

Impact of Diwali firework emissions on air quality of New Delhi, India during 2013-2015

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सार – दिवाली एक बड़ा और अत्यधिक महत्वपूर्ण त्यौहार है जिसे पूरे देश में मनाया जाता है। यह त्यौहार अक्टूबर के उत्तरार्ध में या नवंबर के आरंभ में आता है। यह पटाखे जलाने से जुड़ा है विशेषकर दिवाली की रात वायु गुणवत्ता में कमी आती है और जो काफी समय तक बनी रहती है। पटाखे जलाने पर पटाखों से भारी मात्रा में NO_x, CO, SO₂ और O₃ जैसी ट्रेस गैसों और वायुविलय और पार्टिकुलेट मैटर भारी मात्रा में निकलते हैं। इस शोध पत्र में 2013 से 2015 तक की अवधि में दिवाली के त्यौहार के दौरान भारत के महानगरों और दिल्ली में सतह ओजोन (O₃), नाईट्रोजन ऑक्साइड (NO_x), और पार्टिकुलेट मैटर (PM10 और PM 2.5) सांद्रण पर पटाखों के उत्सर्जन के प्रभाव को केन्द्र में रखकर अध्ययन किया गया है। यह पता चला है कि 2013 से 2015 के नियंत्रण दिन की तुलना में दिवाली के समय सतह ओजोन, NO_x और पार्टिकुलेट मैटर सांद्रण में तेजी से बढ़ोतररी हुई है जो कि पटाखों के जलने के कारण हुई। हालाँकि 2015 और 2014 में 2013 की तुलना में गैसीय प्रदूषकों और पार्टिकुलेट मैटर (PM10 और PM 2.5) के औसत सांद्रण में कमी पाई गई जो कि जनता के बीच पटाखों के प्रति जागरूकता अभियान चलाने तथा पटाखों की कीमतों में वृद्धि की वजह से थी।

ABSTRACT. Diwali is one of the major and most important festivals celebrated all over India which falls in the period late October to early November every year. It is associated with burning of firecrackers especially during the night of Diwali day that leads to degradation of air quality that lasts for a longer duration of time. Firecrackers on burning releases huge amount of trace gases such as NO_x, CO, SO₂ and O₃ and huge amount of aerosols and particulate matter. The present study focuses on the influence of firecrackers emissions on surface ozone(O₃), oxides of nitrogen (NO_x) and particulate matter (PM10 and PM2.5) concentration over the capital urban metropolis of India, New Delhi during Diwali festivity period from 2013-2015. A sharp increase is observed in surface ozone, NO_x and particulate matter concentration during the Diwali day as compared to control day for 2013 to 2015 which is mainly attributed to burning of firecrackers. However the average concentration levels of the gaseous pollutants and particulate matter (PM10 and PM2.5) on Diwali day exhibited a decline in 2015 and 2014 as compared to 2013 due to increase in awareness campaigns among public and increased cost of firecrackers.

Key words – Air quality, NO_x, Surface ozone, Particulate matter, Diwali fireworks emissions.

1. Introduction

Air pollution levels in megacities have been a growing cause of concern in recent years due to increased levels of anthropogenic pollutants and their associated health hazards. To this respect, small air quality degradation episodes have gained increased attention from research communities in recent years as they pose serious health issues due to their long term negative effects on air quality (Pope *et al.*, 2002; Nastos *et al.*, 2010; Samoli *et al.*, 2011). Air quality degradation episodes due to bursting of firecrackers in wedding celebrations worldwide, Diwali festivities of India (Kulshrestha *et al.*, 2004;

Limaye and Salvi, 2010; Mandal *et al.*, 2011), Lantern festival in China (Wang *et al.*, 2007), Independence Day celebrations in USA (Liu *et al.*, 1997) and New Year's eve celebrations (Drewnick *et al.*, 2006) have been well explained by many researchers in recent years.

Diwali also called as the festival of Lights is one of the most important festivals of Hindu community and is widely and enormously celebrated across India. According to the Gregorian calendar, Diwali festival usually occurs in late October/early November and is widely celebrated for three days all over India. Huge amounts of fireworks, crackers and sparklers are burnt mainly during the night of

the festival (Diwali day) and also on the day before and after Diwali (considered as pre-Diwali and post-Diwali day). Fireworks contain about 75% potassium nitrate, 15% carbon and 10% sulphur, potassium and trace elements which significantly affects environment and human health (Agrawal *et al.*, 2011; Khaiwal *et al.*, 2003; Kulshrestha *et al.*, 2004). On large-scale burning they release trace gases such as (CO, NO_x, SO₂, and O₃) and black carbon (BC) particulates that leads to formation of dense clouds of smoke (Khaiwal *et al.*, 2003; Swamy *et al.*, 2013). Depending upon the prevailing meteorological conditions during Diwali period, particulate matter and gases reduces the visibility in air to a larger extent, lasting up to many hours. (Swamy *et al.*, 2013) Many researchers have reported deterioration in air quality due to Diwali festivities over different parts of India (Attri *et al.*, 2001; Babu and Moorthy, 2001; Kulshrestha *et al.*, 2004; Barman *et al.*, 2008; Singh *et al.*, 2010; Mandal *et al.*, 2011). Research studies by Khaiwal *et al.* (2003); Nishanth *et al.* (2012); Sarkar *et al.* (2010); Thakur *et al.* (2010); Sharma *et al.* (2013) and Beig *et al.* (2015) have also reported increase in noise levels of trace gases, such as SO₂, NO₂, O₃, total suspended particulate matter (TSP), trace metals, and BC aerosols during the Diwali period. Attri *et al.* (2001) have reported the formation of a powerful secondary pollutant, ozone at ground level even during night time of Diwali due to burning and polytechnic display of fireworks.

The present study aims to assess the air quality status during the Diwali festival over New Delhi, the capital of India and one of the heavily populated major megacities of the world and its comparison with previous year's air quality data during the same period. For this study, continuous measurements of particulate matter (PM₁₀ and PM_{2.5}), trace gases such as NO_x and surface ozone were carried out during the Diwali period from 2013 to 2015. Average diurnal concentration of seven days before and after Diwali day was considered as control. Furthermore, the particulate matter and trace gases concentrations on control, pre-Diwali, Diwali and post-Diwali day were compared to characterize the role of Diwali firework emissions on the air quality of New Delhi during the festivity period. This study will provide useful information about the changes that have occurred in urban air quality of the capital city of India over recent three years (2013, 2014 and 2015).

2. Datasets and methodology

The System of Air Quality Forecast and Research (SAFAR), a project initiated by Ministry of Earth Sciences (MoES), New Delhi, India in 2010, has a network of air quality monitoring stations (AQMSs) and automatic weather stations (AWS) located in and around

Delhi and NCR (<http://safar.tropmet.res.in/>). The continuous measurements of particulate matter (PM), ozone (O₃), nitrogen oxides (NO_x) were done at SAFAR stations to enable research into spatial and temporal variation of each pollutant and their impact on human health during the Diwali festivity period.

PM₁₀ and PM_{2.5} were continuously monitored using Beta Attenuation Monitor (BAM-1020; Met One Instruments, Inc, USA) which uses the industry-proven principle of beta ray attenuation. The measurement principle involves emission, by a small ¹⁴C (carbon-14) element, of a constant source of high-energy electrons known as beta rays through a spot of clean glass fiber filter tape. These beta rays are detected and counted by a sensitive scintillation counter to determine a zero reading. The BAM-1020 automatically advances this spot of tape to the sample nozzle, where a vacuum pump then pulls a measured and controlled amount of dust-laden air through the filter tape loading it with ambient dust. This dirty spot is placed back between the beta source and the detector thereby causing an attenuation of the beta ray signal which is used to determine the mass of the particulate matter on the filter tape and the volumetric concentration of particulate matter in the ambient air. The instrument measures concentration of ambient aerosols with a resolution of 0.1 μg m⁻³ and lower detection limit of around 1 μg m⁻³. Span check of the instrument is automatic and is verified hourly (Kaushar Ali *et al.*, 2013; Beig *et al.*, 2013).

Synchronous measurements of trace gases, *viz.*, surface O₃ and NO_x, were carried out using O₃ analyzer (49i; Thermo Scientific, USA, precision ~1 ppbv) and NO_x analyzer (42i; Thermo Scientific, USA, precision ~0.4 ppbv). O₃ analyzer works on the principle that O₃ molecules absorb ultraviolet (UV) light at a wavelength of 254 nm. NO_x analyzer operates on the principle that NO and O₃ react to produce a characteristic luminescence with intensity proportional to the NO concentration. Calibration of the O₃ analyzer was done on every alternate day using an inbuilt O₃calibrator, whereas NO_x calibration was performed with multipoint calibration technique (Sahu *et al.*, 2011; Fadnavis *et al.*, 2011; Beig *et al.*, 2013; Swamy *et al.*, 2013).

The five minute interval data obtained from continuous measurement of analyzers were averaged hourly and temporal graphs were plotted from 1800 hrs to 0600 hrs IST next morning when burning of fireworks and crackers are at their peak to assess the air quality during night time of Diwali period from 2013 to 2015. Continuous measurements were analyzed for four different specific time intervals, *viz.*, Control (7 days before and after Diwali day), Pre-Diwali day, Diwali day

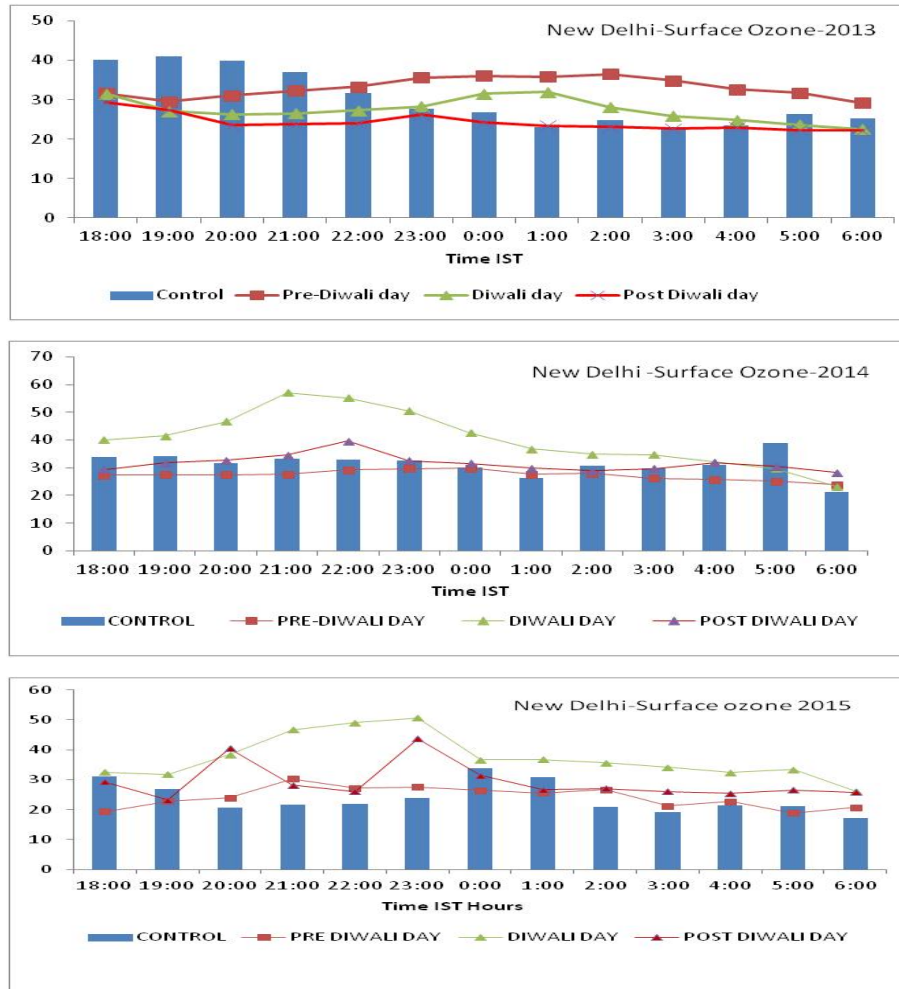


Fig. 1. Temporal variation of nighttime surface O_3 concentration on control, pre-Diwali, Diwali and post-Diwali days during 2013, 2014 and 2015

and post-Diwali day to get a detailed picture of air quality around the Diwali period in New Delhi, India.

3. Results and discussion

3.1. Variation of surface ozone

Surface ozone is a powerful secondary pollutant and the factors affecting the photochemical production of surface ozone are intensity of solar radiation triggered by the presence of precursor gases such as NO_x , CO and hydrocarbons. (Lin *et al.*, 2007). The primary controlling factor of surface ozone production is intense solar radiation during day time. Nevertheless, during nighttime it is chemically removed by titration process by nitrogen monoxides (NO) ($NO + O_3 \rightarrow NO_2 + O_2$) (Crutzen, 1979).

But, Attri *et al.* (2001) have reported formation of surface ozone during night of Diwali attributed to polytechnics display of fireworks.

Therefore, to delineate the effects of these festivities, the surface O_3 concentrations on control (averaged surface ozone concentration for 7 days before and after Diwali day), pre-Diwali, Diwali and post-Diwali day were compared to characterize the role of Diwali firework emissions on the ambient air quality over New Delhi. Fig. 1 shows the temporal variation of nighttime O_3 concentration (1800 hrs IST to 0600 hrs IST the next day) for the above mentioned days during 2013, 2014 and 2015. Generally, surface O_3 exhibits decreasing amplitude of variation during night time in absence of sunlight. This is more marked during control day as compared to pre-

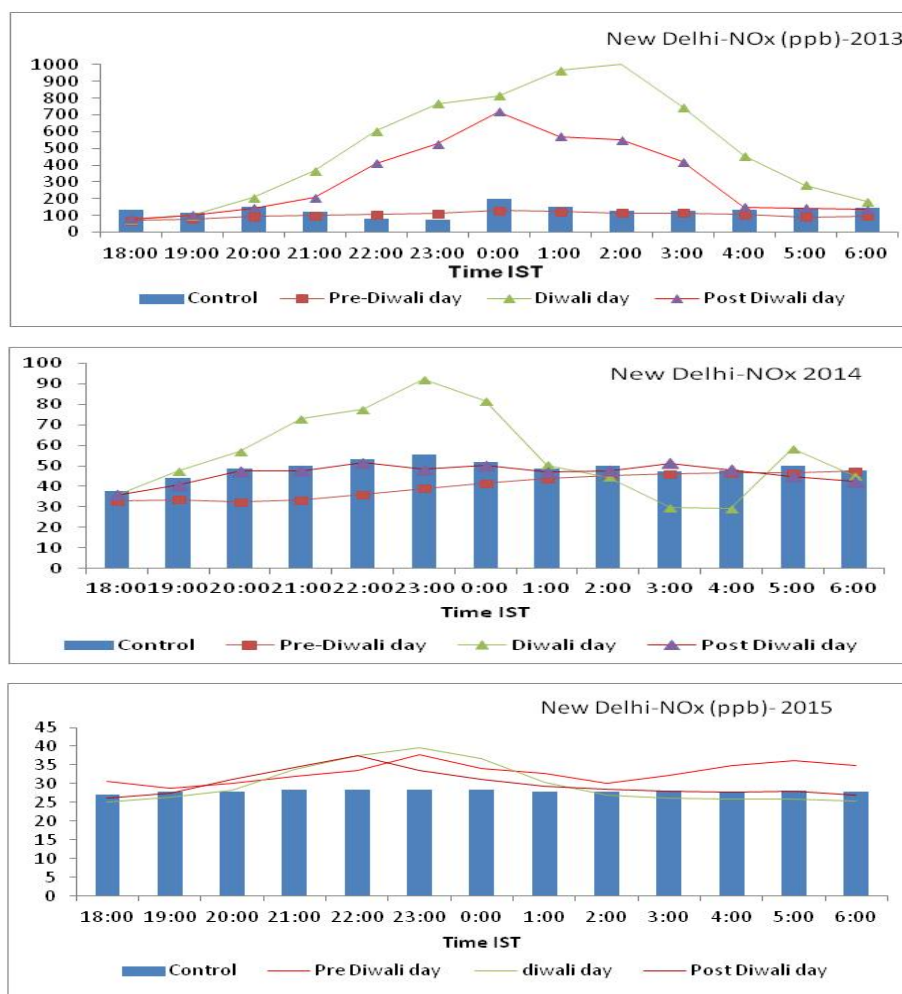


Fig. 2. Temporal variation of NOx (NO +NO₂) during night time (1800 IST to 0600 IST) on Control, Pre-Diwali, Diwali and Post Diwali days from 2013 to 2015

Diwali, Diwali and post-Diwali days. On Control day the surface ozone concentration varied generally between ~10 - ~40 ppb (2013-2015). The night of Diwali in 2013 experienced an increase in surface ozone concentration from 1900 hrs IST reaching its maxima of ~32 ppb at 0000 hrs IST triggered by the burning of fireworks. The increase in nighttime surface O₃ concentrations continued on post-Diwali day as well and attained its maximum level of ~26 ppb at 2300 hrs IST. Again in 2014, surface ozone levels started increasing from 2000 hrs IST reaching its maxima of ~57 ppb at 2100 hrs IST. Similar trend was also observed in 2015 when surface ozone levels rose to their maximum high of ~50 ppb at 2300 hrs IST on Diwali day. Previous researches by Nishanth *et al.* (2012) and Attri *et al.* (2001) have also reported significant increase in nighttime O₃ concentrations due to firecrackers burning during the Diwali period especially during night time.

This unusual nighttime formation of O₃ could be explained with the fact that there exists a linear relationship between the amount of combustible matter present in the firecrackers and cumulative O₃ production (Attri *et al.*, 2001). Polytechnics display of fireworks emits a considerable proportion of light (UV < 424 nm) which enables local nighttime surface ozone formation through enhancement of NO_x during nighttime triggered by the burning of firecrackers. Henceforth, the reaction is as follows: NO₂ → NO + O; O₂ + O → O₃. Nevertheless, a decrease in maximum surface ozone concentration level was observed on Diwali day of 2015 when compared to 2014. This can be due to decrease in time duration of fireworks burning due to increased attentiveness (newspaper publicity against firework-related pollution), increased cost of firecrackers, prevailing meteorological conditions such as wind speed and direction, boundary

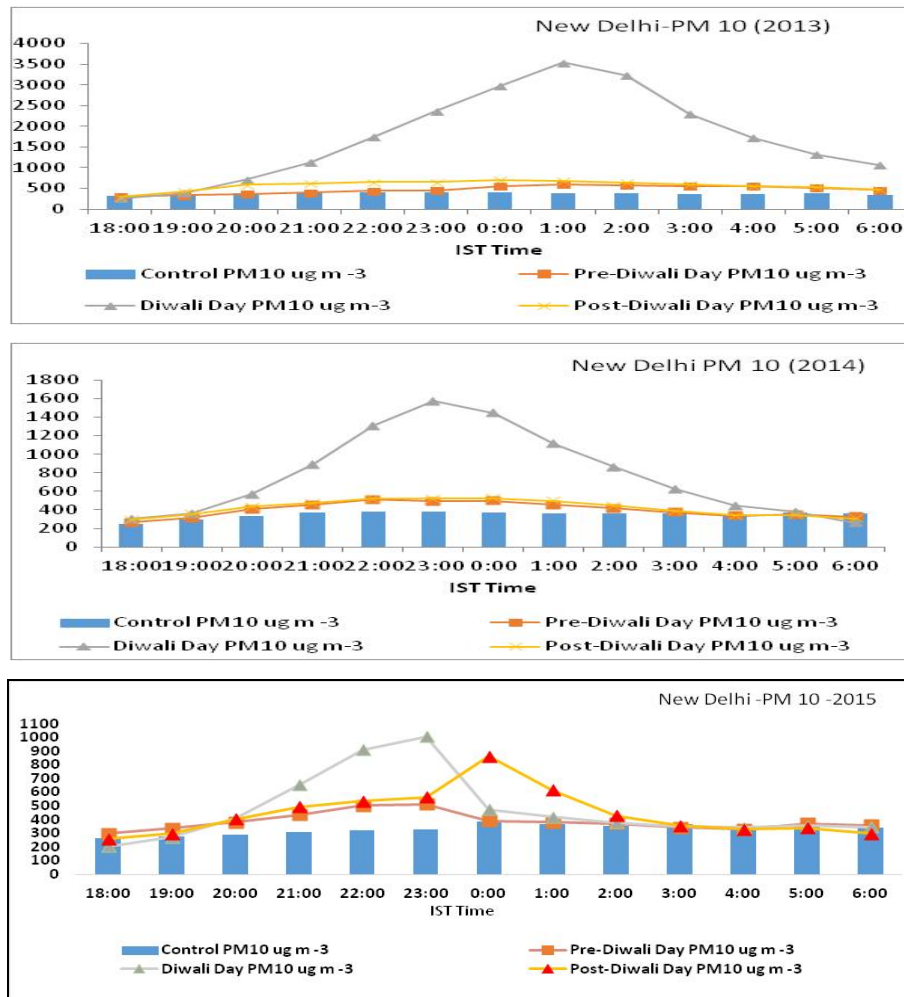


Fig. 3. Temporal variation of nighttime PM10 concentration on control, pre-Diwali, Diwali and post-Diwali days during 2013, 2014 and 2015

layer height, temperature inversion, local emissions and secondary ozone formation during that period.

3.2. Variation of oxides of nitrogen

The night time concentration of NO_x showed a significant increase after 2000 hrs IST in 2013 and continued to rise till 0200 IST next morning reaching its maxima of ~1000 ppb. A threefold increase (about 3.74%) was observed in average concentration of NO_x on Diwali day as compared to control day. Average concentration on Diwali day in 2013 was calculated to be ~504 ppb as compared to control day (average concentration was calculated to be ~130 ppb). However the levels of NO_x reduced back on post Diwali day (average concentration of NO_x was calculated to be ~319 ppb on post Diwali day). This can be due to intensive burning of fire crackers in 2013, local anthropogenic emissions such as vehicular

exhaust and the local prevailing meteorological conditions like humidity, temperature, wind speed and direction and no vertical mixing due to low boundary layer height. Nevertheless, the average concentration levels of NO_x showed a deep decline in 2014 and 2015 (Fig. 2) on Diwali day due to increase in awareness campaigns and increased cost of fireworks.

3.3. Variation of particulate matter (PM10 and PM2.5)

The variation of PM10 and PM2.5 along with gaseous pollutants was also studied during the study period. Figs. 3 and 4 shows temporal variation of PM10 and PM2.5 respectively during nighttime of Control, Pre Diwali, Diwali and Post Diwali days of 2013, 2014 and 2015. The average PM10 and PM2.5 concentrations varied between ~200 - ~400 $\mu\text{g m}^{-3}$ during control period

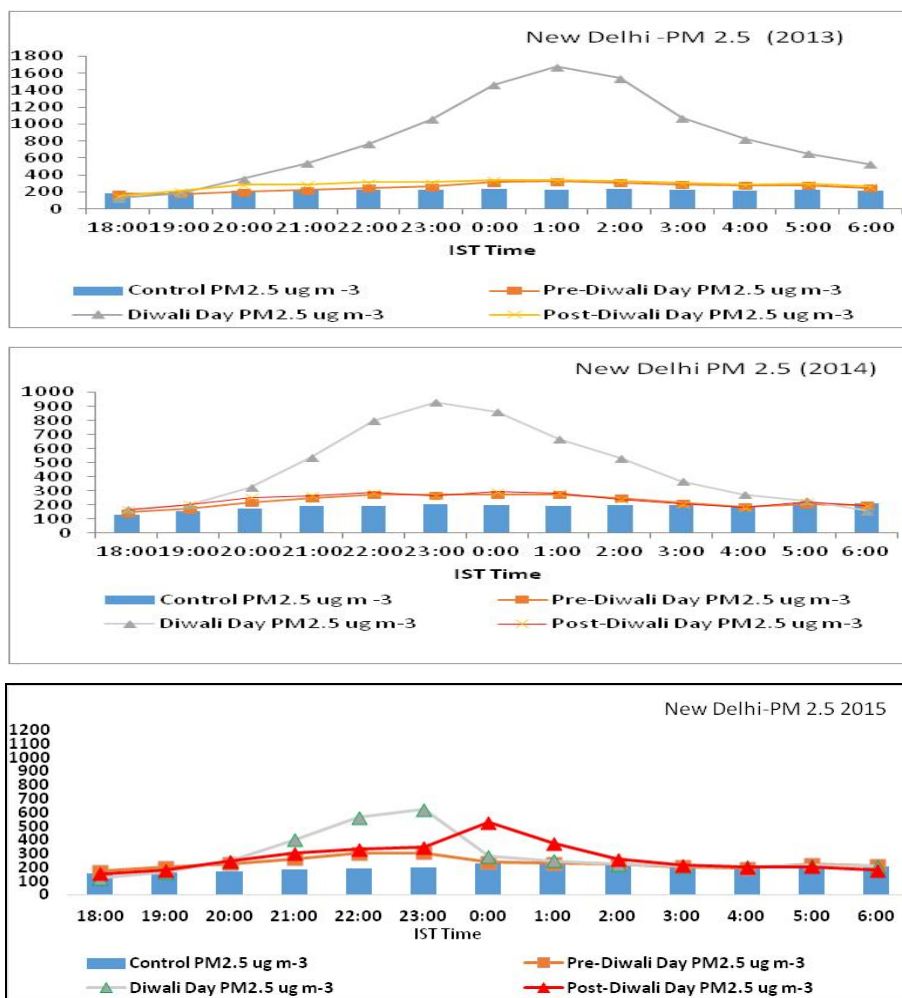


Fig. 4. Temporal variation of night time PM_{2.5} concentration on control, pre- Diwali, Diwali and post-Diwali days during 2013, 2014 and 2015

of 2013 to 2015. However on Diwali day in 2013, PM₁₀ and PM_{2.5} concentrations started to rise after 2000 IST and continued to rise till 0200 hrs IST reaching to its maxima of $\sim 3234 \mu\text{g m}^{-3}$ and $\sim 1624 \mu\text{g m}^{-3}$ respectively, (about 20 times more than their safer limits of $100 \mu\text{g m}^{-3}$ and $60 \mu\text{g m}^{-3}$ (24 hr average respectively). The average nighttime concentration of PM₁₀ and PM_{2.5} on Diwali Day in 2013 was calculated to be $\sim 1750 \mu\text{g m}^{-3}$ and $\sim 831 \mu\text{g m}^{-3}$ (about more than 4 times and 3 times with respect to on control day respectively for PM₁₀ and PM_{2.5}). This increase is mainly attributed to emissions released from enormous burning of fireworks on night of Diwali Day and less dispersion of released particulate matter due to less favorable meteorological conditions like low wind speed, temperature inversion and low boundary layer height due to low temperatures. Nevertheless, the PM levels started to decline on Post Diwali day, the average nighttime PM₁₀ and PM_{2.5} concentration was

calculated to be ~ 571 and $\sim 278 \mu\text{g m}^{-3}$ respectively. However in 2014 and 2015, PM₁₀ and PM_{2.5} showed a declining trend when compared to 2013. On Diwali day in 2015, PM levels were found to be high only between 2000 hrs IST to 2300 hrs IST. The peak was found to be at 2300 IST that was $\sim 1000 \mu\text{g m}^{-3}$ (PM₁₀) and $\sim 621 \mu\text{g m}^{-3}$ (PM_{2.5}) (about 10 times more than their safer limits of $100 \mu\text{g m}^{-3}$ and $60 \mu\text{g m}^{-3}$ respectively). The average nighttime concentration of PM₁₀ and PM_{2.5} on Diwali Day was calculated to be $\sim 469 \mu\text{g m}^{-3}$ and $\sim 286 \mu\text{g m}^{-3}$.

4. Conclusions

The present study investigates the influence of Diwali fireworks episodes on urban air quality of New Delhi for 2013-2015. The enhanced NO_x concentration in the presence of visible radiation due to polytechnic display of firecrackers during the Diwali festivity period

favoured local nighttime production of surface ozone even in the absence of sunlight that triggers its photochemical production. The average surface ozone, NO_x and particulate matter (PM₁₀ and PM_{2.5}) concentration levels showed an average increase of 7,287, 387 and 278% in 2013, 26, 15, 123 and 145% in 2014, 60, 7, 42, and 43% in 2015 on Diwali day with respect to control day. The average nighttime concentration of previously mentioned atmospheric pollutants on Diwali day was calculated to be 27 ppb, 504 ppb, 1750 µg m⁻³, 831 µg m⁻³ in 2013, 37 ppb, 30 ppb, 350 µg/m³, 464 µg m⁻³ in 2014 and 39 ppb, 55 ppb, 469 µg/m³, 286 µg m⁻³ in 2015. This is mainly attributed to emissions released from intensive burning of fireworks especially during the night of Diwali. This also means that 2013 was the most polluted among all the three years during Diwali period as compared to 2014 and 2015. The average concentration levels of gaseous pollutants and particulate matter started to decline in 2014 and 2015 as compared to 2013 which is mainly due to increased awareness campaigns by government organizations, research community and students regarding harmful health effects of emissions produced from burning of firecrackers. A significant finding from this study is observed to be that the averaged concentration of the atmospheric pollutants considered in this study remained high even on the post Diwali Day, suggesting that atmospheric cleansing after burning of firecrackers needs more than 1 day. This fact highlights the additional contribution of the anthropogenic pollutant emissions during festival days in India that further deteriorates the air quality. The significant variations of the pollutant observed during different years are strongly linked with the local meteorological conditions, *i.e.*, average mixing layer height, temperature inversions, wind speed and wind direction and how close the measuring site is to extensive firecrackers burning.

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