Insight into festival ushered pollutants in Indian metro cities: concerns, differences and similarities

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Abstract

Multi-fold increase in particulate matter (PM) and trace gases in connection with celebrations associated with firework displays is a matter of concern all over the world. The current study, commenced as an assessment of pollutant escalation due to the key Indian festival event through observations online and cumulative sampling along with chemical speciation of particulates and trace gases over four SAFAR networked mega and metro cities of India viz. Delhi, Ahmedabad, Mumbai and Pune. It is seen that the amplitude and duration of the event is largely dependent on the attitude and culture of the inhabitants of each city; PM_{2.5} and PM₁₀ in Delhi are observed to increase by 353% and 213% respectively. In Pune and Ahmedabad, enhancement in PM_{2.5} is half of that of Delhi while the effect in Mumbai is just 1/7th of Pune, where variation is atypical to other cities. The enhanced pollution levels may lead to chronic or acute health emergency if they persist for long hours under unfavourable weather conditions. Metal content (K, Mg, Na, Mn and Pb) in PM_{2.5} has nearly doubled in all the cities; huge increase in pulmonary range particulates and the steep elevation in their heavy metal content is a matter of concern due to their toxicity and acute health effects. Trace gases, NO_x and CO which are also a health worry indicate a continuing increase due to the festival episode that happened in a non-conductive weather.

Highlights

- Escalation in particulates and gases assessed concurrently in 4 cities through multi-station network
- Event induced enhancement levels as well as time of peak in particulate is city specific.
- Online and gravimetric samplings are compared for the first time and they agree well.
- Sustained increase in K content at least from PD to 3 days post DD in all cities cites recurrent sub events
- During and post event elevation in gases of major health concern

Introduction

Diwali is celebrated all over India on various scales depending on the local cultures and precedence and for many areas it is a five day event in which bursting crackers could be a small part on any day. However, in the night of the 'Laxmi Pooja' day it is at its peak going on for 2–3 hours. The concern related to health effects on account of fire displays has started since long (Bach et al. 1975), while the atmosphere gets more and more stable, concentration of pollutants also increase (eg. Murthy et al., 2019; Tecer et al., 2008; Tiwari et al., 2014). Parkhi et al., 2016 attribute the sharp differences between two Diwali periods to atmospheric stability and other meteorological variables. However, the inter-annual range of the difference presented in their study in the particulates is difficult to be explained only in terms of meteorology. AP (attributable-risk proportion) is a concept mooted by the World Meteorological Organization (WMO) which says about the health effects due to pollutant inhalation that gets worse with spike in pollution. Methodology to calculate AP is done by Douwes et al., (2002); Rothman and Greenland (2008). Xing et al., (2016) presented a detailed review of the particulate matter in the size less than 2.5 µm which can penetrate deep into the lungs and cause lung diseases, advocating population to restrict exposure to PM_{2.5} and exhorting authorities to create a health index relating to the same.

Adverse health effects like lung disease, neurological and haematological disease are attributed to sudden spike in air pollution due to fireworks which has been getting some serious attention since Hirai et al., (2000) and still is not fully understood for various reasons (Greven et al., 2019). Beig et al., (2013) evaluated Diwali related health effects using AP method to find that 'relative risk (RR)' is more associated with the smaller, PM_{2.5} range particulates. There are many studies (Ghei and Sane 2018; Mukherjee et al. 2018) that dealt with quantification of pollution enhancement due to fire crackers on Diwali day and their health impacts due to increase in airborne microflora (Udaya Prakash et al. 2019).

The concern in India about increase in air pollution during Diwali festival gave rise to a court appeal for court to intervene in controlling the fireworks by law in 2018, in response to which a direction was given in the mode of use of green crackers with a prescribed time frame instead of blanket ban all over the country. They release water vapour and don't allow the dust particles to rise. They are designed to have 30% less particulate matter pollution. They also have a small shell size compared to traditional crackers and are produced using less harmful raw materials. The court held that though there were many studies (Barman et al. 2008; Gautam et al. 2018; Ambade 2018; Singh et al. 2019) in India, there was not enough proof to have a complete ban of fireworks as it is short-lived.

Based on continuous AQMS (Air Quality Monitoring Station) and specific field sample collection (campaign) at four locations under SAFAR network; the study describes how the nature and timing of Diwali celebrations are different in each metropolis. Chemical characterization of the same is done to see the incremental increase in metals, carbonaceous matter and trace gas variations are also

looked into. An effort is also made to look into any characteristic signature for each locality in Diwali celebrations, along with meteorological background. Spatial distribution of anomalous change in PM_{2.5} due to Diwali is studied to know the hot spot localities in each city. Finally, unlike the earlier work the time taken for the Diwali-induced pollution to retract to the pre-Diwali levels at each station is assessed. Possible control measures, suggestions, and the importance of considering the dispersive capacity of the atmosphere are also presented.

Materials And Methods

2.1 Study Area

In this campaign, the study area includes four Metropolitan cities which are Delhi, Pune, Mumbai and Ahmedabad (Figure 1). The System of Air Quality and Weather Forecasting and Research (SAFAR, www.safar.tropmet.res.in) networks were established at these four cities for better air quality forecasting during the period from 2010-2017. Delhi, capital of India, with a current domain of 65 x 70 sq km for the SAFAR network (NCR region) is situated in northern India at an elevation of 216 m above sea level. Pune at 559 m AMSL, ~100 km from west coast of India has a network domain of 50x 50 km which is a fast-growing urban city that includes Pune as well as industrial twin city Pimpri-Chinchwad. Coastal SAFAR network city, Mumbai at 14 m AMSL is the most populous city and has a domain of 35 x 35 km. The fourth city where SAFAR network is established is Ahmedabad in a domain of 30 x 35 km which covers Ahmedabad, Gandhinagar city area and surrounding villages.

Among the SAFAR monitoring network stations in each city the station with considerable residential activity was chosen for filter collection sampling through Low volume sampler so that we get good chemical representation of firework episodes. Malad in Mumbai has a population of 9.3 lakhs whereas Noida in NCR Delhi is with 6.3 lakhs Chandkheda in Ahmedabad and Hadapsar in Pune is about 1 lakh as per the 2011 census are the sampling stations chosen for the special campaign during Diwali.

2.2 Instrumentation

2.2.1 SAFAR networked AQMS

These Air Quality Monitoring Stations, AQMS are equipped with measurements of PM₁₀, PM_{2.5}, NO_x, O₃, CO, VOCx (BTEX) along with meteorological parameters. Instrument details, techniques and correction methods are available in Beig et al., (2013); Kaushar et al., (2013) and also in ("<http://safar.tropmet.res.in>,")

2.2.2 Low volume sampler (LVS)

The newly acquired low volume (16.7 litres per minute, LPM) samplers, model APM 550 (Envirotech, India make with US-EPA equivalent inlet) were used for the Diwali campaign to collect PM_{2.5} with an accuracy better than 2µgm⁻³ similar to the one used by (Perrino et al. 2011). The sampling period was fixed as 10AM to next day 10AM using quartz fiber filter of 47mm with a loss about 15 minutes for the filter changing and other regular checks. The sample collection period was fixed from 03/11/2018 to 12/11/2018 with 7th November as the Diwali day. Decision to sample only PM_{2.5} is based on the RR finding based on Beig et al., 2013.

The sampler was leak checked every day and other regular maintenance were rigorously done. Pre-treated, baked at 900°C for 4hours and pre-weighed 47mm quartz paper filter (Pall make) was used for sample collection. After collection of PM_{2.5} each filter was packed back in its respective petri-dish and sent to Pune for chemical analysis. Filters were post weighed for gravimetric determination of PM_{2.5} using ultra-accurate microbalance; model CPA26P, Sartorius make with an accuracy of 1µg after acclimatizing them to the room temperature in a temperature-controlled condition. Post gravimetric determination, the filter is used for various chemical analyses.

2.2.3 Atomic Absorption Spectrometer (AAS)

AAS works on the principle that liquid sample when atomized in an atomizer; the free atoms in the gas phase absorb its characteristic wavelength which aids the detection of the element. The absorption path length as per the Beer-Lambert's law is proportional to its concentration. This gives the method excellent specificity and detection limit. High Resolution - Continuum Source AAS, model ContraAA-800D (Analytik Jena, Germany make) uses flame technique with C₂H₂/air to achieve 2100-2300°C, and C₂H₂/N₂O for 2600-2900°C for concentrations expected above 25ppb and graphite technique with graphite tubes to detect concentrations further lower. Ca, K, Mg, Fe, Zn available in higher quantities were analyzed by flame technique while Cu, Cr, Cd, Ni, Mn, Pb were analyzed by graphite technique.

Quartz filter samples (3 punches each of 0.5 cm²) were mixed with 3 ml of HNO₃, 2 ml of HCl and 6 drops of HF and then topped with de-ionized water to make 25 ml sample. This was microwaved (Analytik Jena topwave) digested under high pressure (50 bar) and temperature (200⁰C) for an hour for complete dissolution of analyte in solvent. This uniformly mixed solution was used for analysis. Calibration standards are obtained from ISO guide 34 accredited company and is traceable to NIST SRM 3131a. Blank filters with the same digestion procedure were analyzed to eliminate matrix effect of quartz filter. Recovery of 100±10% from standard and relative standard deviation of <10% among sample duplicates was ensured.

The samples are analyzed through EC-OC analyzer as explained in (Ali et al. 2015) to derive OC (organic carbon) and EC (elemental carbon).

2.2.4 Data analysis

The data is processed from the AQMS for PM2.5/10, NOx, Ozone, CO, BTX, NH₃ and surface meteorological parameters depending on the availability at 15 minutes interval and used as hourly averages. Further, the ARC-GIS software is used for IDW overlay for obtaining area averaged plots for finding city scenario and marking of hot spots using the networked data. LVS and online data at a specific location are compared for 24 h duration (10 am to next day 10 am). Generally daily averages for online samplers are averaged starting from 12am to 11pm; however in this study 10am to 10am time period is used. LVS sampled filters are chemically analyzed for OC/EC analyzer, AAS and ion chromatography analysis (m/s Metrohm make). However, only AAS analysis results are presented here. To assess meteorological/dispersion effect meteorological parameters along with Ventilation Coefficient (V) derived from radiosonde flights were made use of at all stations. VC is calculated as the product of mixed layer height and mean wind in that layer; derived from the Wyoming University Radiosonde data ([CSL STYLE ERROR: reference with no printed form.]) for each city. Due to some synoptic system, Pune had rains during this period. Hence VC cannot be deciphered for some days and hence not included in the analysis.

Table 1: Details of time of maximum in particulates during pre-Diwali day (PD) and Diwali day (DD) and the factor of enhancement

City	PM10 (max concentration)				PM2.5(max concentration)			
	Factor Change	difference	time		Factor Change	difference	time	
			pre Diwali	Diwali			pre Diwali	Diwali
Delhi	3.1	1624	5:00 AM	7:00 AM	4.5	1356	5:00 AM	6:00 AM
Pune	2.4	417	12:00 AM	12:00 AM	2.7	310	12:00 AM	12:00 AM
Mumbai	1.2	114	12:00 AM	2:00 AM	1.3	100	12:00 AM	1:00 AM
Ahmedabad	2.5	1407	2:00 AM	2:00 AM	2.7	746	2:00 AM	2:00 AM

Results And Discussion

3.1 Particulate matter - Physical

The specific increase on Diwali day is the highest over Delhi and the lowest in Mumbai while Ahmedabad and Pune are in the second and third place after Delhi (Fig. 2). The time and magnitude of peak indicate the trend of activities at each location (Table 1). The difference in daily maxima between pre-Diwali day (PD) and Diwali day (DD) in Delhi for PM10 is 1624 µgm⁻³ and for PM2.5, it is 1356 µgm⁻³. In Mumbai the daily maxima difference for PM10 and PM2.5 are 114 µgm⁻³ and 100 µgm⁻³ respectively.

Time of peak for PM2.5 changed from PD to DD in Delhi, from 5 am to 6 am; for Mumbai, 12 to 1 am; the peaks for Ahmedabad at 2 am and for Pune at 12 am remained the same; PM10 peak in Mumbai and Delhi occurred an hour later than PM2.5 which may be due to fireworks continuing late or fireworks types that emit bigger sizes or due to growth of particle size as well. The percentage increase at Delhi was 353% for PM2.5 and 213% for PM10. In the absence of other weather systems, the entire additional particulates emitted may be related to Diwali episode. In this study PM2.5 is elaborated more as its sub-index always decided AQI and also as this portion of PM is particularly detrimental to health. Pune and Ahmedabad experienced about 1.7 times amplification in PM2.5 which was less than half times of Delhi. Diwali effect in Mumbai is just 1/7th of that in Pune. The inset figures in Fig. 2 indicate the daily averages (10am to 10am) of PM10 and PM2.5 for the study period at the four locations. It is observed that the concentration shows a significant peak on the DD at all locations except Mumbai. The concentration is highest at Delhi, followed by Ahmedabad, Pune and the least at Mumbai.

An anomaly area-averaged map is prepared as explained in Sect. 2.2.4 using ARC-GIS software to have a total picture of PM_{2.5} surge of each city caused by DD activities and to note probable hotspots under the assumption that all other sources remain unchanged from PD to DD. As illustrated in Fig. 1, central Delhi looks the most polluted. In the case of inter-city comparison, Delhi's south-south-west area exhibited the lowest increase but this is comparable with the most polluted areas of Mumbai in magnitude. Ahmedabad-Gandhinagar stations stands second in particulate density with cleaner Gandhinagar and most polluted south-south-east area. Pune comes third with its south to east quadrant most polluted as it constitutes interstate transport hub and fast developing residential and industrial zone. The only coastal station, Mumbai is least polluted in terms of enhanced PM_{2.5} during DD. A cohort study was conducted by CPCB in collaboration with medical professionals(CPCB 2019) over the residential areas which coincides with the intensely polluted areas depicted in our anomaly figure (Fig. 1). CPCB had found in their study that cough has increased from 6.7–28.9% (Daga et al., 2019) and post-Diwali hospital admissions surged by 50% due to cardiac, stroke, respiratory and burns.

Figure 3 depicts the variations of PM_{2.5} of individual AQMS stations in each SAFAR networked cities. A distinct peak on Diwali day is observed in all three cities except in Mumbai where distributed or multiple peaks are observed. In Delhi the peaks range from about 200 $\mu\text{g m}^{-3}$ at Ayanagar (IMDA), which is more of rural area, to 1100 $\mu\text{g m}^{-3}$ at Delhi University (DU) which is a major residential location.

Only the station NISE-G shows an increase on the next day of Diwali, as it is a remote location the increase is apparently related to the transport of pollutants from other areas. At Ahmedabad which is second highest in the averaged PM_{2.5} concentration on DD, Rakhial station tops with 353 $\mu\text{g m}^{-3}$ and Gift city the least, 89 $\mu\text{g m}^{-3}$. Unlike other cities, in Ahmedabad most of the stations show peak values in close range. Pune comes third with station Pashan having PM_{2.5} at 67 $\mu\text{g m}^{-3}$ and Hadapsar at 257 $\mu\text{g m}^{-3}$ as Diwali day peaks which are minimum and maximum respectively in the range. 50% of the stations in the lower end are overlapping and other 50% with higher values are with significant spread. Mumbai is anomalous with different pattern for Diwali episode; some stations show a peak on 6 November coinciding with southern Indian Deepavali, while another 4 stations show significant peak on 7th itself. However, a secondary smaller peak on 9th is more common among all stations. This seems to be more correlated with people going out of station after Diwali or returning altogether after Diwali and thus the emissions related to the transport activity contribute to the peak in concentrations. Customarily some groups of business people celebrate with firework after Diwali not on the "Laxmi Pooja" day as they expect some business on that auspicious occasion, thus Diwali related firework emissions are not really single day event as further emissions are added post the main day as well. The lower increment in the concentration of PM_{2.5} at Mumbai as compared to other cities is can be mainly attributed to the action of the cleansing land-sea breeze Moreover, many Mumbaites prefer to leave the city on holidays to celebrate festivals elsewhere, thereby not adding up to the anthropogenic load during the festival time.

Previous Diwali related studies over Delhi denotes a lot of variability in PM concentrations, from 400 to more than 2500 $\mu\text{g m}^{-3}$ (Tiware et al., 2012, Yerramsetti et al., 2013, Mandal et al., 2012). Tiware et al., 2014, attributes the inter-annual variability of about 100% merely in terms of mixing height and fractional change in wind speed. Parkhi et al. (2016) attributes the sharp differences in particulates during Diwali period of consecutive years to the difference in mixing layer heights prevailed in the consecutive years of 2010 and 2011 while in 2011 'Diwali' effect seems to be absent. The current study, average of PM₁₀ over ten SAFAR stations in NCR matches with PM₁₀ values of 2010 detailed in (Beig et al. 2013) in Delhi. Mixing layer height (MLH) measurement at Delhi indicates that the rise in PM during 4th and 5th is apparently due to very shallow MLH. Dispersion effects on PM_{2.5} are detailed later.

3.2 Particulate Matter - Chemical Analysis

As detailed in Sect. 2.2.2 low volume samplers (LVS) are used for collecting PM_{2.5} particulates in pre-baked and weighed quartz filters for gravimetric determination as the difference between pre-weight and post-weight. Flow rate is fixed at 1 $\text{m}^3 \text{hr}^{-1}$ while the concentration in $\mu\text{g m}^{-3}$ is obtained. In all four cities, LVS was placed at one of the SAFAR stations that represent the residential area for comparison by gravimetric analysis. Figure 4a shows the association between filter and AQMS (online) based PM_{2.5} quantification for the station where filter sampling is done. Technically, the LVS sampler considers the aerodynamic diameter for deciphering PM_{2.5}. It is susceptible to errors due to increased humidity for the continuous measurements (optical detection) and to avoid that sucked air volume is heated at the inlet stage to control humidity. Though there could be a mismatch both the observations compared well except in Mumbai where increased humidity post-Diwali might have played a role. PM_{2.5} observations reveal that DD value of the station where filter sampling is done exceeded the monthly averaged value of the city by about 150% which implies that choice of station is proper for the study of Diwali impact. On specific comparison among cities, gravimetric and continuous observations are in tandem in Mumbai on DD, at Delhi gravimetric value is slightly less whereas in Pune and Ahmedabad it exceeds the continuous data.

Vecchi et al., (2008) monitored hourly EC, OC during fireworks at Milan, Italy and found that during peak hours both EC and OC rise noticeably. The filter samples of the present campaign are processed to derive organic and elemental carbon content. Our observations show that OC is elevated on DD for all stations though such a pattern is absent for EC. Liu et al., (2004) reports a clear change in OC-EC ratio in connection with spring festival fireworks in China but in this study OC-EC ratio that is in the 1–3 range with no systematic variation (Fig. 4b). This may be indicating a non-generalized nature of firecrackers and their use, emitting particulates differently (Betha and Balasubramanian, 2013).

Particulates emitted due to firework are rich in elemental fraction since many a times heavy metals are used as colorants. The metal content from the filter samples are derived as detailed in Sect. 2.2.4. We analyzed Ca, K, Mg, Fe, Zn through flame technique and Cu, Cr, Cd, Ni, Mn, Pb by graphite technique; the number of metals is restricted by the present availability of standards present. Figure 5 represents the time series of the total concentration of metals together with individual concentration of each metal in stack format for the Diwali campaign period.

The envelope line of the stack illustrates the temporal variation of total metal contribution in PM2.5. On DD total metals contribution rises and its range is 9–23% while on PD the total metal content is equal to or less than 5% at all stations. These increments are similar to that reported by (Chatterjee et al. 2013)) which is a study of fireworks over Kolkata. Delhi witnesses an anomalous increase in other elements post Diwali though other stations generally indicate a decreasing trend; metal content variation at Delhi requires more detailed analysis. While, for Delhi, Ahmedabad and Mumbai, K remains higher than usual on post-Diwali day, Pune has high content of K on PD as well as post Diwali day probably signature of locality and pattern of cracker usage. There are intermittent increases of Ca in this period, at Ahmedabad, Mumbai and small rise at Pune is seen as a possible effect of transport from North West as seen through back trajectories (not shown) and a local wind speed increase is also noticed. Total percentage of analyzed metals in PM2.5 is the highest in Mumbai and lowest in Delhi.

An increase in 'K', a pointer to biomass burning is also a marker for fireworks (Kumar et al., 2016). A similar variation in Delhi on 5th and 10th are also seen which looks similar to the spurt in vehicular traffic with more increase in Pb and Mn and other crustal elements. Evident from elemental variations, it appears that large amount of firework is absent other than DD though in the entire week some scattered ones may be occurring. Potassium (K) is used as an excellent marker of firework as the gun powder, a popular oxidizer has huge contents of potassium nitrates.

Table 2
Concentration of Elements on Pre-Diwali and Diwali day in PM2.5; first 6 rows show increase in all stations, next 3 except single station and the last three, non-systematic. Below LOD is replaced by a constant value less than LOD for that particular element just to get a factor

Elements	Pune			Delhi			Ahmedabad			Mumbai		
	Pre Diwali	Diwali	Factor Change	Pre Diwali	Diwali	Factor Change	Pre Diwali	Diwali	Factor Change	Pre Diwali	Diwali	Factor Change
K	2.89	35.58	12.3	4.2	55.104	13.0	5.081	77.937	15.3	2.89	21.932	7.6
Mg	0.19	2.993	16.0	0.2	5.533	27.7	0.269	2.684	10.0	0.313	0.93	3.0
Mn	0.03	0.094	3.2	0.02	0.23	9.6	0.01	0.064	6.4	0.03	0.037	1.2
Na	0.20	1.25	6.3	0.714	2.617	3.7	0.2	1.089	5.4	0.321	0.957	3.0
Pb	0.17	1.087	6.5	0.175	1.767	10.1	0.076	0.338	4.4	0.02	0.042	2.1
Ca	0.40	8.224	20.6	0.4	6.595	16.5	0.4	0.4	1.0	0.591	0.762	1.3
Cu	0.03	0.141	4.1	0.005	0.389	77.8	0.008	0.008	1.0	0.006	0.064	10.7
Fe	0.08	0.352	4.4	0.376	1.875	5.0	0.471	0.833	1.8	0.04	0.04	1.0
Zn	0.40	0.434	1.1	0.331	2.214	6.7	0.271	0.452	1.7	0.459	0.42	0.9
Cd	0.004	0.004	1.0	0.005	0.014	2.8	0.004	0.005	1.3	0.013	0.042	3.2
Cr	0.02	0.013	0.8	0.009	0.03	3.3	0.004	0.01	2.5	0.019	0.022	1.2
Ni	0.03	0.012	0.4	0.008	0.038	4.8	0.008	0.008	1.0	0.048	0.034	0.7

Vecchi et al., (2008) reported an increase of Sr, Mg, Ba, K and Cu by 121, 22, 12, 11 and 6 times respectively over an hour's period during a firework episode over Italy. 90% of PM_{2.5}, 98% of Pb, 43% of total carbon, 28% of Zn are sole firework contribution as calculated by Wang et al., (2007) over the 'Lantern Night' festival. Over Lucknow, Barman et al., 2008 reported an increase of Cu, Ni, Chromium(Cr), Zn and Cadmium(Cd). Kumar et al., (2016) identified S, K, Ba and Mn during firework days which were absent on normal days, over Varanasi.

Table 2 provides the details of all elements analyzed and their variation from PD to DD. Ca, K, Mg, Mn, Na and Pb shows significant increase in all stations from PD to DD. Many studies have reported Lead (Pb), Manganese(Mn), Copper(Cu), Barium(Ba), Strontium(Sr), Iron(Fe), Nickel(Ni), Magnesium(Mg), Zinc (Zn) etc as the metals found in chemical analyses (eg. Vecchi et al., 2008, Moreno et al., 2007, Liu et al., 2016, Li et al., 2017, Liu et al., 2019). The increase in Mg that is used to produce very bright white is most high in Delhi with 27.7 times followed by Pune with 16.6 times while in the case of Ca, used as Calcium Chloride to produce a hue of Orange the increments are in reverse. Rise in Cu content in Delhi that gives the blue color is extraordinary in Delhi with 77.8 times increase while Mumbai is placed behind it with only 10.7 times. Increase in Pb also reached double digit in Delhi with a 10 times enhancement. These variations in elemental composition may be indicating a preference towards certain type of firework of public or a common supplier. In addition, Fe and Zn also increase significantly over Delhi, Pune and Ahmedabad. Cd, Cr, Cu and Ni did not exhibit a common variation.

The metals which reported an increase in all stations; Mn dust and fumes could result in metal fume fever or skin bubbles or gangrene and the poisoning slowly damages the central nervous system (Greenberg and Vearrier 2015). Mg fumes or dust causes toxicity that could result in lung function changes (Jaishankar et al. 2014). The increased heavy metal Pb in the form of fumes emitted during firework can cause mental retardation and semi-permanent brain damage in children of young age (Naranjo et al. 2020) including unexplained infertility in males (Benoff et al. 2000). The other heavy metal Cu fumes irritates respiratory track and repeated exposure to the same initiates "Wilson's disease" through layered deposition on multiple organs (Pujol et al. 2016). Ions though are not analyzed in this study the excesses of them associated with the firework episodes cause various respiratory illness, allergies, vomiting and so on.

Ion analyses are done for a spectrum of ions like NO₃⁻, NH₄⁺, SO₄⁻, Cl⁻ and so on. The ions NO₃⁻, NH₄⁺ and SO₄⁻ showed significant increase on Diwali and post Diwali days. However the plots are not presented here for the non-uniform data gap among stations.

3.3 Effect On Specified Gas Concentrations

Trace gases, CO, NO_x (NO + NO₂), and O₃ are also observed in SAFAR network and an abundance of the same is deterministic of secondary aerosol formation and also as an adverse health effect. Sulfur, Nitrates etc. are the chemicals used in crackers and burning of it generates oxides of sulphur and nitrogen along with carbon. Hence the trace gases are also important in terms of direct pollution or as medium aiding secondary aerosol, fog formation etc. Many studies related to Diwali also detail the trace gas variations and reported significant increments in connection with firework activity, (Attri et al. 2001; Ravindra et al. 2003). Figure 6 illustrates the variations of NO_x, CO, O₃ and NH₃ during the campaign period for all the 4 cities. NO_x and CO are precursors of O₃, and O₃ is formed due to photochemical reactions between them in the presence of sunlight (Yerramsetti et al., 2013, Gunthe et al., 2016). The diurnal pattern for NO_x indicates bimodal peaks at all the locations. The NO_x concentration at Delhi shows high concentration (~ 117 to 172 ppb) on the post Diwali day between 12 am to 8 am. At Pune a slight increase in concentration is observed on DD as compared to the previous days. In Mumbai the NO_x concentration shows an increase from the night of 7th Nov and further peaks on 10th Nov. There is no significant change in NO_x concentration at Ahmedabad even after Diwali period. A significant change in CO with about 1ppm is seen only over Delhi which is followed by Mumbai and Pune with no change in Ahmedabad. When we observe the O₃, CO and NO_x diurnal pattern inverse correlation is observed between them as the latter two are precursors of O₃.

The particulate overload at Delhi should have resulted in considerable radiation cut-off that led to lower ozone generation while in Pune the rains cleared air to some extent not to curb radiation and at Mumbai increase in particulate itself was minimal but availability of precursors rose

somewhat helping build up of ozone. Source of NO and CO are oxides produced due to high temperature combustion as in internal combustion engine during an intense firework. In Pune, Mumbai and Delhi a considerable increase in the concentration of O₃ is observed after DD, however in Ahmedabad it remains in the same range as before Diwali. NH₃ measurements were available only at 3 cities and

hence the same is shown in Fig. 6. It is observed that after DD there is a considerable increase in the NH₃ concentration at the three locations.

NO₂ generated during this event in escalated levels directly penetrate the smaller airways being less soluble and cause damage to the lining thus impairing smooth oxygen transfer process. Similarly higher levels of O₃ creates various health issues (Lippmann 1989) affects plants too. Increased amount of CO blocks the oxygen exchange in red blood cells reaching up to the cellular level. (CPCB 2019)

Concentrations of O₃, PM_{2.5} and PM₁₀ of Delhi are comparable to the results of (Song et al., 2017) over Jinan, China in connection with their Spring festival, however CO concentrations are only upto 50% of their reports. It is clear that the trends in gases are not in tandem with particulates, presenting more consistent variations in response to Diwali firework episode but having more complex contributing factors like different activities, easier transport or meteorology.

3.4 Meteorology During Diwali Period

Figure 6 depicts the meteorological parameters during the Diwali period. The daily temperature, Relative Humidity (RH), wind speed (WS) and the Ventilation Coefficient (VC) for the period 3–12 Nov is shown in this figure. The Ventilation coefficient (VC) which is the product of mean wind (in mixing layer) and mixing layer height is considered as a measure of dispersive capacity of atmosphere. VC is consistently higher for Ahmedabad. Over Delhi VC is about 3000 m² s⁻¹ prior to Diwali that drops to less than 1000 m² s⁻¹ post Diwali which relates to the enormous aerosol loading and resulting insolation cut off. All cities except Pune sees VC reduction on the next day of DD. VC is based on the radiosonde measurements at 1700 h every day and Pune being cloudy on DD and it rained too the VC on 7th is small and it could not be determined on 6th. On 8th it was clear to a good extent and the same reflected as rise in VC.

Mumbai experiences comparatively low VC, below 1500 m² s⁻¹. The other parameter that assists dispersion of pollution is surface wind. Generally higher winds prevail over Delhi for this period with a rise after Diwali. Ahmedabad falls in the second place with more wind speed but post Diwali there is a little drop, but remained high enough to aid dispersion. Mumbai and Pune experience very low wind speed and these winds could hardly play a part in dispersion. Hence it is clear that Ahmedabad meteorological conditions are conducive for faster dispersal of pollutants in the absence of extreme high levels of pollution. The temperature at the 4 cities does not vary significantly throughout the study period and thus it does not play a role in modulating the pollutants. Though at Delhi wind speed does not change much, the pollution level has reached extreme level. Moreover while considering the size distribution of PM it was observed that Ahmedabad had the highest difference between PM₁₀ and PM_{2.5} range which is bound to help easy gravitational settling.

The swell in pollution is steep and that affected Delhi's pollution distribution by bringing down VC in spite of the strong support from higher winds. Limited rise in PM levels arrested worsening of air quality in Mumbai with increase in pollutant gas levels too after DD. In Pune, the rain washout controlled the impairment of air quality with otherwise non-supportive weather.

Conclusions

The current study is the first-time analysis of simultaneous networked stations of four metro/mega cities of India on Diwali with online as well as campaign mode observations along with chemical analysis. The festival effect on trace gases, metal and carbon content are also analyzed. An area-averaged map indicated an idea of hotspots within each city and similarities and dissimilarities in pollutant enhancement. Station wise observations indicated specific nature of city as a whole and differences within.

Trace gas analysis points at enhancement in Ozone, NO_x and CO to various levels, and continuing at the elevated levels for many days with much less change at Ahmedabad. The PM collected through filter media was analyzed chemically and the results were: 1. OC showed a systematic increase in all station during Diwali and OC/EC ratio did not show any appreciable change. 2. metal analysis showed that Ca, K, Mg, Mn, Na and Pb shows significant increase in all stations from PD to DD. K, an excellent gun powder marker, shoots up by 7 to more than 15 times from PD to DD. Pb increased about 10 times and Cu 77.8 times in Delhi with other cities in lesser quantities. The total metal content which was less than 5% increased to 9–23% on Diwali day. Diwali air pollution raises most concern over health effect which considers the extent in intensity and time duration of the event. An acute health impact due to Diwali event and its endurance hints at a serious possibility revealed by Li et al., (2018) in their study of congestive heart failure (CHF) related hospital admissions at Beijing for 2 years that an increase in PM_{2.5} concentration by 10 µg m⁻³ in a day landed 0.35% more patients in hospital with CHF the same day.

In general, the festival is celebrated in the time of the year when weather conditions are not very conducive for dispersing the effect quickly. As expected, the control measures have to be more stringent where the pollution enhancement is maximum (Delhi as per this study) as the generated pollutants are even capable of reversing the otherwise conducive conditions of spread out. At Ahmedabad though the levels go higher on DD the weather helped diminishing the effect quickly. A bit more limiting action could leave the people without getting affected much. In the absence of rain, Pune, with non-conducive weather and very low wind speed, also would have faced longer bad-air days. Here also curbs are needed for certain areas of city where there are intense fireworks in general. Over Mumbai, again with very low wind speeds and lower VC, any increase in pollution levels, especially gaseous, are to prevail longer in spite of cleansing land-sea breeze.

The management should look into alternatives like less polluting crackers or crackers released high into the air from an open ground with specific time for such display so that more can have a view of the same rather than having more ground-based crackers in congested neighbourhoods that is bound to create more noise and air pollution and health concerns. Stricter enforcement based on air quality forecast is needed for regions with adverse conditions for general well-being of society. Sustained cohort studies involving vulnerable group in collaboration with health professionals for many years in different stations, depending upon the prolonged event-induced higher pollution levels, are needed in future to assess the actual health effect.

Declarations

Ethics approval and consent to participate

Not Applicable

Consent for publication

Not Applicable

Availability of data and materials

Not applicable.

Competing interests

We hereby state that we do not have any known conflict of interest with anyone

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Not applicable

Authors' contributions

LR: Conceptualization, Analysis, Writing and Review, VA: Partial draft writing, Data collection, Analysis, NK: Visualization and Analysis, Data collection, PK: Data Collection. MBS: Editing and review, Investigation

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References

1. Ali K, Panicker AS, Beig G et al (2015) Carbonaceous aerosols over pune and hyderabad (India) and influence of meteorological factors. J Atmos Chem 73:1–27. <https://doi.org/10.1007/s10874-015-9314-4>
2. Ambade B (2018) The air pollution during Diwali festival by the burning of fireworks in Jamshedpur city, India. Urban Clim 26:149–160. <https://doi.org/10.1016/j.uclim.2018.08.009>
3. Attri AK, Kumar U, Jain VK (2001) Formation of ozone by fireworks. Nature 411:1015. <https://doi.org/10.1038/35082634>

4. Bach W, Daniels A, Dickinson L et al (1975) Fireworks pollution and health. *Int J Environ Stud* 7:183–192. <https://doi.org/10.1080/00207237508709692>
5. Barman SC, Singh R, Negi MPS, Bhargava SK (2008) Ambient air quality of Lucknow City (India) during use of fireworks on Diwali Festival. *Environ Monit Assess* 137:495–504. <https://doi.org/10.1007/s10661-007-9784-1>
6. Beig G, Chate DM, Ghude SD et al (2013) Evaluating population exposure to environmental pollutants during Deepavali fireworks displays using air quality measurements of the SAFAR network. *Chemosphere* 92:116–124. <https://doi.org/10.1016/j.chemosphere.2013.02.043>
7. Benoff S, Jacob A, Hurley IR (2000) Male infertility and environmental exposure to lead and cadmium. *Hum Reprod Update* 6:107–121. <https://doi.org/10.1093/humupd/6.2.107>
8. Betha R, Balasubramanian R (2013) Particulate emissions from commercial handheld sparklers: Evaluation of physical characteristics and emission rates. *Aerosol Air Qual Res* 13:301–307. <https://doi.org/10.4209/aaqr.2012.08.0208>
9. Chatterjee A, Sarkar C, Adak A et al (2013) Ambient Air Quality during Diwali Festival over Kolkata-A Mega-City in India. *Aerosol Air Qual Res* 13:1133–1144. <https://doi.org/10.4209/aaqr.2012.03.0062>
10. CPCB (2019) Health impact assessment of fire crackers bursting during Dusshera & Diwali. <https://cpcb.nic.in/report.php>. Accessed 17 Jan 2019
11. Daga M, Mawari G, Bharali D et al (2019) Assessment of the air quality and its impact on health and environment in India. *Indian J Med Spec* 10:117. https://doi.org/10.4103/injms.injms_15_19
12. Douwes J, Gibson P, Pekkanen J, Pearce N (2002) Non-eosinophilic asthma: Importance and possible mechanisms. *Thorax* 57:643–648
13. Gautam S, Yadav A, Pillarisetti A et al (2018) Short-Term Introduction of Air Pollutants from Fireworks during Diwali in Rural Palwal, Haryana, India: A Case Study. *IOP Conf Ser Earth Environ Sci* 120:0–6. <https://doi.org/10.1088/1755-1315/120/1/012009>
14. Ghei D, Sane R (2018) Estimates of Air Pollution in Delhi from the Burning of Fire Crackers during the Festival of Diwali. *Work Pap*
15. Greenberg MI, Vearrier D (2015) Metal fume fever and polymer fume fever. *Clin Toxicol (Phila)* 53:195–203. <https://doi.org/10.3109/15563650.2015.1013548>
16. Greven FE, Vonk JM, Fischer P et al (2019) Air pollution during New Year's fireworks and daily mortality in the Netherlands. *Sci Rep* 9:. <https://doi.org/10.1038/s41598-019-42080-6>
17. Gunthe SS, Beig G, Sahu LK (2016) Study of relationship between daily maxima in ozone and temperature in an urban site in India. *Curr Sci*. <https://doi.org/10.18520/cs/v110/i10/1994-1999>
18. Hirai K, Yamazaki Y, Okada K et al (2000) Acute Eosinophilic Pneumonia Associated with Smoke from Fireworks
19. Jaishankar M, Tseten T, Anbalagan N et al (2014) Toxicity, mechanism and health effects of some heavy metals. *Interdiscip Toxicol* 7:60. <https://doi.org/10.2478/INTOX-2014-0009>
20. Kaushar A, Chate D, Beig G et al (2013) Spatio-Temporal Variation and Deposition of Fine and Coarse Particles during the Commonwealth Games in Delhi. *Aerosol Air Qual Res* 13:748–755. <https://doi.org/10.4209/aaqr.2012.02.0044>
21. Kumar M, Singh RK, Murari V et al (2016) Fireworks induced particle pollution: A spatio-temporal analysis. *Atmos Res* 180:78–91. <https://doi.org/10.1016/j.atmosres.2016.05.014>
22. Li J, Xu T, Lu X et al (2017) Online single particle measurement of fireworks pollution during Chinese New Year in Nanning. *J Environ Sci (China)* 53:184–195. <https://doi.org/10.1016/j.jes.2016.04.021>
23. Li M, Wu Y, Tian YH et al (2018) Association between PM_{2.5} and daily hospital admissions for heart failure: A time-series analysis in Beijing. *Int J Environ Res Public Health* 15:. <https://doi.org/10.3390/ijerph15102217>
24. Lippmann M (1989) Health Effects Of Ozone A Critical Review. *J Air Pollut Control Assoc* 39:672–695. <https://doi.org/10.1080/08940630.1989.10466554>
25. Liu B, Bi X, Feng Y et al (2016) Fine carbonaceous aerosol characteristics at a megacity during the Chinese Spring Festival as given by OC/EC online measurements. *Atmos Res* 181:20–28. <https://doi.org/10.1016/j.atmosres.2016.06.007>
26. Liu J, Chen Y, Chao S et al (2019) Levels and health risks of PM_{2.5}-bound toxic metals from firework/firecracker burning during festival periods in response to management strategies. *Ecotoxicol Environ Saf* 171:406–413. <https://doi.org/10.1016/j.ecoenv.2018.12.104>
27. Mandal P, Prakash M, Bassin JK (2012) Impact of Diwali celebrations on urban air and noise quality in Delhi City, India. *Environ Monit Assess* 184:209–215. <https://doi.org/10.1007/s10661-011-1960-7>

28. Moreno T, Querol X, Alastuey A et al (2007) Recreational atmospheric pollution episodes: Inhalable metalliferous particles from firework displays. *Atmos Environ* 41:913–922. <https://doi.org/10.1016/j.atmosenv.2006.09.019>
29. Mukherjee T, Asutosh A, Pandey SK et al (2018) Increasing Potential for Air Pollution over Megacity New Delhi: A Study Based on 2016 Diwali Episode. *Aerosol Air Qual Res* 18:2510–2518. <https://doi.org/10.4209/aaqr.2017.11.0440>
30. Murthy BS, Latha R, Tiwari A et al (2019) Impact of Mixing Layer Height on Air Quality in Winter. *J Atmos Solar-Terrestrial Phys* 105157. <https://doi.org/10.1016/j.jastp.2019.105157>
31. Naranjo VI, Hendricks M, Jones KS (2020) Lead Toxicity in Children: An Unremitting Public Health Problem. *Pediatr Neurol* 113:51–55. <https://doi.org/10.1016/j.pediatrneurol.2020.08.005>
32. Parkhi N, Chate D, Ghude SD et al (2016) Large inter annual variation in air quality during the annual festival “Diwali” in an Indian megacity. *J Environ Sci (China)* 43:265–272. <https://doi.org/10.1016/j.jes.2015.08.015>
33. Perrino C, Tiwari S, Catrambone M et al (2011) Chemical characterization of atmospheric PM in Delhi, India, during different periods of the year including Diwali festival. *Atmos Pollut Res* 2:418–427. <https://doi.org/10.5094/APR.2011.048>
34. Pujol J, Fenoll R, Macià D et al (2016) Airborne copper exposure in school environments associated with poorer motor performance and altered basal ganglia. *Brain Behav* 6:1–13. <https://doi.org/10.1002/brb3.467>
35. Ravindra K, Mor S, Kaushik CP (2003) Short-term variation in air quality associated with firework events: A case study. *J Environ Monit* 5:260–264. <https://doi.org/10.1039/b211943a>
36. Rothman. KJ, Greenland SLT (2008) *Modern Epidemiology*, 3rd edn. Williams & Wilkins, Philadelphia
37. Singh A, Pant P, Pope FD (2019) Air quality during and after festivals: Aerosol concentrations, composition and health effects. *Atmos Res* 227:220–232. <https://doi.org/10.1016/j.atmosres.2019.05.012>
38. Tecer LH, Süren P, Alagha O et al (2008) Effect of meteorological parameters on fine and coarse particulate matter mass concentration in a coal-mining area in Zonguldak, Turkey. *J Air Waste Manag Assoc* 58:543–552. <https://doi.org/10.3155/1047-3289.58.4.543>
39. Tiwari S, Bisht DS, Srivastava AK et al (2014) Variability in atmospheric particulates and meteorological effects on their mass concentrations over Delhi, India. *Atmos Res* 145–146:45–56. <https://doi.org/10.1016/j.atmosres.2014.03.027>
40. Tiwari S, Chate DM, Pragya P et al (2012) Variations in mass of the PM₁₀, PM_{2.5} and PM₁ during the monsoon and the winter at New Delhi. *Aerosol Air Qual Res* 12:20–29. <https://doi.org/10.4209/aaqr.2011.06.0075>
41. Udaya Prakash NK, Sriprya N, Gowtham K et al (2019) A study on the impact of fire crackers on airborne microflora during diwali. *Heliyon* 5:. <https://doi.org/10.1016/j.heliyon.2019.e02202>
42. Vecchi R, Bernardoni V, Cricchio D et al (2008) The impact of fireworks on airborne particles. *Atmos Environ* 42:1121–1132. <https://doi.org/10.1016/j.atmosenv.2007.10.047>
43. Wang Y, Zhuang G, Xu C, An Z (2007) The air pollution caused by the burning of fireworks during the lantern festival in Beijing. *Atmos Environ* 41:417–431. <https://doi.org/10.1016/j.atmosenv.2006.07.043>
44. Xing YF, Xu YH, Shi MH, Lian YX (2016) The impact of PM_{2.5} on the human respiratory system. *J Thorac Dis* 8:E69–E74
45. Yang Song X, Wan S, Bai D, Guo C, Ren Yu, Zeng, Yirui Li XL (2017) The Characteristics of Air Pollutants during Two Distinct Episodes of Fireworks Burning in a Valley City of North China. *PLoS One*
46. Yerramsetti VS, Sharma AR, Gauravarapu Navlur N et al (2013) The impact assessment of Diwali fireworks emissions on the air quality of a tropical urban site, Hyderabad, India, during three consecutive years. *Environ Monit Assess* 185:7309–7325. <https://doi.org/10.1007/s10661-013-3102-x> <http://safari.tropmet.res.in>
47. Wyoming University Radiosonde data. <http://weather.uwyo.edu/upperair/sounding.html>

Figures

Figure 1

SAFAR network cities with stations marked along with India map and the spatial plots indicate the anomaly of PM_{2.5} on DD with respect to PD Day

Figure 2

Temporal variation of PM_{2.5} and PM₁₀ for the four cities: top pane indicates hourly averages of PM₁₀ with inset showing the daily averages and bottom pane, same for PM_{2.5}

Figure 3

Daily averages of PM_{2.5} of each monitoring station during Diwali campaign

Figure 4

(top: a) Comparison of PM2.5 online and discrete sampling using sampler (bottom: b) OC, EC concentration in PM2.5 and the ratio of OC/EC

Figure 5

Metal contribution in PM_{2.5} as percentage, total percentage of metals shown by line

Figure 6

Temporal variation of trace gases, NO_x, CO, Ozone and NH₃ during Diwali period

Figure 7

Daily means of Temperature, Relative Humidity, wind speed and Ventilation coefficient for the Diwali period 3-12 November also shown as histogram

Supplementary Files

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