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Variations in black carbon and particulate matters (PM_1, $PM_{2.5}$ and PM_{10}) during firecrackers bursting episodes and biomass burning: A case study during the Diwali festival

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ABSTRACT

Introduction: The Black Carbon (BC) and Particulate Matters (PMs) was measured in the Diwali festival during 3-7 November, 2021. Diwali is being one of the main festivals of India accompanied by lighting and firecrackers bursting.

Materials and methods: BC concentration was measured by aerosol black carbon low-cost sensor/detector and PM_1, $PM_{2.5}$ and PM_{10} mass concentration as well as number concentration was measured using Grimm Aerosol Spectrometer at Agra, India.

Results: Average mass of PM_1 (<1 µm), $PM_{2.5}$ (<2.5 µm) and PM_{10} (<10 µm) were 218.32±56.82 µg/m^3, 261.56±74.38 µg/m^3 and 380.40±67.78 µg/m^3 respectively in Diwali day (2021). The observed concentration of PM was much higher than National Ambient Air Quality Standards (NAAQS) and World Health Organization (WHO) standard limits. Diurnal peaks for all the pollutants (PM_1, $PM_{2.5}$ and PM_{10}) were perceived in the evening time which was due to festival celebration events. Particle Size number Distribution (PSND) showed one major peak in the particle <1 µm size range. BC mass concentration was found to be 16.28±5.62 µg/m^3 in Diwali days. BC/PMs ratio decreases as the PM size increases due to the heavy load of $PM_{2.5}$.

Conclusion: BC and PM concentration was significantly amplified on Diwali due to firecrackers bursting and candles and biomass burning which was responsible for the poor air quality. Particle Mass Size Distribution (PSMD) showed multiple peaks while PSND showed one major peak in fine mode. Higher $PM_1/PM_{2.5}$ indicated the abundance of fine particles as compared to coarse. BC concentration was increased by 20 % on Diwali day due to firecracker bursting, other burning materials and more vehicles movement.

Introduction

Air pollution is a severe environmental issues in rising countries resulting from a complex interaction between sources (natural and anthropogenic) and environmental circumstances. In Asian countries (especially South and South-East Asia) have led to a substantial increase in aerosols emission on a regional scale due to speedy commercial growth like growing urbanization, industrialization and

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vehicular practice in the eras [1]. These elements are joined with trans-boundary haze pollution and the Asian dust phenomenon which added to surge concentration of aerosol in Asian cities [2-4]. Air pollution in India has developed a thoughtful difficulty due to fine particles ($PM_{2.5}$) which accounting for over one million early demises in 2015 [5] and also impact on regional climate change. The Indo-Gangetic Plain (IGP) is a tremendously compactly inhabited zone in Northern India which involvements the highest levels of $PM_{2.5}$ and PM_{10} in the world [6-8].

In addition, huge amounts of air pollutants are released when traditional festivals are celebrated in a fabulous manner in India [9]. Diwali, the festival of lights, is considered as one of the biggest and most important festivals which are celebrated with bursting of firecrackers throughout the country in the post monsoon period (October-November). The Indian Fireworks industry boasts of about 90.19 million US Dollar worth of annual turnover, at an annual growth rate of about 10 percent [10]. The bursting of firecrackers releases significant amounts of particulates (PM_1, $PM_{2.5}$ and PM_{10}) and BC which can cause adverse impact on human health as well as on regional climate disturbance [11]. Fireworks display a great strength of manmade movement that cause air-quality ruin which can have important community fitness inferences and produce thick smoke clouds that are complete of aerosol particles (PM_1, $PM_{2.5}$ and PM_{10}) and BC along with water-soluble ions, insoluble fraction and trace metals [12-16].

In India, several researchers have investigated the ambient air quality during festivals in term of Suspended Particulate Matter (SPM) and coarse mode particles [17-18]. But few studies have been done on fine particles and associated chemical constituents on Diwali. In this connection, many researchers reported $PM_{2.5}$ was the leading contaminant over New Delhi which suggests the mortality rate can be decreased (6.2 - 6.5%) when the level of $PM_{2.5}$ meets the Indian and World Health Organization (WHO) standards [19]. Another study conducted at Delhi on Diwali in terms of morphology and chemical characteristics of SPM which was reported higher level of metals (56.95%), black carbon (1.98%) and aromatic organics (1.11%) [20]. In addition, several researchers studied the short-term changes in air quality due to Particulate Matter (PM) and its influence on social fitness since of fireworks in the festival's seasons [21-29]. According to the above discussion, it is inferred that the high level of air pollution as compared to the recommended frontier of reviewing National Ambient Air Quality Standards (NAAQS) link with assured festivals which results short-term incidents of air pollution [11]. Considering that there are limited measurements of air quality on Diwali in the Indian scenario with respect to real-time aerosol size distribution and BC measurement. Thus, the current study has been accompanied at Agra which is extremely contaminated city situated in the Indo-Gangetic Plain (IGP) to measure real-time BC and PM_1, $PM_{2.5}$ and PM_{10} mass concentration along with PMSD and PNSD during Diwali period (2021). The short-term impact of Black Carbon (BC) on air quality during Diwali 2021 due to firecrackers bursting and biomass burning was also examined.

Materials and methods

Site description

Agra (27°10' N, 78°02' E), city is situated in the Northern part of India which is~200 km of south of Delhi in the state of Uttar Pradesh. Agra is one of the most famous tourist spots in North India due to the presence of TajMahal. The climate of Agra during winter time is cooled with moisture, the temperature ranges from 3.5 to 30.5 °C and downwind West-North-West (WNW 9.4%) and North-North-West (NNW 11.8%). Air pollution is greater when wind blows from WNW due to oil refinery located at Mathura which is near to study location and transportation of air pollutants toward the study location from different neighboring polluted areas. Agra has about 1.3 million residents and the population density is about 21,150 persons/

km2 with 386,635 vehicles registered and 32,030 generator sets. In Agra, 60% air pollution is mainly due to traffic emissions as four national highways (NH-19, NH-44, NH-21 and NH-93) cross the city [6-7].

Sample collection and analysis

Black carbon mass concentration was measured using Aerosol Black Carbon Detector (ABCD) low cost sensor at Agra in Diwali period (November, 3 -7 2021). This instrument is integrates a condensed weather resistant inclusion, solar-powered rechargeable battery, and cellular message to permit long-term, remote action [30]. This BC sensor was developed by Distributed Sensing Technology (DST), USA. The ABCD sensor translates measured light to BC mass concentration in the sampled air flow and air is strained into the cell with a rotary vane pump and through two Teflon-coated glass-fiber filters that lie between Light Emitting Diodes (LEDs) and photodiodes. The LEDs operate BC mass at 880 nm and it is considered as the predominant PM constituents to absorb light [31-32]. The photodiodes produce electrical voltages that are linearly comparative to the power of light conveyed through each filter. The intensity of light success the photodiode located below the first filter in series (sample filter) is attenuated by the buildup of BC. The sensor Microcontroller Unites (MCU) computes optical attenuation and calculates BC concentrations. The filters in the optical cell are swapped to avoid potential optical saturation [33-35].

Relative Humidity (RH) and temperature sensors are attached in the sample flow path between the sample and reference photodiodes. In order to reducing the effect of environmental situations such as Relative Humidity (RH) and Temperature on measured BC mass, air was drawn through both the reference and sample filters [30]. The Portable Aerosol Spectrometer (Grimm: model No.1.109) was used for PM_1, $PM_{2.5}$ and PM_{10} mass concentration measurement as well as number concentration in the Diwali campaign. This instrument is runs at a persistent flow rate of 1.2 L/min ± 5% with controller for constant aerosol measurement. The detailed description and working principle of aerosol size measurements is given in previous research paper [36]. The measured data for BC and PM were analyzed and checked for scientific quality control. The final data were used for graphical representation using Origin software.

Results and discussion

PMs (PM_1, $PM_{2.5}$ and PM_{10}) concentrations during Diwali campaign

To assess rapid changes in air quality, the short term disparity of PM_{10}, $PM_{2.5}$ and PM_1 mass concentration was studied. The PM_{10}, $PM_{2.5}$ and PM_1 average values were 380.40±67.78 µg/m^3, 261.56±74.38 µg/m^3 and 218.32±56.82 µg/m^3 respectively in Diwali (2021). PM_{10} and $PM_{2.5}$ mass concentration was much higher than NAAQS standard limit values for 24 h (100 and 60 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively). In order to examine the density of atmospheric particles $PM_1/PM_{2.5}$, PM_1/PM_{10} and $PM_{2.5}/PM_{10}$ ratios were assessed. $PM_1/PM_{2.5}$ ratio was higher (0.84±.03) as compared to PM_1/PM_{10} (0.57±0.07) and $PM_{2.5}/PM_{10}$ (0.68±0.09) ratios which inferred that the ultrafine particles (<PM_1) was dominant over the study region during the campaign. This may be very serious issues for the public health as the fine particles can enter intensely into the lung which affects the alveolar wall consequently harm lung functions along with asthma and heart diseases [37].

Fig. 1 shows the variability of PM_1, $PM_{2.5}$ and PM_{10} concentration at Agra during the Diwali campaign due to anthropogenic activities such as firecrackers bursting, partial combustion, fossil fuels and biomass burning and candles flaming. The highest and remarkable peaks of PMs were observed on the Diwali days indicating the contribution of firecrackers bursting episodes. Fig. 2 depicts daily variability of PM_1, $PM_{2.5}$ and PM_{10} which exhibited upper levels in prominent days (4-6 November 2021) as compared to pre

(3/11/2021) and post (7/11/2021) Diwali. This short-term increase of PMs in Diwali days was due to large anthropogenic activities (such as vehicular movement, firecrackers bursting and other materials burning events) taking place in large scale on festival night.

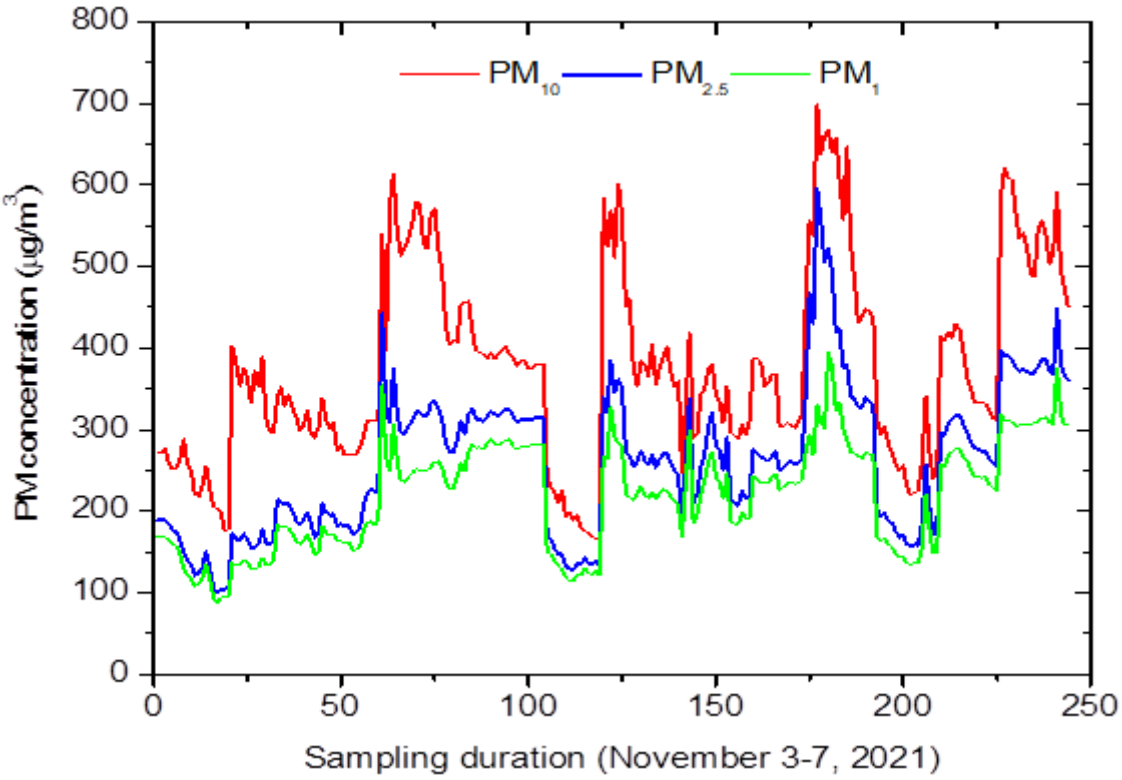

Fig. 1. The variability of PM_1, $PM_{2.5}$ and PM_{10} concentration at Agra during the Diwali campaign

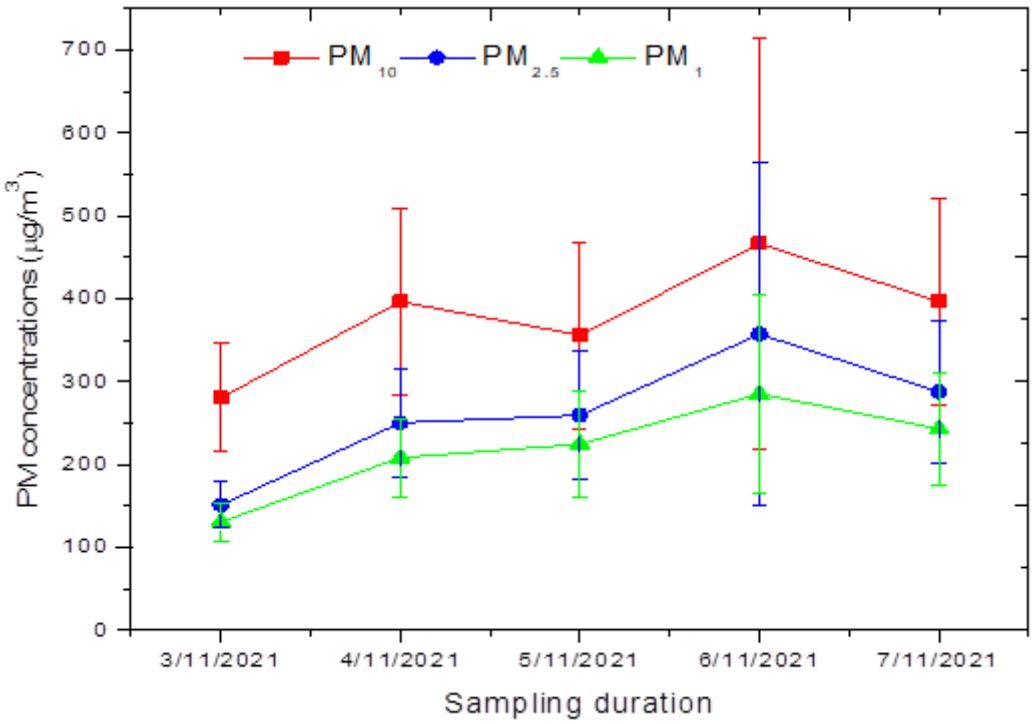

Fig. 2. Comparision of daily variability of PM_1, $PM_{2.5}$ and PM_{10} in prominent days (4-6 November 2021) with pre (3/11/2021) and post (7/11/2021) Diwali

Table 1. Comparison of PMs and BC mass concentration with other studies in various region of India during Diwali period

Location	Festival period	Observation	BC	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_1 ($\mu g/m^3$)	References
Agra	November, 2021	Real time	16.6±5.6	380±6	262±7	218±5	Present study
Jamshedpur	October, 2014	Gravimetric		505.6		-	[38]
Kanpur	November, 2015	Real time	-	-	244±9	-	[36]
Raipur	November, 2015	Gravimetric	-	-	230	-	[8]
Raipur	October, 2017	Real-time			344	-	[39]
Delhi	October, 2016	Real time	-	-	250	-	[37]
Patiala	October 2017	-	9 ± 1	140±1	-	-	[35]

Table 1 shows PM_1, $PM_{2.5}$ and PM_{10} mean concentration, out of them only $PM_{2.5}$ mass level is comparable with other studies conducted in various regions of India due to unavailable data for PM_1 and PM_{10} in the literature. $PM_{2.5}$ concentration (262 $\mu g/m^3$) in the present study on Diwali 2021 was higher as compared to other reported studies (Table 1). This means that the air quality of Agra city during festival time was more deteriorated as compared to previous year's festival events in Indian cities due to unawareness of people's and non-restriction of firecrackers bursting on the festival occasion. Another study also found higher BC concentration (9 $\mu g/m^3$) on Diwali period which was lower than our findings (16.5 $\mu g/m^3$) [38]. The diverse researchers have been reported their findings on Diwali which are as follows: in a study it was found higher $PM_{2.5}$ concentration level by the factor of 1.8 (day) and 1.3 (night) in Diwali day at Kanpur (November 2015) [39]. A study reported higher $PM_{2.5}$ concentration (230 $\mu g/m^3$) on Diwali (November 2015) at Raipur, India [10]. Another study also reported 250 $\mu g/m^3$ for $PM_{2.5}$ mass during Diwal at Delhi in 2016 [40]. In addition, the higher PM_{10} concentration on Diwali in Jamshedpur, India was reported by many rearchers [41]. As seen in Table 1, $PM_{2.5}$ mean concentration along with other studies conducted in various region of India during Diwali periods. Many researchers reported higher $PM_{2.5}$ mass concentrations (171.20-517.67 $\mu g/m^3$) on Diwali which was higher than before (137.17-564.05 $\mu g/m^3$) and after (79.46-266.26 $\mu g/m^3$) Diwali. It was remained in atmosphere for two days causing adverse impact on human cardiovascular and respiratory systems [42]. Researchers reported a high concentration of PM_{10} (900 $\mu g/m^3$) and $PM_{2.5}$ (950 $\mu g/m^3$) on Diwali day which was 8-9 times higher than that regulatory standard. The higher concentration was maintained for two days in atmosphere in festival period and these particles includes components of the firecracker such as heavy metals, alkali, alkaline earth metals [43]. Other researchers reported ~5 times greater PM_{10} concentrations on Diwali night as compared to the normal day night-time average. The rise in night-time concentrations of the metals on Diwali night crossed over a extensive range such as 5-12 times increase in Al, Zn, Pb and Cd, 25-40 times increase in Cu, Fe and Mn and Co and V revealed 70–80 times increase as associated to normal night-time concentrations [44]. According to above mentioned studies and present observation, it was noticed that the ambient air quality is worsened in festival time due to large scale anthropogenic activities in urban areas of India. It was reported in other study

that higher concentration of TSP, PM_{10}, SO_2, and NO_2 on Diwali day which may be attributed to contrary meteorological conditions. The decrease temperature, wind speed, and mixing height (24 hourly averages) on Diwali days as compared to the previous day has caused accumulation of air pollutants at lower level, thus may be the reason for significant increasing the air pollutants concentration [45]. Many researcherts reported the variation in air pollutants ($PM_{2.5}$, PM_{10}, NO_2, and SO_2) outline between Christmas and new year celebrations in 2019, 2020, and 2021 and found the substantially higher concentration of all pollutants in festivity days in reported years which was higher than permitted restrictions [46].

In order to examine the relationship among PMs, correlation matrix was applied and found that PM_1 was strongly correlated with $PM_{2.5}$ (R^2: 0.92) while $PM_{2.5}$ strongly correlated with PM_{10} (R^2:0.9). This means that the density of PM_1 particles were more shifted towards $PM_{2.5}$ as compared to PM_{10} because of the emission of primary particles.

To recognize the outlines of exposure, to assess and develop representation in models, to relate satellite examinations and to design measurement systems, the diurnal disparity of PM_1, $PM_{2.5}$ and PM_{10} is very significant [47]. Fig. 3 displays the diurnal pattern of PM_1, $PM_{2.5}$ and PM_{10} which indicated that PMs concentration in Pre-Diwali was higher in morning and evening time while during the Diwali period the trend was changed as higher in afternoon and evening time due to the festival celebration events. This study also inferred that the PMs concentration varied as the function of time. The PMs concentration was also found to be higher in morning time in next day (5/11/2021) due to accumulation of pollutants from the large emission on previous night. The particle mass size distribution (PMSD) was also analyzed in order to examine the effects of particle density. Fig. 4 shows two major peaks, one was in fine mode and another was in coarse mode. The diurnal pattern inferred that higher PMSD was found to be in evening time as compared to morning and noon time period.

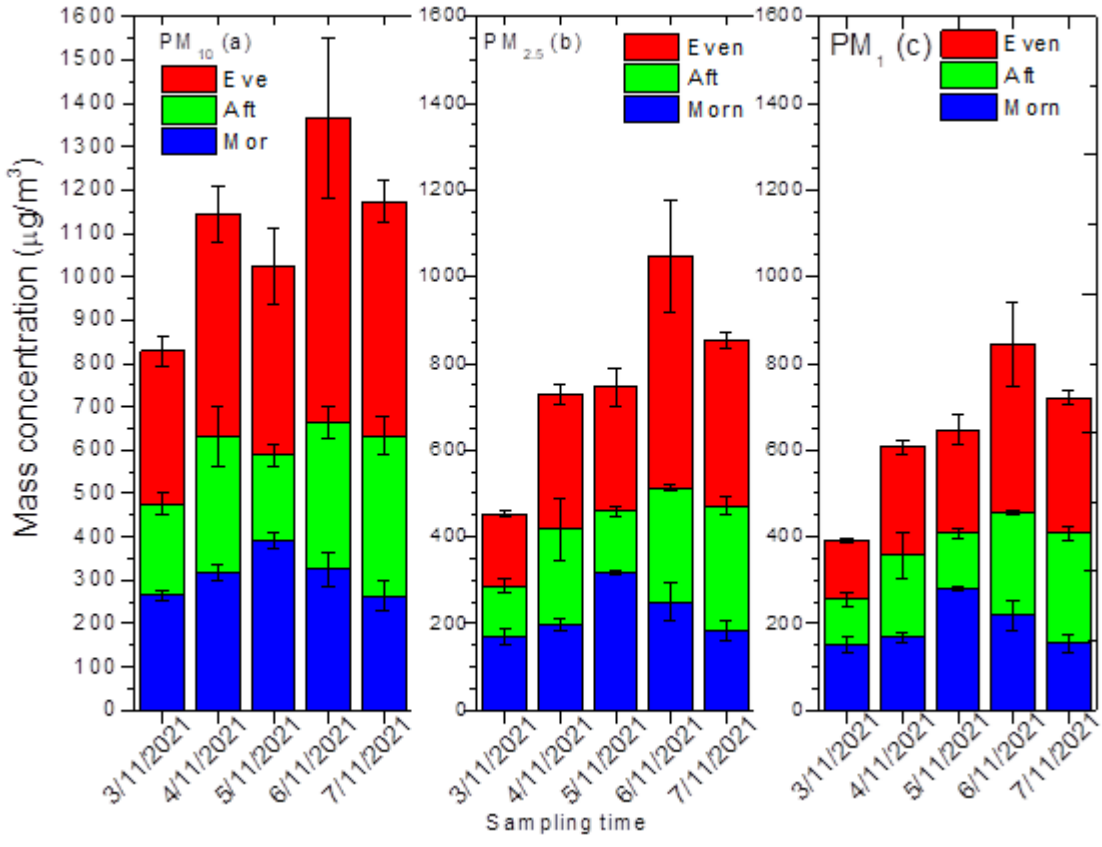

Fig. 3. The diurnal pattern of PM_1, $PM_{2.5}$ and PM_{10} concentration in Pre-Diwali in morning and evening

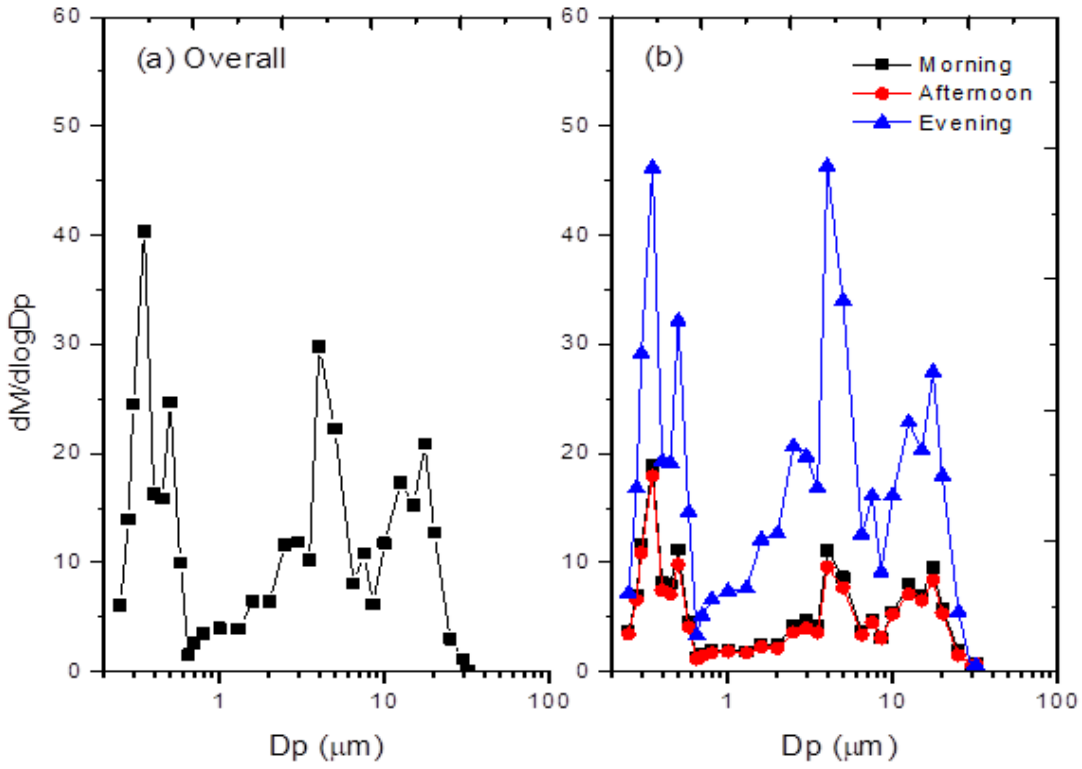

Fig. 4. Two major peaks in fine mode and in coarse mode

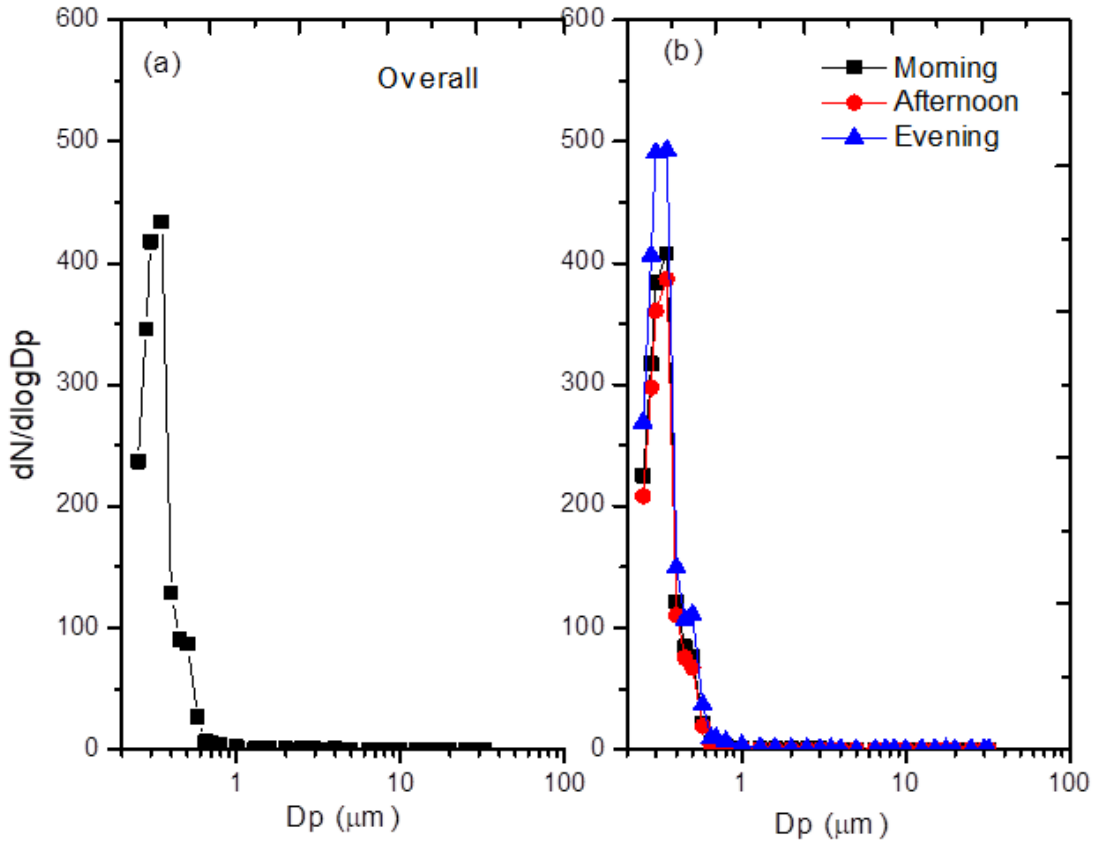

Fig. 5. The daily and diurnal pattern which is marked by the presence of one major peak in PNSD during the Diwali period

Number size distribution

The physical (size) and chemical (composition) properties of aerosols over urban regions exhibit wide variability as they are emitted from a variety of sources. The Particle Number Size Distribution (PNSD) was also measured during the Diwali period at Agra. It is one of the crucial physical properties that govern the aerosol interface with atmospheric radiation, cloud development, transportation, and deposition and health effects at regional and global level. The particles with definite size which are existent at a known site that depends on different causes such as the origin of atmospheric particles, processes (condensation, nucleation and evaporation), chemical reactions, deposition and removal with precipitation (wet and dry). The daily and diurnal pattern of PNSD reveals that the majority of particle number concentration was found to be in the fine size range (<1 µm). Fig. 5 shows the daily and diurnal pattern which is marked by the presence of one major peak in PNSD during the Diwali period.

BC mass concentration and its impact on air quality during Diwali events

BC is a primary air pollutant which is mainly light absorbing constituent of PM produced from fossil fuel ignition and biomass burning [48]. Exposure to BC is related with amplified threat of pulmonary and cardiovascular diseases, cancer and premature death [49, 50].Therefore, the real-time BC measurements are highly required to examine its impact on air quality which results the negative effects on human health as well as regional climate change. BC average mass concentration was 16.28±5.62 µg/m^3 at Agra. The large variability in BC mass concentration was observed in the Diwali period due to the anthropogenic activities occurred in festival events (Fig. 6).

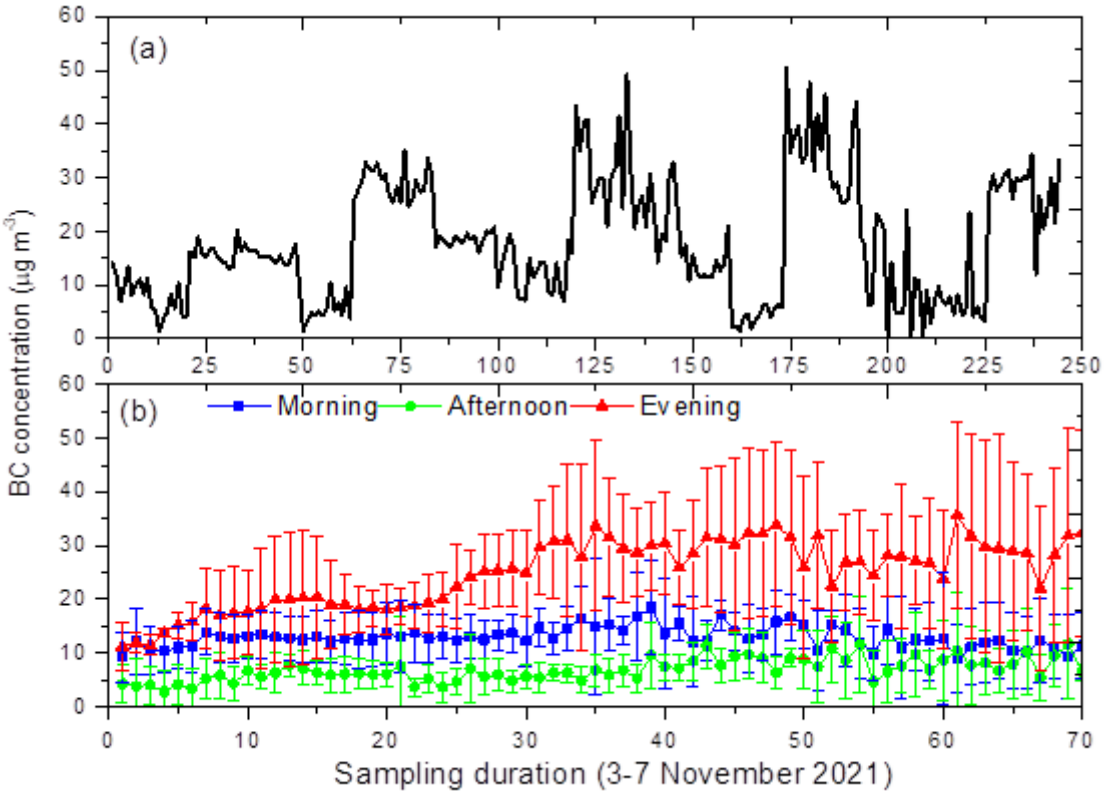

Fig. 6. The large variability in BC mass concentration in the Diwali period due to the anthropogenic activities occurred in festival events

The higher levels of atmospheric BC during Diwali as compared to normal days were reported [41]. In order to examine the contribution of BC into different sizes of PMs (PM_{10}, $PM_{2.5}$ and PM_1), ratios of BC/PM_1, $BC/PM_{2.5}$ and BC/PM_{10} were estimated. The average ratios of BC/PM_1, $BC/PM_{2.5}$ and BC/PM_{10} were 0.08±0.03, 0.06±0.02 and 0.04±0.01 respectively. BC/PMs ratio decreases as the size of PM increases which indicates that BC concentration was found to be prominent in smaller size as compared to larger size particles. BC mass concentration was compared with PMs size distribution which revealed that BC was significant correlated with fine particles. The BC concentration was highest (25 µg/m^3) on Diwali day (04/11/2021) in comparison to other days. This broad peak was due to incomplete combustion, fossil fuel and candles burning and firecrackers bursting events carried out in large scale during the festival events. Real-time measurement of non-refractory particulate matter (<1µm) and BC was conducted by many researchers during the Diwali. They found that organics were the dominant contributor (~85%) as compared to other pollutants (23%) (SO_4^{2-}, Cl^-, NO_3^- and NH_4^+ towards smaller particles on the Diwali night [51]. The percentage contribution of BC, PM_1 and $PM_{2.5}$ indicating that ~10-20 % increase in BC concentration on Diwali days (4-6 November 2021) as compared to pre-Diwali Days (Fig. 7).

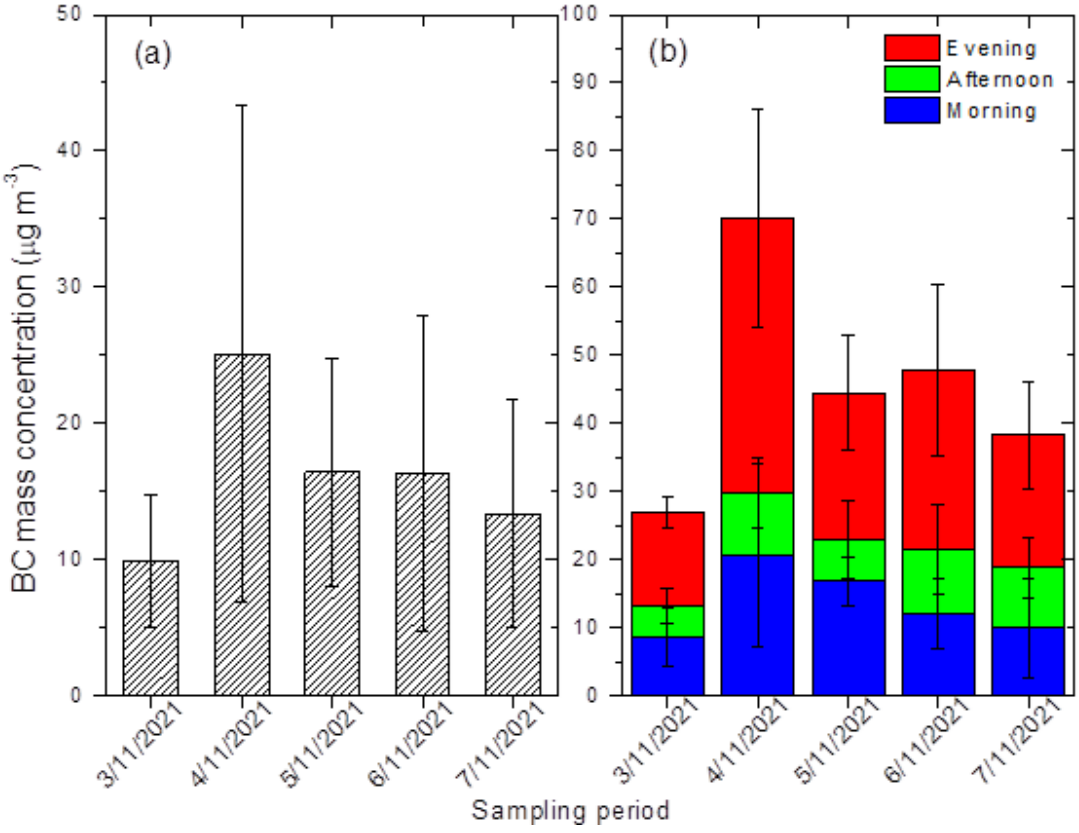

Fig. 7. The percentage contribution of BC, PM_1 and $PM_{2.5}$ on Diwali days and pre-Diwali Days

This clearly represents that air quality of Agra city deteriorated with increase in BC level due to short term enhancement of anthropogenic activities which was more concern for the human health and regional climate change. Diurnal variability showed higher BC was observed in evening time as compared to morning and afternoon (Figure 7). This was only due to manmade happenings which are completed in evening time. Whereas, in morning time higher BC concentration was due to traffic rush and more vehicles movement.

Impact of firecrackers episode and biomass burning on local air quality

Particulate air pollution is a key environmental health hazard in urban zones. BC is an significant element of PM which released in the imperfect ignition of biomass and fossil fuels (diesel engines) and other burning activities that is intensely allied to antagonistic health influences. It comprises a significant portion of PM and worldwide ecological difficulties that have undesirable consequences for public health issues and climatic problems. Consequently, the BC measurement is imperative to inspect the incineration discharges and quantify their influence on public fitness and on the atmosphere. Therefore, the present study campaign was conducted in Diwali period to observe the significant impact of BC on air quality of Agra during the firecrackers and candles burning activities. It was observed that BC significantly influences the air quality by enhancing ~20 % BC level on Diwali time. This was the severe episode in terms of BC which is generally associated with fine particles that are very harmful for human health. The inhalation of BC is directly connected with human health issues like respiratory and cardiovascular illness, cancer and natal flaws. Moreover, the ability of BC to captivate light as heat and adds to regional and global climate alteration. BC concentration was also found higher in evening hours that clearly inferred the festival celebration effects (Fig. 7). In addition, air quality was influenced by BC concentration in morning hours due to biomass and useless material burning after cleaning the homes. Thus, the study revealed that the firecrackers and biomass burning activities significantly deteriorated the air quality at local and regional level in terms of BC associated with atmospheric fine particles.

Limitations and future perspective

The present study has been conducted in a very short-term period in the Diwali 2021 at India city of Agra located in the IGP region. This region is considered as the most polluted area in the world. The present campaign reveals the rising concentration of air pollutants which was responsible for deterioration of air quality due to the anthropogenic activities occurring in the festival period. The reported data is not enough to current examination of the air quality and will not be used as the decision making policies for future perspectives. Thus, particulate matter and associated chemical contents is an important constituent of the atmosphere. BC is a worldwide environmental delinquent that has adverse consequences for people health problems and regional/global climate change. Breathing of BC is linked with wellbeing difficulties with respiratory and cardiovascular illness, cancer, and birth imperfections. Thus, the long term measurement of particulate matter and BC concentration is playing an important role in examining the probable impacts of these air pollutants on human health as well as regional climate change.

Conclusion

Measurement of BC and PM_1, $PM_{2.5}$ and PM_{10} was conducted during Diwali festival week campaign in 2021. Significant variations in BC and PMs were found in Diwali 2020 due to the change in meteorological factors and local source profile. The $PM_{2.5}$ particles were predominant and associated with BC as compared to large one during the festival events. Significant variations in BC and PMs (PM_1, $PM_{2.5}$ and PM_{10}) were observed due to the firecrackers bursting episodes which deteriorated air quality by enhancing

BC (20%) and PM (8%) concentrations on the prominent day of Diwali. Diurnal pattern indicated that BC concentration was found to be higher (56%) in evening as compared to morning (29%) and afternoon (15%) time. Higher PM_1/ $PM_{2.5}$ indicated the abundance of fine particles as compared to larger particles. BC/PM ratios decreased as the size of particle increases which clearly indicates that BC was significantly associated with fine particles (<$PM_{2.5}$) which are associated with the primary pollutants. PSMD showed multiple peaks while PSND showed one major in lower size range (<1μm) of particles. The strong correlation (R^2: 0.8-0.9) was found amongst all sizes of PMs while in the case of BC the correlation was not significant. This inferred the dissimilarities in BC and PMs source origin. Higher levels of BC and PMs during firecrackers bursting leads to a considerable rise in contrary fitness belongings equated with in non-firecrackers days. Therefore, the present study is an effort to attempt for public awareness and policymakers to prevent urban air quality from human activities in festivals.

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Competing interests

The authors declare that they have no conflict of interest.

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the authors".

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