International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2020; SP-8(6): 167-174

Received: 16-11-2020
Accepted: 10-12-2020

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Deterioration of air quality and source of apportionment in Delhi during Deepawali Festival, India

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DOI: https://doi.org/10.22271/chemi.2020.v8.i6c.11069

Abstract
The enhance concentrations were reported in festival time over Delhi, India because of fire crackers in Deepawali period and biomass blazing in north-west region of India which severely influence climate situations, air classes and visibility. The mass concentrations of PM_{10} vary from 654 to 833 μgm^{-3} with a mean value of 756 µgm-3 and $PM_{2.5}$ varies from 107 to 700 μgm^{-3} with a mean value of 483 μgm^{-3} during the pre-Deepawali day (Nov. 9, 2020). However, the mass concentrations of PM_{10} vary from 533 to 953 μgm^{-3} with a mean value of 691.66 μgm^{-3} and $PM_{2.5}$ varies from 120.0 to 865.0 μgm^{-3} with a mean value of 440.66 μgm^{-3} during the Deepawaly day (Nov. 14, 2020). During the both pre-Deepawali day and Deepawaly day, the mass concentration of both PM_{10} and $PM_{2.5}$ were much higher than the threshold limit. During the Deepawali (Nov.14, 2020), a 40% enhancement in SO_2 and 3% enhancement in NO_2 was observed in the Delhi. The lowest mixing height, wind speed ad temperature were observed during the Deepawali day (Nov. 14, 2020) which play a significant role in low dispersion of air pollutants and high pollution level in Delhi. The backward trajectories are coming at Delhi from the high biomass/crop residue burning areas of Northwest Countries (Pakistan and Afghanistan), northern region of India (Punjab and Haryana) during the Deepawali days that raise the surface concentration of $PM_{2.5}$ and PM_{10}. The significant deterioration in the air quality of Delhi is observed in the Deepawali days because of fire cracking, transportation, low mixing height and temperature. The Air Quality Index (AQI) in Delhi was mostly reported as 'Poor to Sesvere' in the both pre Deepawali (Nov. 9, 2020) and Deepawali (Nov. 14, 2020).

Keywords: Air pollution, Deepawali, air quality index, traffic, industries, CPCB

1. Introduction
Air pollution has been considered as a serious dilemma in the world due to natural and anthropogenic emissions. About 91% of population in the world could not breathe fresh air and more than half population of urban area are exposed to 2.5 time higher ambient air pollution than the prescribed standard (WHO, 2016) [27]. The rapid urbanization, industrial growth, use of vehicles, high energy demand, poor waste management practices and open burning of biomass are significant sources of air pollution in the world with a variety of harmful pollutants like $PM_{2.5}$ and PM_{10} (Venkataraman *et al.*, 2005; Bond *et al.*, 2007; Gustafsson *et al.*, 2009) [26, 3, 10] including fine soot particles. In addition of these factors, growth of local industries is also one of the key drivers of air pollution in rural and urban areas still using outdated machinery with inadequate emissions control measures. The exposure of particulate matter is a cause of various respiratory and cardiovascular diseases. In India, air pollution has been acknowledged as the fifth most imperative cause of mortality due to high emissions from burning of fossil fuels in industries (brick kilns and thermal power plants), biomass burning (Venkataraman *et al.*, 2005; Bond *et al.*, 2007; Gustafsson *et al.*, 2009), agricultural residue burning and transportation [26, 3, 10].
As per the WHO, 14 Indian cities have been considered among the top 15 most polluted cities namely Kanpur, Varanasi, Faridabad, Delhi, Gaya, Lucknow, Patna, Agra, Patiala, Muzaffarpur, Jodhpur, Srinagar, Jaipur, Gurgaon and Ali Subah Al Salem (Kuwait) in terms of high $PM_{2.5}$ concentrations in 2018 (WHO, 2018) [28]. In India, the Indo-Gangetic Plain (IGP) region has been considered as one of the greatest source of emissions (Ramachandran and Cherian, 2008; Arif *et al.*, 2018; Pandey and Venkataraman, 2014; Saud *et al.*, 2012;

Kharol *et al.*, 2012; Kaskoutis *et al.*, 2014; Singh and Kaskoutis, 2014; Chauhan and Singh 2018; Sarkar *et al.*, 2018; Prasad *et al.*, 2006) [18, 1, 15, 22, 14, 12, 23, 24, 7, 20, 17].

Several researchers have been reported negative health effects of exposure to particulate matters due to emissions from transportation sector, residential area and other sources. The quantity and size of particulate matter is directly related to its probable undesirable health impacts with high morbidity and death allied with both $PM_{2.5}$ and PM_{10} particulate matters. The long time exposure to these fine particles may lead to heart or lung diseases. A number of research have confirmed the unfavorable effects on humans due to inhalation of these fine particles (PM_{10} and $PM_{2.5}$) from combustion of fossil and biofuels (Penn *et al.*, 2005; Rom and Samet, 2006; Schwarze *et al.*, 2006; Dockery and Stone, 2007; Grahame and Schlesinger, 2010, Casper *et al.* (2008) [16, 19, 21, 8, 9, 4] has also reported "anthropogenic air pollution" as the cause of global premature deaths of about 2-3 million people due to cardiovascular and respiratory disease. About 1·24 million deaths in India was attributable to air pollution in 2017, which include 0·67 million death from ambient and 0·48 million death from household air pollution (ICMR, 2017; Balakrishnan *et al.*, 2018) [11, 2].

The enhance concentrations were also reported in festival time over Delhi, India because of fire crackers in Deepawali period and biomass blazing in north-west region of India (Chauhan and Singh, 2017) which severely influence climate situations, air classes and visibility. Moreover, the MoEF&CC has prohibited straw combustion in north India but this exercise is happening in many parts of India. It is noticed that the farmer's burns residue in the May-June, mid-October and mid-November for the subsequent crop that generates enormous amount of aerosols across the IGP. Thus, the serious effect of straw burning is seen over Delhi because of low temperature and mixing height in the months of October-November. Hence to quantify the status of air pollution in one of the highly polluted locations of Delhi, we have carried out an analysis of PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO, at six locations in Delhi during pre-Deepawali and Deepawali time. A significant deterioration in the air quality of Delhi was observed due to Diwali festival.

2. Study Area and Methodology

Delhi (28°36′36″N 77°13′48″E) consists in eleven districts and second largest metropolition city after the Mumbai (Fig. 1). Delhi region is one of the highly dense inhabited regions and the strong seasonal variability of aerosol optical properties across the Delhi is observed. This is under the influence of various pollutants emitted through the various sources and further being governed by the large seasonal variability of the meteorological conditions. The primary contributors to air pollution in the Delhi region are both natural and anthropogenic like industrial units, vehicular emission, road dust, tire pads, construction activities, etc. (CPCB, 2016) [5]. The emission data of various pollutants were collected from continuous ambient air quality monitoring (CAAQM) network, Central Pollution Control Board (CPCB). The data of 6 monitoring stations were analyzed for Delhi in two phases: pre-Deepawali day (09.11.2020) and on Deepawali day (14.11.2020). AQI values have also been calculated to observe the air quality in the Delhi.

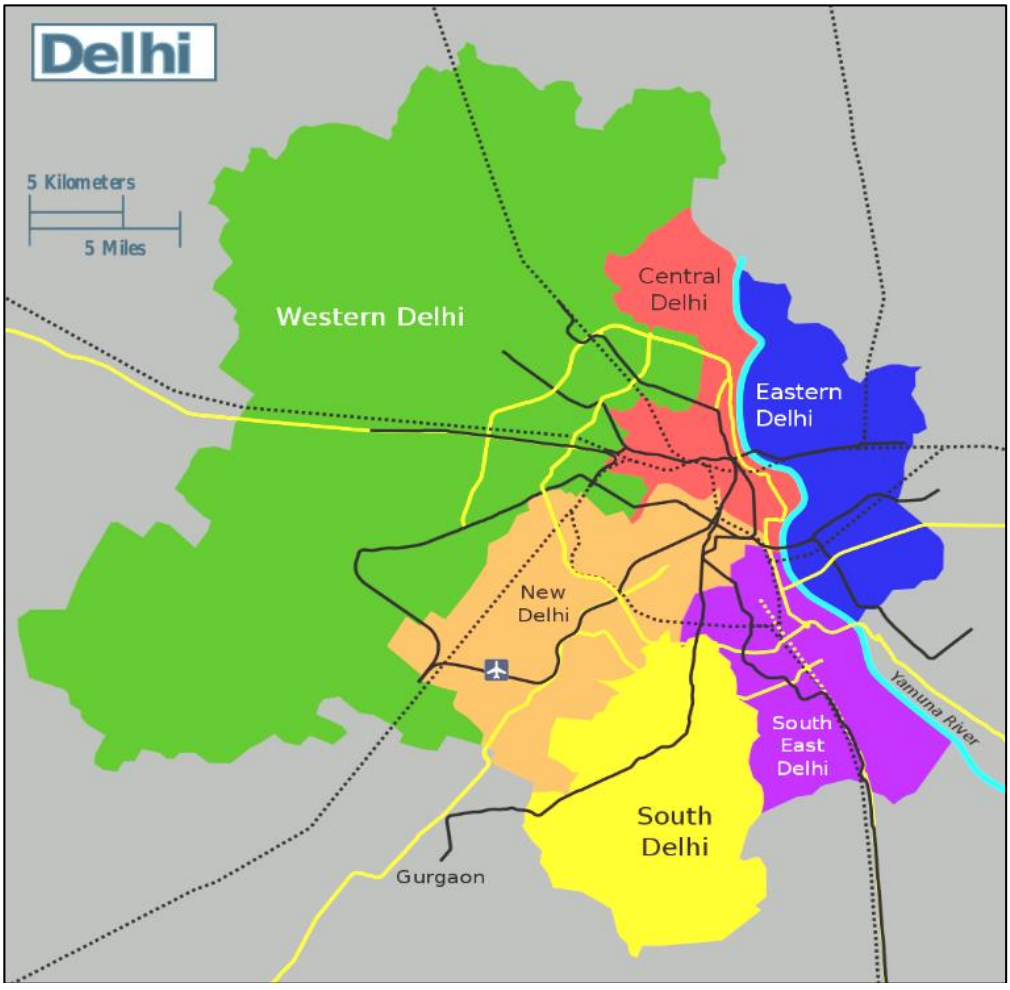

Fig 1: National Capital Delhi, showing various region

3. Results and Discussion

3.1 Emission of PM_{10} and $PM_{2.5}$

In Delhi, the mass concentrations of PM_{10} vary from 654 to 833 μgm^{-3} with a mean value of 756 μgm^{-3} (Fig. 2a) and $PM_{2.5}$ varies from 107 to 700 μgm^{-3} with a mean value of 483 μgm^{-3} (Fig. 2b) during the pre-Deepawali day (Nov. 9, 2020). However, the mass concentrations of PM_{10} vary from 533 to 953 μgm^{-3} with a mean value of 691.66 μgm^{-3} and $PM_{2.5}$ varies from 120.0 to 865.0 μgm^{-3} with a mean value of 440.66 μgm^{-3} during the Deepawaly day (Nov. 14, 2020). The largest concentration of PM_{10} was observed at Pitampura followed by Janakpuri and ITO during the Deepawaly day (Nov. 14, 2020). $PM_{2.5}$ are so small they can get deep into the lungs and into the bloodstream which was observed maximum at Pitampura followed by Janakpuri, Dilshad Garden, ITO, Shadipur and Dwarka during the Deepawaly day (Nov. 14, 2020). The daily mean concentration of $PM_{2.5}$ and PM_{10} were also correlated with the national ambient air quality standards (NAAQS) of India (http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php). These exercises helped in understanding that the concentrations were much greater than the threshold limit of $PM_{2.5}$ (60.0 μgm^{-3}) and PM_{10} (100.0 μgm^{-3}) on a daily basis in the study area which is very vulnerable to the health problem. During the both pre-Deepawali day and Deepawaly day, the mass concentration of both PM_{10} and $PM_{2.5}$ were much higher than the threshold limit. The mass concentrations of these locations were also correlated with both pre-Deepawali day and Deepawaly day of last four years (2016-2019). It is observed that the mass concentrations are highest during the Nov., 2020 as compared to last four years due to fire crackers and transportation of air pollutants from the other nearby regions of Delhi.

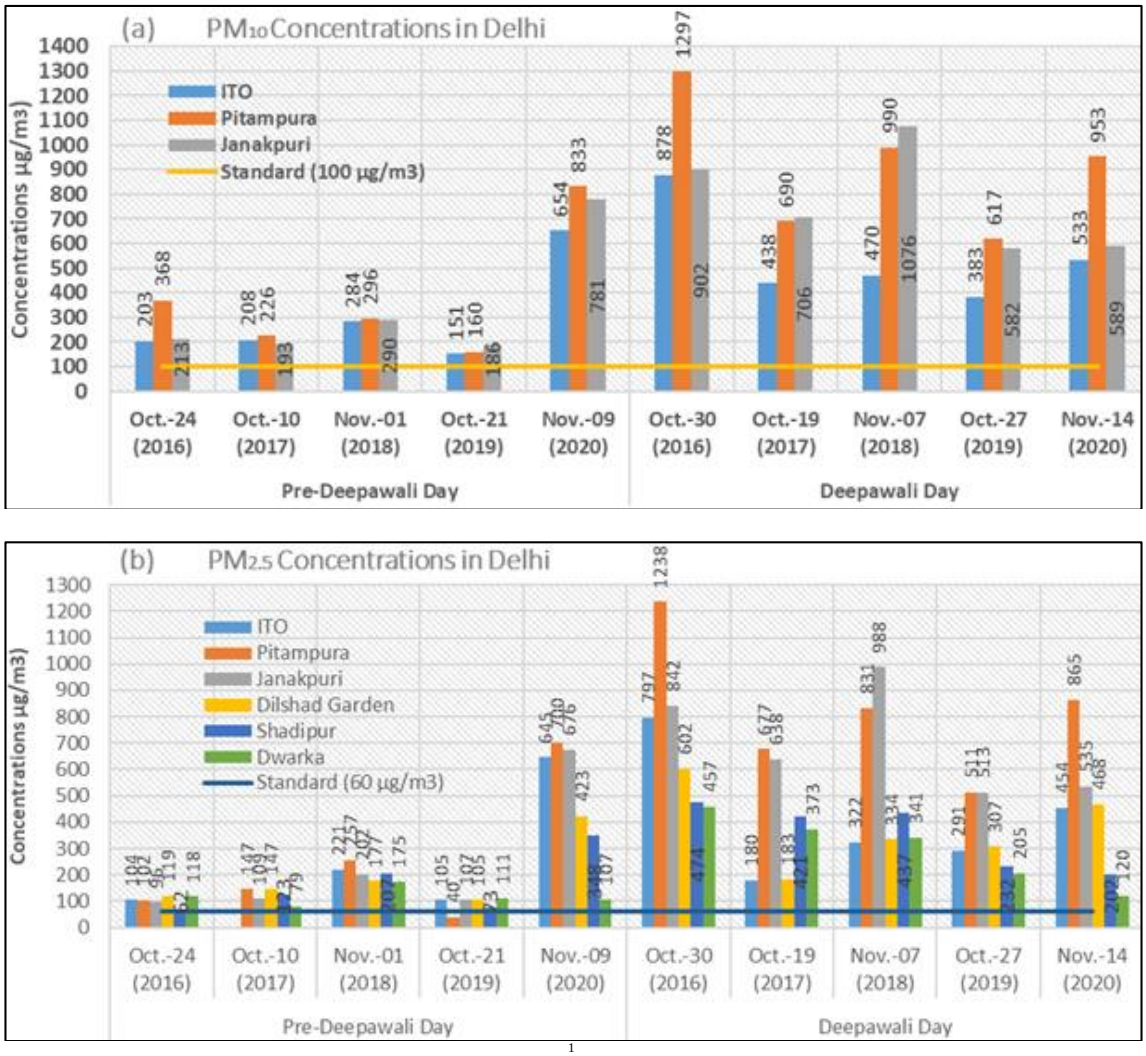

Fig 2: (a) average mass concentration of PM_{10} and (b) average mass concentration of $PM_{2.5}$ in the Delhi during the Pre-Diwali days and Deepawali days

3.2 Emission of SO_2 and NO_2

The transportation and industrial sectors are the major sources of NOx and SO_x in the Delhi. The mass concentrations of SO_2 varied from 4.0 to 25.0 μgm^{-3} with a mean value of 15.16 μgm^{-3} (Fig. 3a) and NO_2 varied from 55.0 to 150.0 μgm^{-3} with a mean value of 104.0 μgm^{-3} (Fig. 3b) in the Delhi during the Deepawali day (Nov. 14, 2020). However, the mass concentrations of SO_2 varied from 4.0 to 16.0 μgm^{-3} with a mean value of 9.0 μgm^{-3} and NO_2 varied from 59.0 to 160.0 μgm^{-3} with a mean value of 101.0 μgm^{-3} during the pre-Deepawali day (Nov. 9, 2020). During the Deepawali (Nov.14, 2020), a 40% enhancement in SO_2 and 3% enhancement in NO_2 was observed in the Delhi due to the festival, transportation and industrial activities. The daily mean concentrations of both SO_2 were observed within the threshold limit of NAAQS during the pre-Deepawali and Deepawali days (Fig. 3). However, The daily mean concentrations of both NO_2 were observed high as compared to the threshold limit (80.0 μgm^{-3}) of NAAQS during the pre-Deepawali and Deepawali days at Shadipur, Dilshad Garden

and ITO. The mass concentrations of these locations were also correlated with both pre-Deepawali day and Deepawaly day of last four years (2016-2019). It is observed that the mass concentrations were highest during the Deepawali days as compared to pre-Deepawali days in all years due to fire crackers and transportation of air pollutants from the other nearby regions of Delhi.

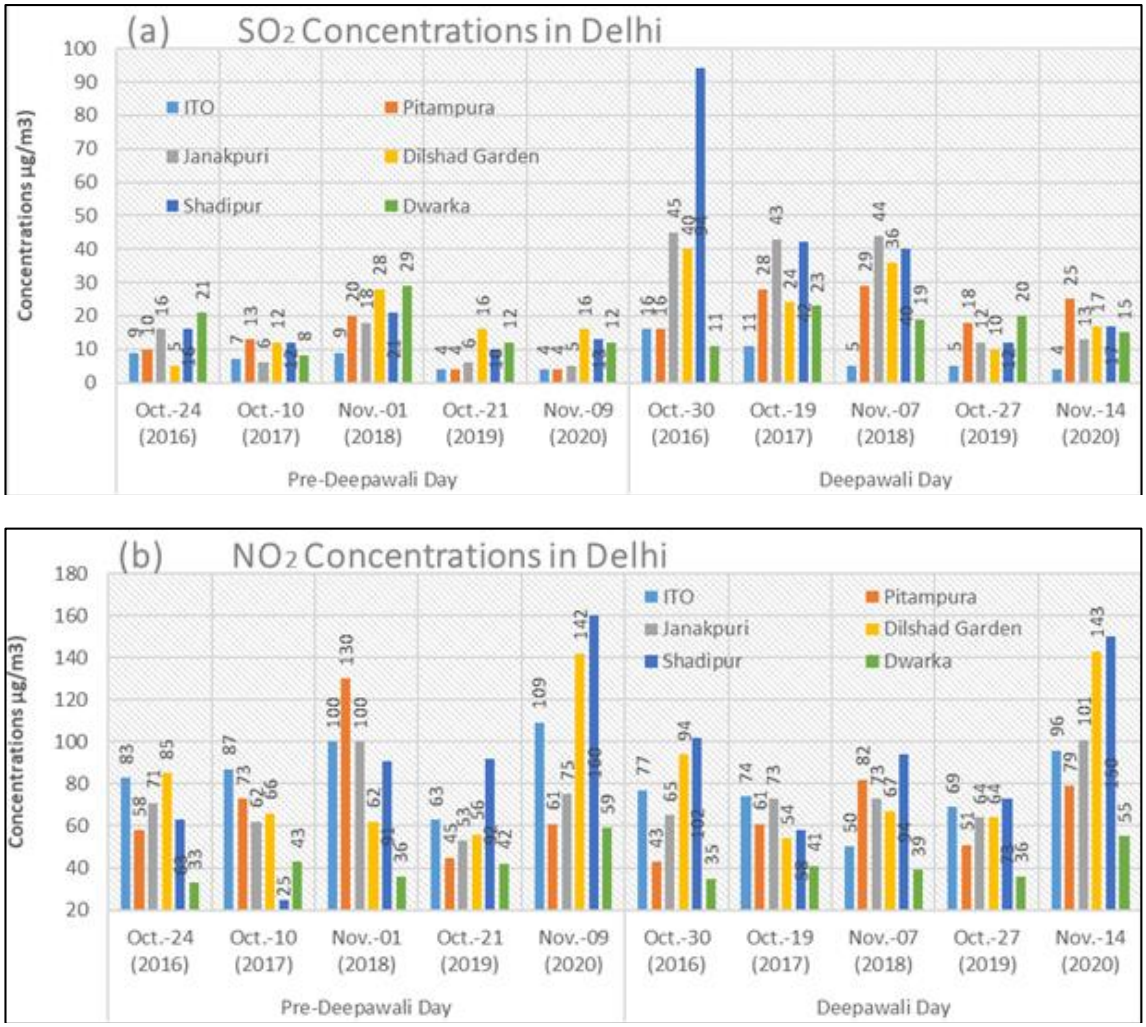

Fig 3: (a) Average mass concentration of SO_2 and (b) Average mass concentration of SO_2 in the Delhi during the Pre-Diwali days and Deepawali days

3.3 Emission of CO

The mass concentrations of CO varied from 1718 to 3227µg m^{-3} with a mean value of 2455.33 mg m^{-3} (Fig. 4) during the pre-Deepwali day (Nov.9, 2020). However, the mass concentrations of CO varied from 1245 to 2411 µg m^{-3} with a mean value of 1937 µg m^{-3} in the Delhi during the Deepwali day (Nov.14, 2020). The daily mean concentrations of both CO were observed within the threshold limit of NAAQS during the pre-Deepwali day and Deepwali day.

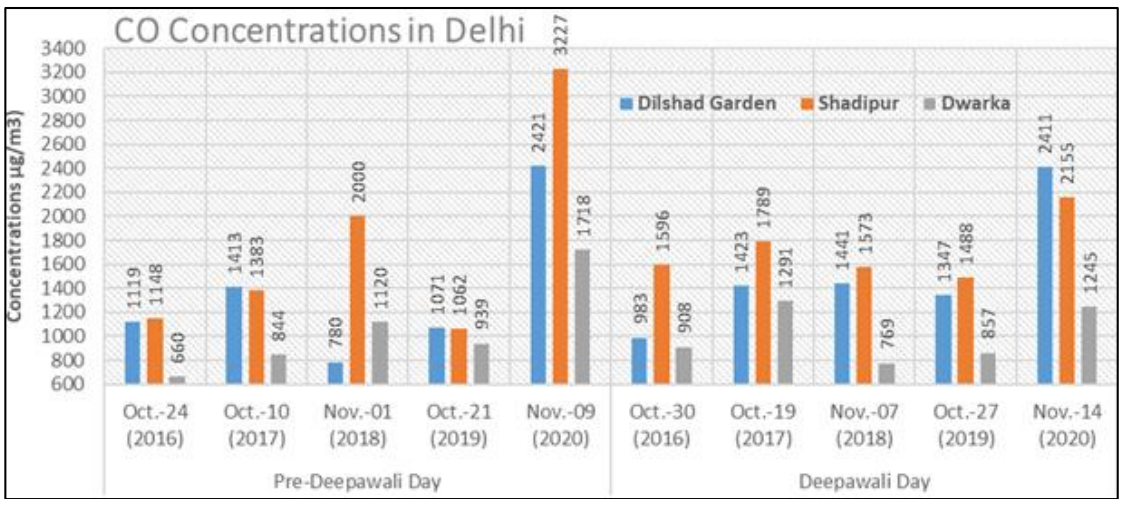

Fig 4: Average mass concentration of CO in the Delhi during the Pre-Diwali days and Deepawali days

3.4 Source of Apportionment in Delhi

The climate of the Delhi is 'subtropical humid-semi arid' and classified as 'Cwa and BSh' type with high variation between summer and winter temperatures and precipitation. The Wind speed, direction, and mixing height have a significant role in the dispersion of air borne materials and influence air quality of the area (Fig. 5a). The lowest mixing height and wind speed were observed during the Deepawali day (Nov. 14, 2020) as compared to pre-Deepawali day (Nov. 9, 2020). The lower mixing height and wind speed play a significant role in low dispersion of air pollutants and high pollution level in Delhi. The lowest temperature (22.4 ^{O}C) was observed during the both pre Deepawali (Nov.9, 2020) and Deepawali day (Nov. 14, 2020) as compared to last four years which is also major reason for high pollution level in Delhi (Fig. 5b). Similarly, low relative humidity was during the both pre Deepawali (Nov.9, 2020) and Deepawali day (Nov. 14, 2020) as compared to last four years (Fig. 5b).

We also examined the other sources of pollution in the Delhi during the Deepawali days. It was observed that the backward trajectories are coming at Delhi from the high biomass/crop residue burning areas of Northwest Countries (Pakistan and Afghanistan), northern region of India (Punjab and Haryana) during the Deepawali days that raise the surface concentration of $PM_{2.5}$ and PM_{10} (Fig. 6). However, India's National Green Tribunal has banned crop residue burning in the country, though the practice continues in the northwest, north and central regions of India. Similar findings were also reported at Peshawar, Pakistan (Khan *et al.*, 2015) [13], Iran (Shahsavani *et al.*, 2012) [25] and Beijing, China (Zhao *et al.*, 2009) [29]. Wheat is usually harvested in months of May–June and leaves behind crop residue in the field. These residues are subjected to open burning to clear the field for the next crop, which produces plenty of biomass aerosols over the region during the dry season (Singh *et al.*, 2014) [23, 24].

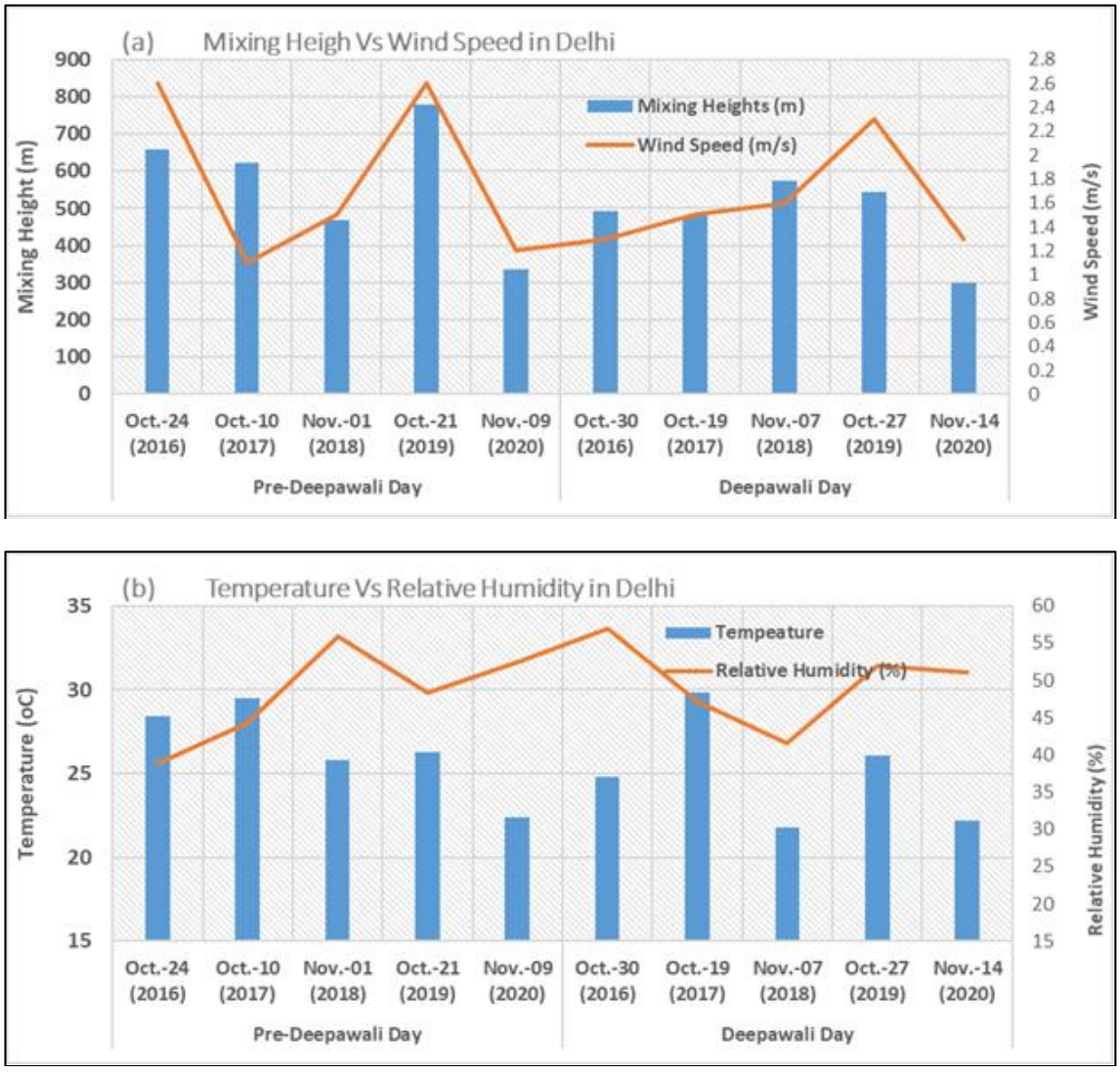

Fig 5: Meteorological conditions at Delhi (a) Daily average mixing height and wind speed (b) Daily average temperature and humidity at Delhi during the Pre-Diwali days and Deepawali days

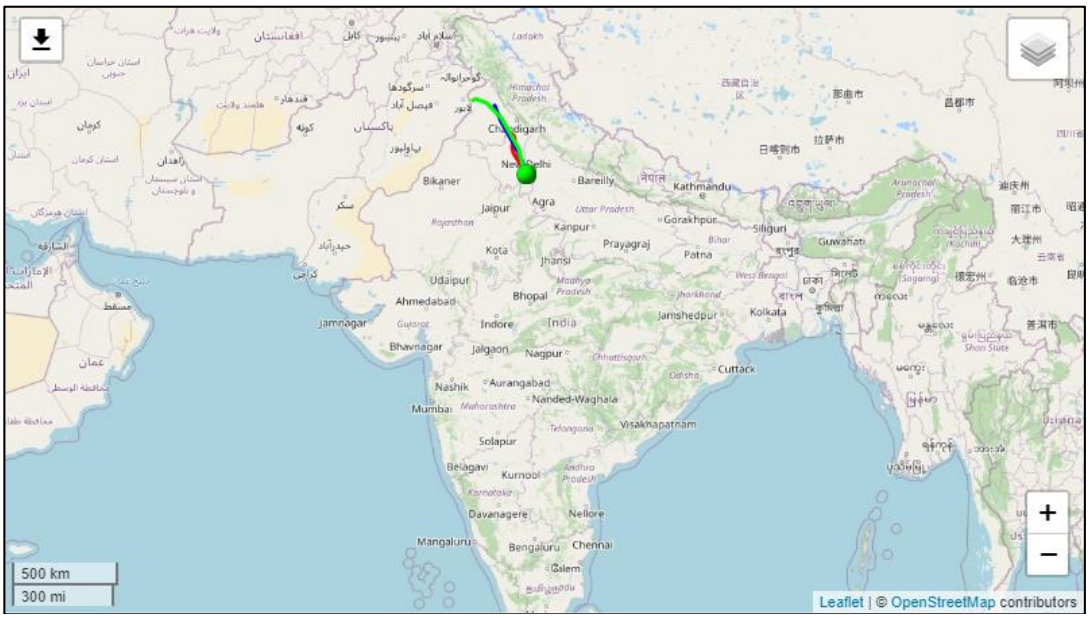

Fig 6: Back trajectories at 500, 1000 and 1500 m level at Delhi during Pre-Diwali days and Deepawali days, 2020.

3.5 Air Quality Index

The significant deterioration in the air quality of Delhi is observed in the Deepawali days because of fire cracking, transportation, low mixing height and temperature. Based on the concentrations, the Air quality Index was also calculated during the both pre-Deepawali and Deepawali. The Air Quality Index (AQI) in Delhi was mostly reported as 'Poor to Severe' in the both pre Deepawali (Nov. 9, 2020) and Deepawali (Nov. 14, 2020) (Table-1). The severe air quality was observed at ITO, Pitampura, Janalpuri and Dilshad Garden during the both pre Deepawali (Nov. 9, 2020) and Deepawali (Nov. 14, 2020). However, Poor air quality was observed at Dwarka during the Deepawali day (Nov. 14, 2020). Fig. 7 shows various classes of air quality in Delhi.

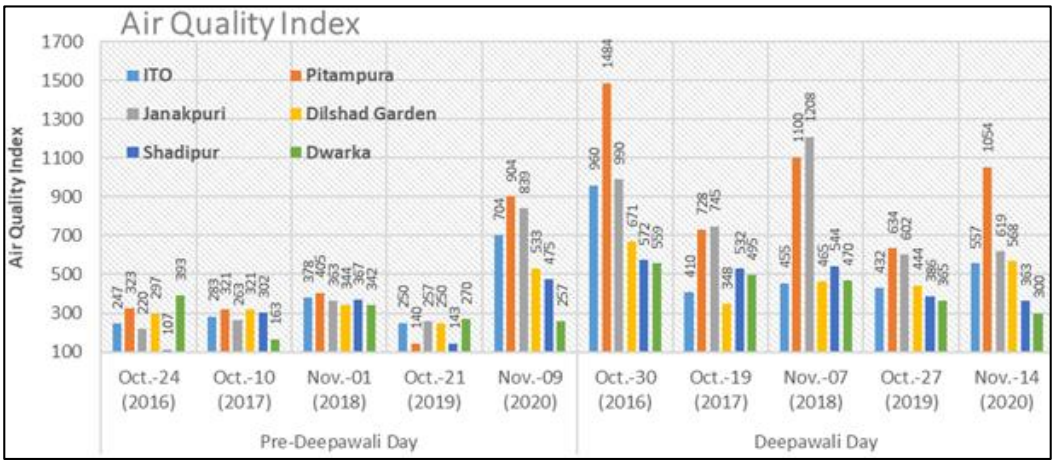

Fig 7: Air Quality Index of Delhi during the Pre-Diwali days and Deepawali days

Table 1: Air Quality Index in the Delhi during the Pre-Diwali days and Deepawali days

	Pre-Deepawali Day					Deepawali Day				
	Oct.-24 (2016)	**Oct.-10 (2017)**	**Nov.-01 (2018)**	**Oct.-21 (2019)**	**Nov.-09 (2020)**	**Oct.-30 (2016)**	**Oct.-19 (2017)**	**Nov.-07 (2018)**	**Oct.-27 (2019)**	**Nov.-14 (2020)**
ITO	247	283	378	250	704	960	410	455	432	557
Pitampura	323	321	405	140	904	1484	728	1100	634	1054
Janakpuri	220	263	363	257	839	990	745	1208	602	619
Dilshad Garden	297	321	344	250	533	671	348	465	444	568
Shadipur	107	302	367	143	475	572	532	544	386	363
Dwarka	393	163	342	270	257	559	495	470	365	300

	Legends			
	Good (0–50)	Minimal Impact	Poor (201–300)	Breathing discomfort to people on prolonged exposure
	Satisfactory (51–100)	Minor breathing discomfort to sensitive people	Very Poor (301–400)	Respiratory illness to the people on prolonged exposure
	Moderate (101–200)	Breathing discomfort to the people with lung, heart disease, children and older adults	Severe (>401)	Respiratory effects even on healthy people

4. Conclusion

Air pollution has been considered as a serious dilemma in the world due to natural and anthropogenic emissions. Delhi has been considered among the top 15 most polluted cities in terms of high $PM_{2.5}$ concentrations in 2018. In India, the IGP region has been considered as one of the greatest source of emissions. The enhance concentrations were also reported in festival time over Delhi, India because of fire crackers in Deepawali period and biomass blazing in north-west region of India which severely influence climate situations, air classes and visibility.

The mass concentrations of PM_{10} vary from 654 to 833 μgm^{-3} with a mean value of 756 μgm^{-3} and $PM_{2.5}$ varies from 107 to 700 μgm^{-3} with a mean value of 483 μgm^{-3} during the pre-Deepawali day (Nov. 9, 2020). However, the mass concentrations of PM_{10} vary from 533 to 953 μgm^{-3} with a mean value of 691.66 μgm^{-3} and $PM_{2.5}$ varies from 120.0 to 865.0 μgm^{-3} with a mean value of 440.66 μgm^{-3} during the Deepawaly day (Nov. 14, 2020). The largest concentration of PM_{10} was observed at Pitampura followed by Janakpuri and ITO during the Deepawaly day (Nov. 14, 2020). $PM_{2.5}$ are so small they can get deep into the lungs and into the bloodstream which was observed maximum at Pitampura followed by Janakpuri, Dilshad Garden, ITO, Shadipur and Dwarka during the Deepawaly day (Nov. 14, 2020). During the both pre-Deepawali day and Deepawaly day, the mass concentration of both PM_{10} and $PM_{2.5}$ were much higher than the threshold limit. During the Deepawali (Nov.14, 2020), a 40% enhancement in SO_2 and 3% enhancement in NO_2 was observed in the Delhi due to the festival, transportation and industrial activities.

The lowest mixing height, wind speed ad temperature were observed during the Deepawali day (Nov. 14, 2020) as compared to pre-Deepawali day (Nov. 9, 2020) which play a significant role in low dispersion of air pollutants and high pollution level in Delhi. It was observed that the backward trajectories are coming at Delhi from the high biomass/crop residue burning areas of Northwest Countries (Pakistan and Afghanistan), northern region of India (Punjab and Haryana) during the Deepawali days that raise the surface concentration of $PM_{2.5}$ and PM_{10}. However, India's National Green Tribunal has banned crop residue burning in the country, though the practice continues in the northwest, north and central regions of India. The significant deterioration in the air quality of Delhi is observed in the Deepawali days because of fire cracking, transportation, low mixing height and temperature. The Air Quality Index (AQI) in Delhi was mostly reported as 'Poor to Severe' in the both pre Deepawali (Nov. 9, 2020) and Deepawali (Nov. 14, 2020).

5. Acknowledgments

The authors are grateful to CPCB for providing data for the various locations of Delhi.

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