)$$

$$\beta_{abs}=\frac{\beta atn}{C} \quad (2)$$

where: β_{atn} = optical, attenuation coefficient, S = spot area, F_{in} = measured flow rate, and C = factor affecting optical absorption due to the scattering of light within the filter, respectively. Further detailed information is described in Drinovec et al.[25].

It is assumed that the total β_{abs} at wavelength λ is the total light absorption ascribed to the light absorbing BC, dust etc. from different sources. It is noted that, the total light absorption at 880 nm here can be primarily due to light absorption by black carbon from liquid fuels (i.e., traffic source) and solid fuels (i.e., coal and biomass burning) for the reasons that sampling period in this study is during the winter season BC in Jamshedpur is primarily from combustion of solid fuel and liquid fuel[27].

The sum of absorption fraction of fossil fuel and biomass burning gives the total absorption coefficient which is shown in the equation below:

$\beta_{abs} = \beta_{abs}(FF) + \beta_{abs}(BB)$ (3)

The wavelength dependence of aerosol absorption coefficient is proportional to $\lambda^{-\alpha}$, where λ is the wavelength and α is the light absorption exponent. The absorption exponents for liquid and solid fuel sourced BC are as follows:

$$\frac{\beta abs\ (370)FF}{\beta abs\ (880)FF} = \left(\frac{370}{880}\right)^{-\alpha 1} \quad (4)$$

$$\frac{\beta abs\ (370)BB}{\beta abs\ (880)BB} = \left(\frac{370}{880}\right)^{-\alpha 2} \quad (5)$$

where α1 and α2 represent Angstrom absorption exponent (AAE) for fossil fuel and biomass burning sources of BC respectively. From previous experimental studies, the Angstrom absorption exponent for FF as α1 was found to range from 0.8 to 1.1[26,28-30]. While the AAE value for solid fuel, mostly biomass burning has been reported around from 1.8 to 2.1[26,29-31]. However, α values falling between α1 and α2 include the mixture source of FF and BB. The percentage of biomass burning can be calculated using the formula as:

$$BB\ (\%) = \frac{\beta abs(\lambda)BB}{\beta abs(\lambda)} \quad (6)$$

$$FF\ (\%) = 100 - BB\ (\%) \quad (7)$$

Results and Discussion

Emission patterns and diurnal variations of BC during Diwali event: BC mass concentration was monitored 24 hours a day on four consecutive days at NIT, Jamshedpur. The average BC was calculated with standard deviation (SD), maximum and minimum mean concentration for DP1 and DP2 as mentioned in Table-2. The concentrations of BC at before Diwali (BD), Diwali 1 (D1), Diwali 2 (D2) and after Diwali (AD) days were 7.1 ± 5.31μg m^{-3}, 14.38 ± 44.48μg m^{-3}, 13.5 ± 8.4μg m^{-3} and 9.1 ± 4.44μg m^{-3} respectively during the first Diwali period (DP1). Whereas in DP2, the concentrations observed in Table-2 on four consecutive days were 8.5 ± 7.86, 17.4 ± 1.32, 15.5 ± 7.44 and 11.9 ± 6.86μg m^{-3}, respectively. The collected BC mass concentrations ranged from 2.15 to 136.9μg m^{-3} and 2.5 to 185.6μg m^{-3} in DP1 and DP2 respectively as shown in Table-3.

Hourly variation of BC concentration was examined throughout the four days during the study period, with higher concentration levels found on D1 day during both the Diwali periods. The reason behind the high intensity during the first two days of Diwali was attributed due to the extensive use of firecrackers and burning of oil lamps. On the Diwali days (D1 and D2), the gradual peak due to Diwali event were observed at 8 – 10 pm at DP2 (Figure-2). However, the concentration of BC in DP1 is lower as compared to DP2 because of less suspended aerosols in the atmosphere after COVID waves.

Although slight fluctuations were seen in D1 while a wave of high concentration was reflected after 8 pm on evening as displayed in Figure-2(c). This might happen due to less demand and supply chain of firecrackers before the DP2. From other research article, significant changes in aerosol concentrations were found during bursting of crackers in Dibrugarh, when crackers were burst between 16:00 and 22:00 hours on day 1 and 2 [32]. Many studies have cited poor ambient air quality in urban bodies due to fireworks during Diwali[33,34].

The average concentration of Black carbon in Delhi was 34% greater i.e., 25.6μg m^{-3} than previous Diwali[35]. The Box plot represents concentration distribution of BC with parameters of maximum, 99%, mean, 1% and minimum values for the four consecutive Diwali days throughout both periods (Figure-3).

Table-2: Diurnal variations of BC concentration (μgm^{-3}) in two Diwali periods.

	DP1 (μgm^{-3})				DP2 (μgm^{-3})			
	Mean	Sd	Max	Min	Mean	Sd	Max	Min
B D	7.1	5.31	86.97	3.3	8.5	7.86	74	2.5
D 1	14.38	11.48	136.9	2.7	17.4	10.32	186.5	3.3
D 2	13.5	8.4	67.2	2.15	15.5	7.44	103.68	2.7
A D	9.1	4.44	50.8	2.2	11.9	6.86	115.6	2.56

Table-3: Daily $PM_{2.5}$ and BC concentration with BC/$PM_{2.5}$ (%).

D P	BC/$PM_{2.5}$	B D	D 1	D 2	A D	Range	BC/$PM_{2.5}$ (%)
1	BC (μgm^{-3})	7.1	14.38	13.5	9.1	2.15 - 136.9	24.2
	$PM_{2.5}$ (μgm^{-3})	89.26	216.84	187.26	101.24	27.8 - 885.6	
2	BC	8.5	17.4	15.5	11.9	2.5 - 185.6	19.6
	$PM_{2.5}$	98.76	255.64	232.17	174.63	32.4 - 947.2	

$PM_{2.5}$ concentrations: The concentration of $PM_{2.5}$ was observed similar trends as Black Carbon because it is a subgroup of fine particulate matter. We found concentrations of around 89.26, 216.84, 187.26 and 101.24μgm^{-3} on the respective days during DP1, which ranged from 27.8 to 885.6μg m^{-3}. And in DP2, the concentrations ranged from 32.4 to 947.2μg m^{-3}, with average daily values of 98.76, 255.64, 232.17 and 174.63μg m^{-3} over the 4 consecutive mentioned days (Table-3).

The average daily concentration statistics showed that most of the deposition of $PM_{2.5}$ occurred significantly on day 1 of Diwali. This unpredictable increase in average $PM_{2.5}$ concentrations on days D1 and D2 was due to the extent of firecracker burning, local biomass and industrial emissions (Figure-4). The observed BC/$PM_{2.5}$ percentage was around 24.2 and 19.6% during DP1 and DP2 respectively which indicates the contribution BC present in fine particulate matter.

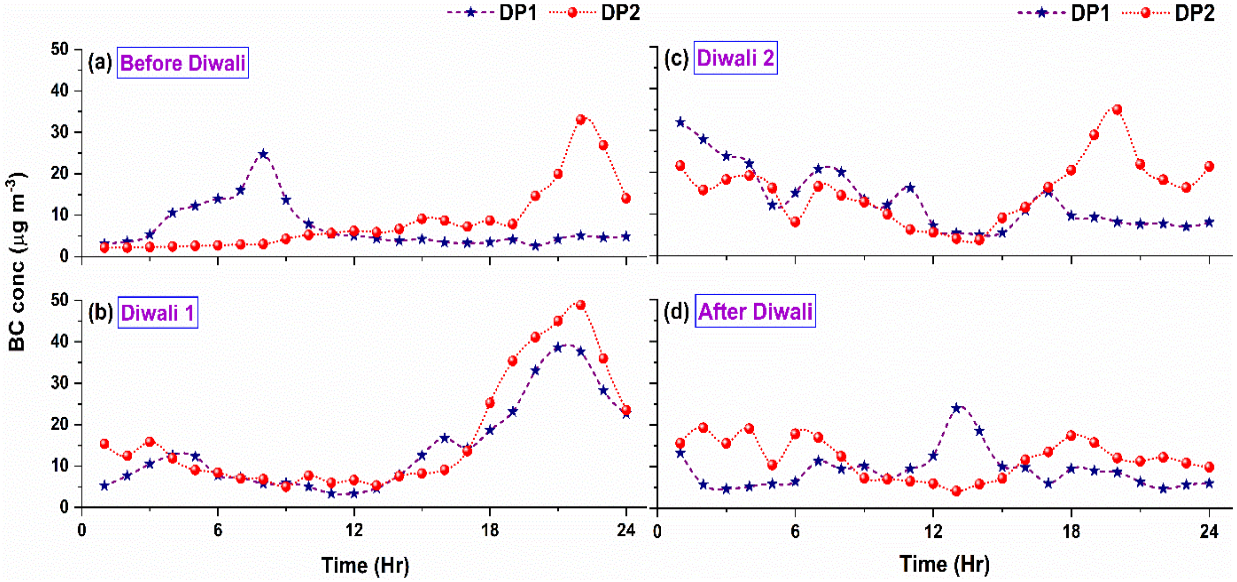

Figure-2: Hourly based temporal variation of BC concentration investigated during **(a)** Before-Diwali, **(b)** Diwali Day 1, **(c)** Diwali 2 and **(d)** Day after Diwali during the study period.

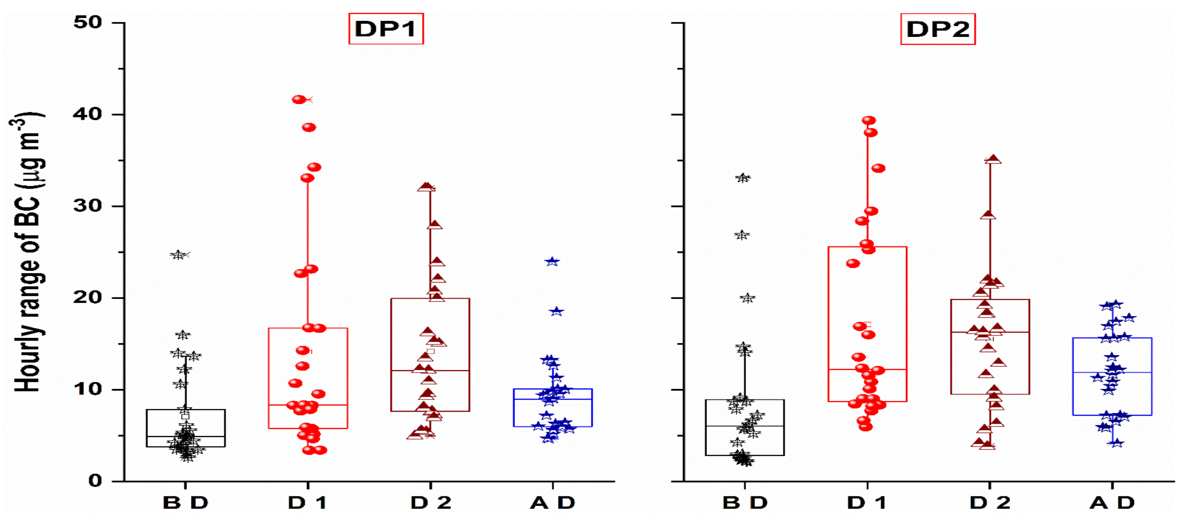

Figure-3: Box plot representing the hourly average concentration distribution of BC having parameters as Max, 99%, Mean, 1% and Min values for the four consecutive Diwali days during DP1 and DP2 respectively.

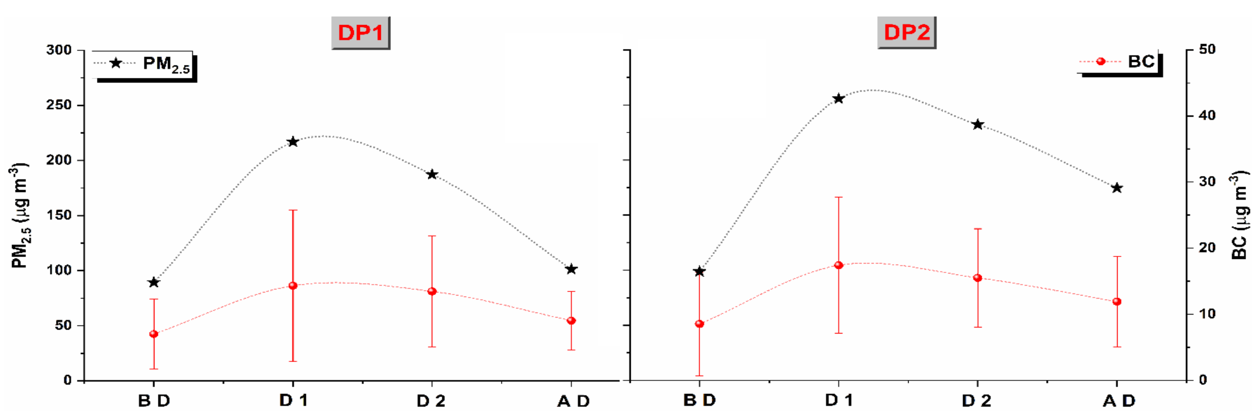

Figure-4: Comparison of mean BC (±SD) and $PM_{2.5}$ in four consecutive days of Diwali Periods.

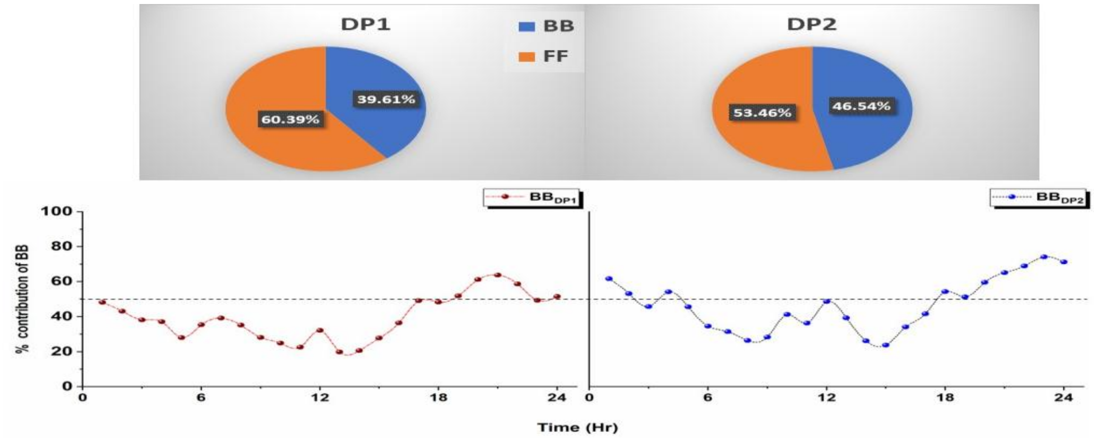

Figure-5: % Contribution of Biomass Burning diagnosed by Aethalometer model during Diwali events.

Source Apportionment analysis of BC emission: The concentration of aerosol particles generally varies during the Diwali period compared to other days due to transient fluctuations in the atmospheric layer as November enters. During the entire sampling session, BC concentration emitted mainly from two sources i.e., BB and FF. Sources of biomass burning are seen on Diwali more than other days mainly due to the fireworks residue. BC_{BB} concentrations during DP1 ranged from 0.51 to 24.62µg m^{-3}, while in DP2 it ranged from 0.65 to 33.7µg m^{-3}. During the observation time, we observed that BB contribution remained low throughout the day but increased by more than 50% after 6 pm in the Diwali session as shown in Figure-5. In DP1, the BC_{BB}/BC ratio was found to be around 0.39 which is lower than 0.46 studied in DP2. The % contribution of BB & FF was calculated around 39.61 & 60.39 % in DP1 and 46.54 & 53.46 % in DP2 respectively.

Previous study also found in the rise of biomass burning contribution from 41 to 56.9 % over three different strategic location during the cultural practices[36]. The festival activities enhanced the fine medium particles as indicated through angstrom exponent in a research work[37]. The main reason behind that in the second round of COVID, due to the reshuffle in the Covid restriction lots of firecrackers burst with joy. The reason behind the continuous rise in contribution of BC_{BB} was due to increase in stubble burning activities in parts of Punjab, Haryana and Uttar Pradesh as seen in Figure-5. The increased blood pressure and respiratory disorders in middle-aged and elderly people are the consequences of high concentration of BC_{BB} during November.

Table-4: Source Apportionment of BC: % of biomass burning (solid fuels) contribution during Diwali events.

	Biomass burning (% BB)	Fossil fuel (% FF)
DP1	39.61	60.39
DP2	46.54	53.46

Giovanni satellite model analysis for surface mass concentration: According to the Geospatial Interactive Online Visualization and analysis Infrastructure (GIOVANNI) – a geophysical data visualization tool developed by the Goddard Earth Sciences Data and Information Services Center, NASA, which predict the surface mass concentration of suspended aerosol utilizing satellite. The model demonstrated higher surface mass concentration of BC was observed over Indo-Gangetic Plain (IGP) which includes Uttar Pradesh, Punjab, Haryana, Delhi, Bihar, Jharkhand, and West Bengal. However, Uttar Pradesh and northern states celebrate Diwali grandly by lighting oil lamps and crackers, resulting in higher BC concentrations on the surface. Time averaged graph of monthly Black Carbon over November 2020 and 2021 was displayed in Figure- 6. The Fgure-6 shows that the concentration was found to be lower in DP1 compared to DP2 which may be due to the passing of the first COVID waves. During the first wave, all anthropogenic activities were completely stopped while a partial lockdown was imposed during the second wave. The study was done during the month of November, from this month winter starts. During the wintertime, the temperature falls lead to the lowering of planetary height result in the BC concentration closer to the earth's surface. The concentration also influenced due to the Indo-Gangetic Plain (IGP) region which appear haze and foggy condition in the atmosphere. The mentioned situation occurs visibility issue in the atmosphere.

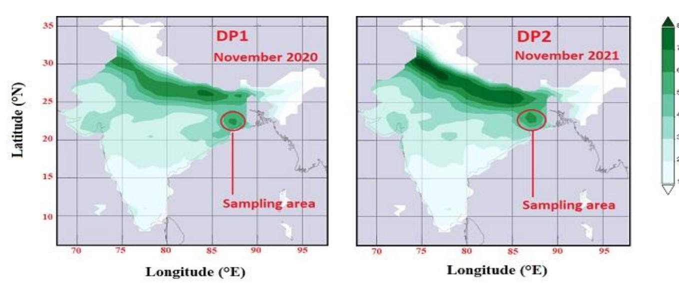

Figure-6: Time averaged map of Black Carbon Surface mass concentration monthly 0.5×0.625deg. (MERRA-2 Model M2T MNXAER v5.12.4) kg m^{-3} over November 2020 (DP1) and 2021 (DP2) in India (https://giovanni.gsfc.nasa.gov/giovanni).

Conclusions

The study shows significant variation in BC concentration related to the two Diwali periods. The festival is celebrated with fireworks and oil lamps along with other man-made activities mixed with industrial discharges and regional sources. Increased aerosol particles in the atmosphere can enter human bodies through inhalation and cause serious respiratory and cardiovascular health problems. The present research will alert the administration to impose some restrictions regarding the increasing levels of BC concentrations in the environment due to human negligence. BC emitted at high intensity on D1 day of Diwali, as being widespread use of firecrackers and lighting of oil lamps.

The study revealed that BC concentrations were observed higher during DP2 than DP1, which was due to burning of more firecrackers after the revocation of Covid restrictions during the second Diwali period. BC concentrations were increasing rapidly after 18:00 IST on BD, D1 and D2 days during DP2 due to higher use of firecrackers, oil lamps, some public gatherings and traffic load before and during the festival. While the concentrations in DP1 were much higher at 19:00 IST on D2 day but in lesser amounts compared to DP2.Source apportionment analysis of BC found that the % contribution of BB and FF was calculated around 39.61 and 60.39 % in DP1 and 46.54 and 53.46 % in DP2 respectively. With Covid regulations being lifted, BB's contribution to DP2 was seen to be higher because of the large-scale bursting of crackers during the festival.

However, satellite model analysis shows that surface mass concentrations accumulate primarily in the IGP (Indo-Gangetic Plain) region, which is visible due to the Himalayan ranges blocking aerosols driven by south-westerly winds. It also justified our observation of high surface mass concentrations of BC during the study month in DP2.

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