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Study on air pollution trends (2010-2015) due to fireworks during Diwali festival in Delhi, India

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Abstract: The burning of massive amount of fire crackers on the evening(s) of a nation-wide celebrated festival called 'Diwali' in India, gives rise to a remarkably high concentration of criteria air pollutants and it is of utmost importance to investigate the impact of such high loads originated during a relatively shorter time span in a mega-city like Delhi where the situation of ambient air quality has already been alarming almost through-out the year. In view of the same, the present study analyzes available concentration data during this festival's night for five criteria pollutants namely PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO (Particulate Matter, Sulfur Dioxide, Nitrogen Dioxide and Carbon Monoxide respectively) along with NH_3 at six key locations of Delhi. Following the analysis, PM_{10} concentration in Anand Vihar during nighttime of Diwali was reported to be ~8 times higher than the 24 hours values prescribed by National Ambient Air Quality Standards (NAAQS). On the other hand, the same at IGI airport was recorded lowest even though about 3.5 times that of the guiding standard. $PM_{2.5}$ concentrations were reported as highest and lowest at RK Puram and Civil lines respectively, in both the cases quite exceeding the comparable standard values. Interestingly, remaining criteria pollutants, namely, SO_2, NO_2 and CO along with NH_3 measured in 2015 showed no values in excess of corresponding 24-hrs guidelines, thereby reporting a better scenario compared to previous years. Further, the extensive use of firecrackers during Diwali festival leads to substantial increase in air pollutants necessitating special measures to control.

Keywords: Fireworks, Diwali, Aerosols, Criteria pollutants, NAAQS.

1. Introduction

The Indian sub-continent witnesses Diwali as the festival of lights and crackers in October/November every year which is celebrated with inordinate zest. Most widely reflected by firing crackers and enlightened lanterns almost all over the country during festival night(s), the celebration often characterizes itself filled with trace gases and particulates including metals into the atmosphere, giving rise to thick smoke clouds, characteristics and concentration of which are determined by composition of sparklers and crackers (Barman et al., 2009). Having constituents such as potassium nitrate, charcoal, sulphur, potassium and trace elements, the crackers are reported to have significant adverse effect on environment as well as human health (Barman et al., 2009). The effect of firework activities on the air pollutants like particulate matter, its components and trace gases during various festivities has been studied by many researchers and reported worldwide. Kong et al. (2015) studied the impact of firework-burning particles on air quality and human health during the winter season in Nanjing in 2014 and reported that fireworks contributed to about 50% of the $PM_{2.5}$ during the spring festival period. Vecchi et al. (2008) observed that particles number concentrations driven by firecracker's burning increased significantly during the celebration of FIFA world Cup win in 2006 over Italy (up to 6.7 times in 1h for the $0.5<d<1\mu m$ size bin).

Drewnick et al. (2006) studied the chemical composition and chemically resolved size distributions of fine aerosol particles at high time resolution (5 min) during the New Year's 2005 fireworks in Mainz, central Germany and found that main non-refractory components of the firework aerosol were potassium, sulfate, total organics and chloride. Wang et al. (2007) studied the effects of the burning of fireworks on air quality in Beijing from the ambient concentrations of various air pollutants (SO_2, NO_2, $PM_{2.5}$, PM_{10} and chemical components in the particles) during the lantern festival in 2006 reporting measured values

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as five times higher in the lantern days than in the normal days and also that over 90% of the total mineral aerosol and 98% of Pb, 43% of total carbon, 28% of Zn, 8% of NO_3^-, and 3% of SO_4^{2-} in $PM_{2.5}$ were from the emissions of fireworks on the lantern night.

Moreno et al. (2007) investigated aerosol samples collected during Las Fallas in Spain and during the Guy Fawkes celebrations in London, reported that the celebrations added to the pollution spikes in suspended particles, NO, SO_2, and the creation and dispersal of an aerosol cloud enriched in a range of metallic elements.

In India's perspective also, various researches and studies have been conducted in a bid to assess the deterioration in air quality caused by firework activities during Diwali festival and few of them are presented as below.

Khaparde et al. (2012) studied the influence of burning of fireworks on particle size distribution of PM_{10} and associated Barium in Nagpur city, India reporting an increase of 4 to 9 times in PM_{10} levels while an increase in Ba levels by 8 to 20 times higher in alveolar region, when compared with the levels observed before Diwali festival. Chatterjee et al. (2013) studied the diurnal variations in PM_{10} and SO_2 in metropolitan region of Kolkata, and reported that their maximum concentrations were on Diwali night between 8 P.M.–3 A.M., indicating maximum firework activities during this period. PM_{10} and SO_2 concentrations increased by ~5 times compared to those on normal days during this period at this site. Ravindra et al. (2003) investigated the effect of fireworks on air quality from the ambient concentrations of various air pollutants (SO_2, NO_2, PM_{10} and TSP) during Diwali festival in Hisar city, India, in November 1999 and reported that due to extensive use of fireworks during the festival, the concentration of SO_2 was observed to be increased ∼10-fold at few sites, whereas the concentrations of NO_2, PM_{10} and TSP increased 2–3 times, compared to the data collected on a typical winter day in December 1999.

Thakur et al. (2010) reported the pollutant concentrations as recorded during Diwali in Salkia, Kolkata, India, to be several times higher (6.44 times for SPM, 7.16 times for PM_{10}, 5.35 times for $PM_{2.5}$, 1.73 times for SO_2 and 1.27 times for NO_2) compared to a typical winter day value. The particulate concentrations on festival night exceeded its respective 24 hour residential standards by several times (11.6 times for SPM, 22.3 times for PM_{10}, and 34.3 times for $PM_{2.5}$).

Kulshrestha et al. (2004) studied high magnitude of concentration of metals on the day of Diwali festival (compared to background values on previous days) and reported that the concentrations of Ba, K, Al and Sr went up to 1091, 25, 18 and 15 times higher. Barman et al. (2008, 2009) while studying the effect of fireworks on ambient air quality during Diwali Festival in Lucknow City, covering PM_{10}, SO_2, NOx and 10 trace metals, reported 24 hrs. average concentration of these pollutants to be as high as 2.49 and 5.67 times for PM_{10}, 1.95 and 6.59 times for SO_2 and 1.79 and 2.69 for NOx, when compared with the respective concentration of Pre-Diwali and normal day, respectively. Also, on Diwali day, 24 hour values for PM_{10}, SO_2, and NOx were found to be higher than prescribed limits of National Ambient Air Quality Standard (NAAQS), and exceptionally high (7.53 times) for PM_{10}. Ganguly et al. (2009) and Attri et al. (2001) have reported effect of firework activities during Diwali on surface Ozone in Delhi. While former's study found normally observed surface ozone levels higher during Diwali and in excess of NAAQS values by 5.4 - 13.3 ppbv, the later presented the detailed process and source identification of formation of ozone due to cracker burning.

Similar to those on ambient air quality, there has been worldwide studies attempting human health effects of aerosols, trace gases, metals and other constituents of air pollution and are well documented to an extent that adversative health impact of PM_{10} are recognized by all leading health institutions and researchers (WHO, 2003).

Clark (1997) reported that owing to excessive firecracker burning during the Diwali festival in India, cases of respiratory diseases, wheezing, exacerbation of the bronchial asthma and bronchitis patients of all age and gender groups, amid a family's history of asthma or not, have seen rise of 30–40%. Hirai et al. (2000) reported a case wherein inhalation of smoke from fireworks for 3 consecutive nights, led to complaint of cough, fever and dyspnea in patients and ultimately an acute eosinophilic pneumonia (AEP).

Dockery et al. (2005) found statistically significant associations between air pollution and

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ventricular arrhythmias for episodes within 3 days of a previous arrhythmia.

Barnett et al. (2005) studied the strength of the association between outdoor air pollution and hospital admissions in children and reported that the largest association found was a 6.0% increase in asthma admissions (5-14 years) in relation to a 5.1 ppb increase in 24 hour NO_2, inter alia for $PM_{2.5}$ and PM_{10}, nephelometry and SO_2. Barman et al. (2008) reported that fireworks which induce short-lived but relatively substantial emission of trace elements were able to aggravate human health in terms of hematological and neurological effects on the recipients and while Pb, Cd & Ni were reported to give rise to carcinogenic effects, Cr was shown to be associated to neurotoxic problems.

Delhi, being national capital of India, gradually expanding towards neighboring states under the arena of NCR (National Capital Region) has witnessed an ever-seen rapid pace of industrialization and urbanization, high vehicular density plying on insufficient road space, with air quality over this region severely affected resulting in to heavy PM loadings in almost all its districts. The country's capital celebrates Diwali festival with great zeal along with rest of India. Massive quantities of crackers and sparklers both manufactured indigenously and imported from neighboring countries are burnt on almost 3 days, that is, day before (pre-Diwali day), on the festival (Diwali day) and even after (post-Diwali day) improvised by the mythological belief in this festival of lights and sound.

The available secondary data with respect to the measurement of effect of fire-cracker burning on aerosol and its components during Diwali festival in Delhi have been used to analyze the trends of air pollution from 2010 to 2015. Five of the criteria air pollutants namely aerosols (PM_{10} and $PM_{2.5}$), oxides of sulphur and nitrogen, ammonia and carbon monoxide were analyzed for the available data during Diwali night at six locations of the capital state (Figure 1 and 2) and the study attempted to assess the extra load on urban air quality due to Diwali festival over these locations, where air pollution is prevailing as a grave problem through-out the year.

2. Materials and methods:

2.1. Study area and general climatic feature

Delhi, situated between 28°21′17″ to 28°53′,00″ latitude and 76°20′37″ to 77°20′37″ longitude, is at around 160 km away in south from the southern part of Himalayas. The average altitude of Delhi is ~218 meter above mean sea level while is bounded by the Thar-Desert of Rajasthan in the West, plains of central India in the South and Indo-Gangetic Plains (IGP) in the East. The megacity extends over 1,483 km^2 with the present inhabitants of ~18 million. The study areas lie between 28.36° N–28.92° N and 76.82° E–77.41° E (Figure 2). The climate of Delhi is semi-arid and is mainly influenced by its inland position and prevalence of continental air during most of the year. India Meteorological Department (IMD), Delhi configures four distinct seasons, such as, winter (December–March), pre-monsoon or summer (April–June), monsoon (July–September) and post-monsoon (October–November). Summer is extremely hot, with maximum temperatures of 45–48 °C. Dust storms from nearby Thar Desert are influencing the weather of Delhi during summer (April–June). Humidity is high during monsoon, characterized by heavy rainfall (between 600 and 800 mm); while the air is dry during the rest of the year. Winter is moderately cold, with minimum temperatures around 1–4 °C. During winter, conditions of atmospheric stability (low wind speed and temperature inversion) lead to the accumulation of atmospheric pollutants in the lower atmospheric layer, causing morning hour foggy conditions. Winds are predominantly westerly and north-west

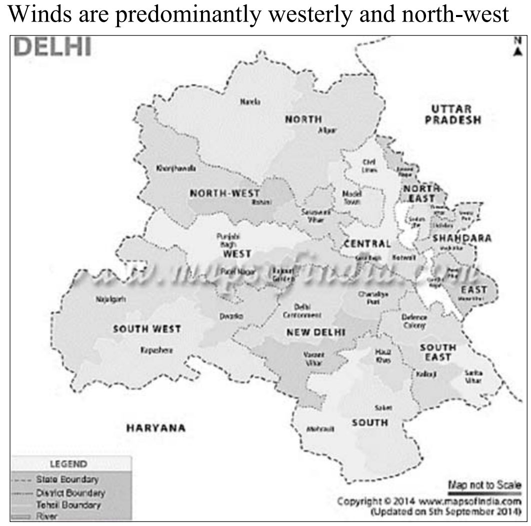

Figure 1. Geographical representation of district and sub-district's boundaries of Delhi.

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and north-west during most of the year, except for the monsoon season, when they are easterly and north-easterly. During such conditions, pollutants could not be dispersed or mix with free troposphere.

The six locations/stations for the current study in the mega city of Delhi were selected based on the different land-use patterns features which are presented in Table 1.

Figure 2. Geographical locations of study areas in map of Delhi.

According to the available data from the general and economic census of Delhi, the rapid pace of urbanization and growth of urban population, have led to the continuous decline in rural population and rural areas (from 0.95 million in 1991 to 0.42 million in 2011) with number of villages reduced from 209 in 1991 to 112 in 2011. Further, for the first time since 1951, the decadal growth rate of population of Delhi declined and was recorded at 21.2% in 2011 compared to 47.02% in 2001. However, the swift increase in population has raised density of population from 6352 persons per km^2 in 1991 to 11320 in 2011. District-wise population and enterprise employment status are presented in Table 2.

Delhi is the most prosperous state with highest per capita income in India with average per capita income remaining more than INR (Indian National Rupees) Rupees 0.2 million in two consecutive years i.e., 2013-14 and 2014-15. The gross state domestic
product (GSDP) of Delhi at current prices during 2014-15 is INR 451.154 billion, which recorded growth of 15.35% over previous year. Delhi's economy has a predominant service sector with its share of contribution to GSDP at 87.48% during 2014-15 followed by contribution of Industries and Agriculture sectors (DSH, 2015; ESD, 2014-15).

Table 1. Land use pattern of selected locations.

No	Location /Study Area	District	Land-use Pattern
1	Civil Lines	North Delhi	Residential
2	Anand Vihar (ISBT)	East Delhi	Mixed (Passenger circulation - Major Railway and Bus stations / District parks / Residential)
3	Mandir Marg	New Delhi	Proximity of southern and central ridge forest covers
4	RK Puram	South-west Delhi	Residential
5	IGI Airport	South-west Delhi	Mixed (Passenger circulation - Largest International Airport / Commercial districts)
6	Punjabi Bagh	West Delhi	Residential

Table 2. Population and enterprise employment status in different districts of Delhi.

No	District	Geo. Area (km^2)	Popl. (mill.)*	No. of Enterprises and Persons employed**
1	North Delhi	59	0.89	74875/ 31641
2	East Delhi	64	1.71	82329/ 218314
3	New Delhi	35	0.14	38498/ 273212
4	South-west Delhi	421	2.29	41953/ 100001
5	West Delhi	129	2.54	106524/ 305626

* *As per Census 2011;* ** *As per Economic census 2011(Geo.–Geographical;Popl.–Population;Mill Million)*

2.1 Data collection

Secondary data available for six years (from 2010 to 2015) on Diwali night for five air pollutants for the referred six locations of Delhi were collected from print and electronic media and used for further analysis. These published data can be accessed at http://epaperbeta.timesofindia.com/index.aspx?eid=31808&dt=20151113 which further showed it to have been sourced from the dedicated air quality monitoring stations belonging to various Indian government agencies like 1) DPCC (Delhi Pollution Control Committee; 2) MOES (Ministry of Earth Sciences) and 3) CPCB (Central Pollution Control Board). These stations do record 24 hours. X 365 days concentration data of different air pollutants covering almost the entire megacity of Delhi. This is to be mentioned here that the secondary data available for the years 2010 to 2015 refer to various dates of the Diwali festival i. e., 5th Nov. in 2010; 26th Oct. in 2011; 13th Nov. in 2012; 3rd Nov. in 2013; 23rd Oct. in 2014 and 11th Nov. in 2015 thus generally spanning between 15th Oct. and 15th Nov.

3. Result and discussion

The collected data were analyzed using MS-EXCEL programme and pollutant-specific graphs were plotted. The inferences were drawn in terms of the magnitude of the recorded concentration and compared with the corresponding 24 hrs. and 1 hr. values as prescribed in National Ambient Air Quality Standards (NAAQS). The analysis and results along with pollutant-wise graphs are presented as below:

3.1 PM_{10}

Figure 3 depicts PM_{10} concentration measured during festival night in six locations of Delhi which was recorded maximum at Anand Vihar at 777.8 µg/m^3 followed by other locations in descending order as RK Puram, Punjabi Bagh, Mandir Marg, Civil Lines and IGI Airport. A close look in to the data in view of corresponding 24 hrs. NAAQS value of PM_{10}, reveals that at all locations under investigation, pollutant exceeds the limit of 100 µg/m^3 as per NAAQS. A possible reason of minimum observed concentrations at IGI airport is due to attributable to the fact that this is an area with relatively less population density and restricted public movement whereas all other areas fall in category of highly dense residential areas. The presence of one of the largest inter-state bus terminal (ISBT) and railway terminus in the close proximity, together catering to about 400,000 passengers per day at Anand Vihar location signifies it as a major transport hub thereby contributing to a very high vehicular emission (from terminal buses, railway diesel locomotives and road traffic) leading to the highest value of PM_{10} recorded.

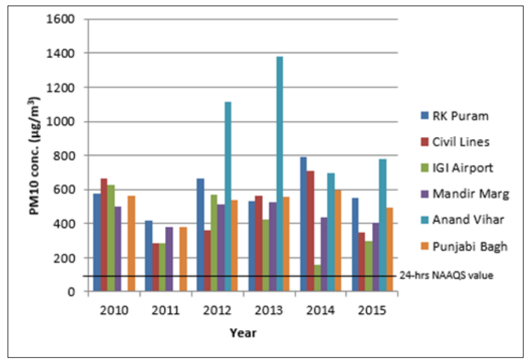

Figure 3. PM_{10} concentration data during Diwali in Delhi (2010:2015) sourced from print media (cross-referred from the monitoring stations of DPCC, MOES and CPCB).

It is also noted that a comparison of PM_{10} concentration at all six locations during previous years (2012:2014) reveals that there has been a decrease in it over the years although never below NAAQS values. The graph also presents that Anand Vihar recorded maximum ever concentration of PM_{10} in 2013 as 1378 µg/m^3 during the period 2010 :2015 whereas IGI Airport recorded a minimum ever concentration of 156.1 µg/m^3 in 2014.

3.2 $PM_{2.5}$

Figure 4 presents $PM_{2.5}$ concentration measured during festival night in six locations of Delhi which was reported maximum at RK Puram at 369.1 µg/m^3 followed by other locations in descending order as Punjabi Bagh, Anand Vihar, IGI Airport Mandir Marg and Civil Lines. It is evident that observed values of $PM_{2.5}$ at all six locations exceed the corresponding 24 hours. NAAQS value of this criteria pollutant which is prescribed as 80 µg/m^3 It is also noted that a comparison of $PM_{2.5}$

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concentration at all six locations during previous years (2010–2014) reveals mixed values as different locations exhibit different pattern, for e. g., RK Puram, Mandir Marg and Punjabi Bagh showed some improvement in levels of $PM_{2.5}$ in 2011, Civil Lines in 2013 whereas IGI Airport in 2014 reported lowest ever recorded values. The trend of $PM_{2.5}$ generally follows the trend of population density areas and existence of higher vehicle ownership and/or movement.

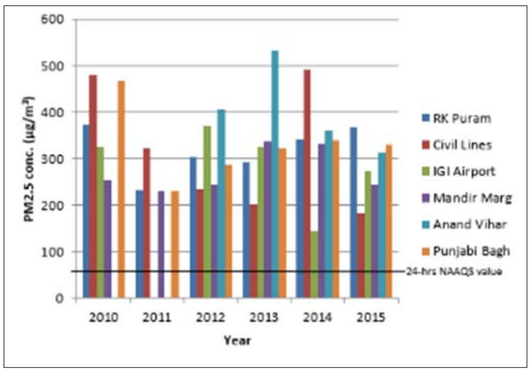


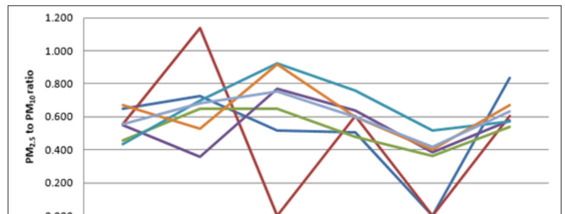
Figure 4. $PM_{2.5}$ concentration data during Diwali in Delhi (2010:2015) sourced from print media (cross-referred from the monitoring stations of DPCC, MOES and CPCB).

The $PM_{2.5}$ to PM_{10} ratios for all six locations have been presented in Figure 5 which reveals the significant proportion of the former in the ambient air quality recorded during festival nights from 2010 to 2015 and is found to vary from 0.35 to 0.92 barring only one erroneous data available as 1.11 for Civil Lines location in the year 2011 which might be a typo error. Also, the figures of 0.000 indicate non-availability of data for the particular location / year.

3.3 SO_2

Figure 6 depicts SO_2 concentration measured during festival night in six locations of Delhi which was recorded maximum at Anand Vihar at 64.2 µg/m^3 followed by other locations in descending order as R K Puram, Punjabi Bagh, Mandir Marg, Civil Lines and IGI Airport.

A close look in to the data in view of corresponding 24 hours. NAAQS value of SO_2 reveals that at none of the six locations under investigation, pollutant exceeds the limit of 80 µg/m^3. It is also noted that a comparison of SO_2 con-centration at all six locations during previous years (2010–2014) reveals that while for three locations, namely RK Puram, IGI Airport and Mandir Marg there has been a decrease in it over the years although never above NAAQS values, for other three locations, the data brings about that at least once or twice, the observed values do exceed the guideline values. While Anand Vihar recorded maximum ever concentration of SO_2 in 2012 as 117.3 µg/m^3, Mandir Marg recorded a minimum ever concentration of 8.3 µg/m^3 in 2014.



	RK Puram	Civil Lines	IGI Airport	Mandir Marg	Anand Vihar	Punjabi Bagh
2010	0.650	0.724	0.515	0.507	0.000	0.834
2011	0.553	1.137	0.000	0.605	0.000	0.604
2012	0.458	0.646	0.646	0.478	0.365	0.536
2013	0.549	0.358	0.770	0.638	0.387	0.578
2014	0.432	0.697	0.924	0.758	0.515	0.571
2015	0.668	0.526	0.917	0.600	0.403	0.671
Avg.	0.552	0.681	0.755	0.598	0.418	0.632

Figure 5. $PM_{2.5}$ to PM_{10} ratios for all six locations during Diwali festival in Delhi (2010:2015).

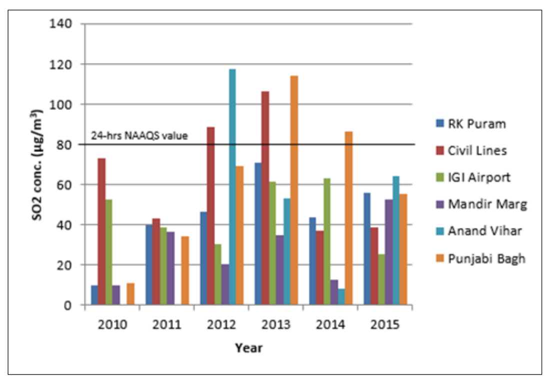


Figure 6. SO_2 concentration data during Diwali in Delhi (2010:2015) – sourced from print media (cross-referred from the monitoring stations of DPCC, MOES and CPCB).

The reason of higher SO_2 at Anand Vihar location can be understood from the presence of vehicular emission from ISBT, railway terminus and inter-state traffic whereas for IGI Airport, the low population density and restricted public movement helps. For remaining areas of study, relatively lesser but closer concentrations can be linked to lesser dense residential areas having distributed traffic.

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3.4 NO_2

The NO_2 concentration measured during festival night in six locations of Delhi which was reported maximum at RK Puram at 79 µg/m^3 followed by other locations in descending order as Punjabi Bagh, Anand Vihar, Civil Lines, IGI Airport and Mandir Marg (Figure 7).

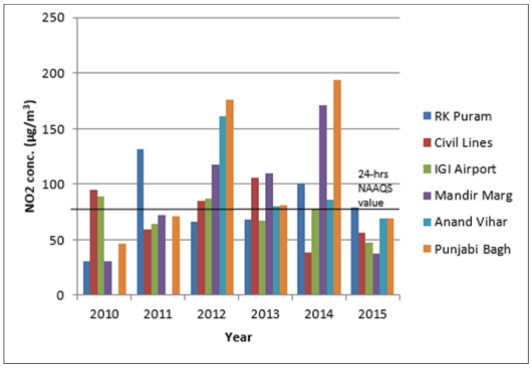

Figure 7. NO_2 concentration data during Diwali in Delhi (2010:2015) sourced from print media (cross-referred from the monitoring stations of DPCC, MOES and CPCB).

It is evident that observed values of NO_2 at all six locations in 2015 do not exceed the corresponding 24 hours. NAAQS value of this criteria pollutant which is prescribed as 80 µg/m^3. It is also noted that a comparison of NO_2 concentration at all six locations during previous years (2010–2014) in terms of values in excess of NAAQS reveals that in year 2011, RK Puram recorded maximum NO_2 concentration as 131.7 µg/m^3 whereas Civil Lines saw maximum observed value in year 2013 at 105.6 µg/m^3. Further, IGI Airport recorded maximum value of 89.3 µg/m^3 in the year 2010 and Mandir Marg observed 171.4 µg/m^3 in year 2014. While Punjabi Bagh recorded maximum observed value as 193.8 µg/m^3 in 2014, from the available data between 2012 to 2014, Anand Vihar observed 161.6 µg/m^{3}value in 2012.

3.4 CO

Figure 8 denotes CO concentration measured during festival night in six locations of Delhi which was recorded maximum at Civil Lines at 4 mg/m^3 followed by other locations in descending order as RK Puram, Anand Vihar, Punjabi Bagh, Mandir Marg, and IGI Airport. A close look in to the data in view of corresponding 1 hours. NAAQS value of CO reveals that at none of the six locations under investigation, pollutant exceeds the limit of 4 mg/m^3.

It is also noted that a comparison of CO concentration at all six locations during previous years (2013, 2014) reveals that, in fact, the maximum recorded values never exceed the NAAQS limits for any locations and there has been a gradual decrease in CO values as far as festival night is concerned, while for preceding years (2011 –2012) except two locations, i. e., RK Puram and Mandir Marg where the recorded values show violation of the limits at least once, the other locations have been fairly within the limits. While Civil Lines recorded maximum ever concentration of CO in 2010 as 9.5 mg/m^3, Mandir Marg recorded a minimum ever concentration of 0.6 mg/m^3 in the very same year.

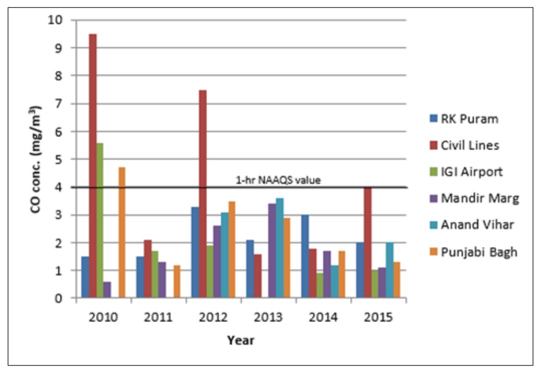

Figure 8. CO concentration data during Diwali in Delhi (2010:2015) – sourced from print media (cross-referred from the monitoring stations of DPCC, MOES and CPCB)

The improvement over the years can generally be seen in context of increased public awareness focusing on the harmful human and environmental effects of firecracker activities. This is further induced by campaigning by Government agencies, Non-governmental Organizations (NGOs) and to some extent by the Courts directing local administration to ensure compliance to its previous orders on control over public and off-late firecracker burning during the festival night.

3.5 NH_3

Figure 9 presents NH_3 concentration measured during festival night in six locations of Delhi which was reported maximum at Mandir Marg at 77.4 µg/m^3 followed by other locations in descending order as RK Puram, Anand Vihar, Punjabi Bagh, Civil Lines and IGI Airport.

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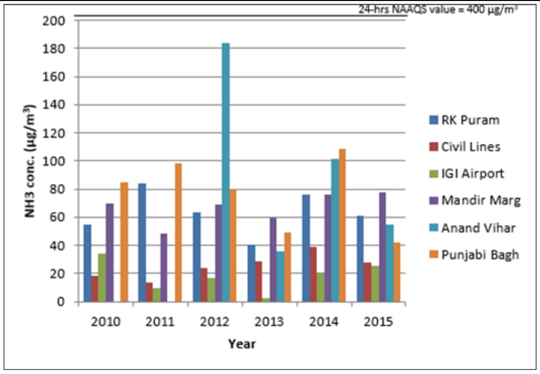

Figure 9. NH_3 concentration data during Diwali in Delhi (2010:2015) – sourced from print media (cross-referred from the monitoring stations of DPCC, MOES and CPCB).

A summary of observed minimum, maximum, average concentrations during the festival night over six years along with % increase vis-à-vis. NAAQS values for minimum observed value is presented in Table 3.

Table 3. Severity of air pollution during Diwali night in Delhi.

No	**Pollu.**	**Observed Conc. (2010-15)**			**% Incr. above AQS (for Min. conc.)**
		Avg.	**Max.**	**Min.**	
1	PM_{10}	549.6	1378.0 (Anand Vihar/ 2013)	156.1 (IGI Airport /2014)	56.1
2	$PM_{2.5}$	318.1	533.1 (Anand Vihar /2013)	144.3 (IGI Airport /2014)	80.4
3	SO_2	50.2	117.3 (Anand Vihar /2012)	8.3 Anand Vihar /2012)	-89.6
4	NO_2	85.9	193.8 (Punjabi Bagh /2014)	30.7 (Mandir Marg, RK Puram /2010)	-61.6
5	CO	2.6	9.5 (Civil Lines /2010)	0.6 (Mandir Marg /2010)	-85.0
6	NH_3	55.3	183.4 (Anand Vihar /2012)	2.7 (IGI Airport /2013)	-99.3

(Pollu.–Pollutant; Conc.–Concentration; Avg.–Average; Max.–Maximum; Min.–Minimum; Incr.–Increase; AQS – Air Quality Standards/NAAQS)

It is evident that observed values of NH_3 at all six locations under investigation in 2015 do not exceed the corresponding 24-hrs. NAAQS value of this air pollutant which is prescribed as 400 µg/m^3. It is also noted that a comparison of NH_3 concentration at all six locations during previous years (2010–2014) in terms of values in excess of NAAQS reveals that in years 2012 and 2014, Anand Vihar recorded maximum NH_3 concentrations as 183.4 and 101.5 µg/m^3 respectively while Punjabi Bagh saw maximum observed value in year 2014 at 108.2 µg/m^3 highlighting that no location under the study ever reported a value above NAAQS' 24-hrs. guideline. This trend is similar to that observed for CO and is understandable for similar reasons of improvement over the years.

4. Conclusion

The present investigation shows that the burning of firecrackers, sparkles etc. in huge amounts has a substantial impact on increase in the concentration of criteria air pollutants especially PM_{10} and $PM_{2.5}$ and that of trace gases (CO, SO_2, NO_2 and NH_3) components over all six study areas. Vehicular emission remains the most prominent source of air pollution at all the six locations undergone the study and second major one during the Diwali festival night. The most prominent source of criteria air pollutants are burning of various types of firecracker during the Diwali festival night throughout the city aggravating the concentration of pollutants in the ambient air already coming from exhaust emissions. Late evening mass entry of the inter-state diesel-driven heavy-duty vehicles in the city also contribute to elevated level of air pollution. In addition to the above-mentioned mobile sources, the dust sourced from the on-going construction activities such as road/flyover, metro

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rail track, station and various other buildings such as commercial, institutional, retail etc. prevailing in the study areas also contribute greatly to the air pollution levels. Importantly, burning of crackers and sparkles during Diwali festival also emit a huge amount of metals in the atmosphere (for e. g., Al is added to make the crackers more bright and colorful and to produce white flames and sparks; Zn is used in the crackers to create smoke effects; Fe, Cu, Co are used as coloring agents and to produce sparks; The oxides, nitrates and nitrites of some elements like Pb, Mn, Cd and V are used as the ready source of oxygen for the process of combustion of the firecrackers Chatterjee et al. (2013). However long-term data collection and analysis is required to exactly pinpoint sources of these elements in Delhi's atmosphere. A location-wise interpretation leads to a conclusion that PM_{10} and $PM_{2.5}$ are most affected by firework activities and the observed concentration during 2015 or the preceding years have been dangerously above the NAAQS values of 24-hrs. Though other trace gases reveal a rather mixed pattern over the years (2010-2015), sometimes reporting a decreased value and vice-versa as far as records of values exhibit during festival night. The prevailing short-term exposure of referred criteria pollutants and the associated remarkable surge in their concentrations during Diwali festival can not only present a threat to overall ambient urban air quality, but also can trigger severe human health effects.

This situation is further worsened by the un-favorable meteorological conditions (which are further intensified by presence of vehicular air pollutants throughout the day-night cycle in this megacity) during night-time when Diwali, the festival of light and sound attains peak celebration activities attributing to the accumulation of air pollutants near the earth surface till next day day-time. While, such persisting concentration of aerosols and trace gases has been reported in megacity of Delhi (with present study on trends during 2010-2015), the situation is most likely to be existing in other urban areas of the country. Therefore, in view of the above, it is need of the hour to adopt and ensure compliance of adequate and appropriate measures so as to not only reduce the excessive firework activities on festival nights, but also to control, as far as possible, the emission and subsequent dispersion of the pollutants.

References

Barman, S.C., Singh, R., Negi, M.P.S., & Bhargava, S.K. (2009). Fine Particles ($PM_{2.5}$) in Ambient Air of Lucknow City due to Fireworks on Diwali Festival. *Journal of Environmental Biology*, *30,* 625–632.

Kong, S.F., Li, L., Li, X.X., Yin, Y., Chen, K., Liu, D.T., … Ji, Y.Q. (2015). The impacts of firework burning at the Chinese Spring Festival on air quality: insights of tracers, source evolution and aging processes. *Atmospheric Chemistry and Physics*, *15,* 2167–2184.

Vecchi, R., Bernardoni, V., Cricchio, D., D'Alessandro, A., Fermo, P., Lucarelli, F., …Valli, G. (2008). The Impact of Fireworks on Airborne Particles. *Atmospheric Environments* , *42*, 1121–1132.

Drewnick, F., Hings, S.S., Curtius, J., Eerdekens, G. & Williams, J. (2006). Measurement of Fine Particulate and Gas-Phase Species during the New Year's Fireworks 2005 in Mainz, Germany. *Atmospheric Environments, 40,* 4316–4327.

Wang, Y., Zhuang, G., Xu, C. and An, Z. (2007). The Air Pollution Caused by the Burning of Fireworks during the Lantern Festival in Beijing, China. *Atmospheric Environments, 41,* 417–431.

Moreno, T., Querol, X., Alastuey, A., Minguillon, M.C., Pey, J., Rodriguez, S. et al. (2007). Recreational Atmospheric Pollution Episodes: Inhalable Metalliferous Particles from Firework Displays. *Atmospheric Environments ,41,* 913–922.

Khaparde, V. Pipalatkar, P., Pustode, T., Chalapati, Rao, C. V. & Gajghate, D. (2012). Influence of burning of fireworks on particle size distribution of PM_{10} and associated Barium at Nagpur. *Environmental Monitoring and Assessment, 184,* 903–911.

Chatterjee, A, Sarkar, C., Adak, A., Mukherjee, U., Ghosh, S.K. & Raha, S. (2013). Ambient Air Quality during Diwali Festival over Kolkata – A Mega-City in India. *Aerosol and Air Quality Research*, *13,* 1133–1144.

Ravindra, K., Mor, S. and Kaushik, C.P. (2003). Short-term Variation in Air Quality Associated with Firework Events: A Case Study. *Journal of Environmental Monitoring, 5,* 260–264.

Suan Sunandha Science and Technology Journal

Thakur, B., Chakraborty, S., Debsarkar, A., Chakraborty, S. & Srivastava, R.C. (2010). Air Pollution from Fireworks during Festival of Lights (Deepawali) in Howrah, India - A Case Study. *Atmosfera, 23,* 347–365.

Kulshrestha, U.C., NageswaraRao, T., Azhaguvel, S. & Kulshrestha, M.J. (2004). Emissions and Accumulation of Metals in the Atmosphere due to Crackers and Sparkles during Diwali Festival in India. *Atmospheric Environments, 38,* 4421–4425.

Barman, S.C., Singh, R., Negi, M.P.S. & Bhargava, S.K. (2008). Ambient Air Quality of Lucknow City (India) during Use of Fireworks on Diwali Festival. *Environmental Monitoring and Assessment, 137,* 495–504.

Barman, S.C., Singh, R., Negi, M.P.S. & Bhargava, S.K. (2008b). Fine Particles ($PM_{2.5}$) in Residential Areas of Lucknow City and Factors Influencing the Concentration. *Clean-Soil Air Water, 36,* 111–117.

Ganguly, N.D. (2009). Surface Ozone Pollution during the Festival of Diwali, New Delhi, India. *Earth Science (India), 2,* 224–229.

Attri, A.K., Kumar, U. and Jain, V.K. (2001). Formation of Ozone by Fireworks. *Nature*, 411: 1015.

WHO. (2003). *Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide,* Available on WHO website, Bonn, Germany.

Clark, H. (1997). Air Pollution from Fireworks. *Atmospheric Environments, 31,* 2893–2894.

Hirai, K., Yamazaki, Y., Okada, K., Furuta, S. & Kubo, K. (2000). Acute Eosinophilic Pneumonia Associated with Smoke from Fireworks. *Internal Medicine (Japan)*, *39*,401–403.

Dockery, D.W., Luttnabb-Gibson, H., Rich, D.Q., Link, M.L., Mittleman M.A., Gold, D.R., …Verrier R.L. (2005). Association of Air Pollution with Increased Incidence of Ventricular Tachyarrythmias Recorded by Implanted Cardioverter Defibrillators. *Environ Health Perspect., 113,* 670–674.

Barnett, A.G., Williams, G.M., Schwartz, J., Nekker, A.H., Best, T.L., Petriescgevsjt, A.L. et al. (2005). Air Pollution and Child Respiratory Health: A Case-Crossover Study in Australia and New Zealand. *American Journal of Respiratory and Critical Care Medicine, 171,* 1272–1278.

Delhi Statistical Handbook. (2015). Directorate of Economics & Statistics. Govt. of NCT of Delhi.

Economic Survey of Delhi. (2015). Planning Department. Govt. of NCT of Delhi. Retrieved 15th December 2015, 4:00 pm. http://www.delh.gov.in/wps/wcm/connect/Doeconomic+survey+of+dehli/economic+urvey+of+delhi+2014+-+2015.