

Chapter 4

Analysis of Atmospheric Pollutants During Fireworks Festival ‘Diwali’ at a Residential Site Delhi in India



Pallavi Saxena, Anju Srivastava, Shivangi Verma, Shweta, Lakhwinder Singh and Saurabh Sonwani

Abstract Globally, a number of firework events have been celebrated on a large scale in the names of different festivals. Diwali is one among the popular Indian festival held during October or November every year with huge fireworks. In the present study, various air pollutants like nitrogen oxides (NO_x), particulate matter ($\text{PM}_{2.5}$ and PM_{10}) and ozone (O_3) were analyzed in pre, during and post Diwali in two consecutive years i.e. October 2016 and October 2017 in capital city of India, Delhi. The results showed that the background values of particulate matter are exceeding 5–6 times in 2016 and 7–8 times in 2017 than permissible limits set by National Ambient Air Quality Standards (NAAQS), India. In Diwali-2016, the highest PM_{10} and $\text{PM}_{2.5}$ concentrations were about 8 times and 7 times higher than NAAQS limits respectively. For Diwali-2017, there was rapid increase in PM_{10} and $\text{PM}_{2.5}$ concentrations that were about 10 times and 13 times higher than NAAQS threshold value respectively. Moreover, PM_{10} and $\text{PM}_{2.5}$ concentrations in 2017, higher than 2016 were found to be 5–8 times more as compared to background concentrations. However, the concentrations of NO_x and O_3 look similar during background event, pre Diwali, Diwali and post Diwali periods in both the years of 2016 and 2017. The huge Diwali induced air pollution is influenced by transboundary air mass movements from nearby regions of Delhi and adjoining countries in both the selected years of 2016 and 2017 particularly in case of particulate matter in Diwali and Post Diwali. The study concludes that during background and in and around Diwali period receives the air masses containing the emissions from biomass burning which significantly increases the air pollution load.

Keywords Air pollution · Fireworks · Diwali · Delhi

P. Saxena (✉)

Department of Environmental Sciences, Hindu College, University of Delhi, Delhi 110007, India
e-mail: pallavienvironment@gmail.com

A. Srivastava · S. Verma · Shweta · L. Singh

Department of Chemistry, Hindu College, University of Delhi, Delhi 110007, India

S. Sonwani

School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India

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4.1 Introduction

India is considered as the land of festivals due to its diverse culture and traditions in its different states. It is also observed to have rapid increase in industrialization and urbanization since 19th century onwards. The global organizations like World Health Organization (WHO) and the World Bank have observed that Delhi is one of the metropolis of India which is second most polluted in the world particularly in case of one of the primary air pollutant i.e. particulate pollution (World Bank 2004). The main sources of these air pollutants are high traffic density, high emissions from industries, biomass burning, transboundary mass air movements from adjoining states and domestic activities (Saxena et al. 2012; WHO 2014). Delhi is the 7th highest populated metropolis at global scale. The population of Delhi is 16.75 million during 2001–2011. The total population of Delhi has been ascended to 20.26% during 2001–2011 period with annual growth rate of 1.92% per annum. Upraise in population is mainly due to the migration of people from other states and it is expected to rise by 40% by 2021 (Census of India 2011). Delhi's drastic increase, on the basis of economic aspect and population growth would give rise to an increasing need for transport, imposing excessive pressure on the city's transport infrastructure. Delhi has the highest number of vehicles (~7.4 millions) among the Indian cities (GNCT of Delhi report 2011–2012).

Diwali is famous fireworks festival that is celebrated with great joy and passion all over India every year in October/November. Firing crackers is a significant part of the celebrations in Diwali. Normally the crackers consists of 75% potassium nitrate, 15% charcoal, 10% sulphur, potassium and trace elements, that highly affects the environment as well as human health (Kulshrestha et al. 2004; Agrawal et al. 2011). On burning, fire crackers release air pollutants like CO, NO_x, SO₂ and O₃, Black carbon and particulates are responsible for the production of dense clouds of smoke (Khaiwal et al. 2003; Swamy et al. 2012). A large quantity of crackers are burnt mostly on the onset of festival (Diwali day), on the day before (pre-Diwali day) and after (post-Diwali day) Diwali. Burning of firecrackers produces toxic substances which release toxic gases and particulate matter of fine size to the atmosphere leading to severe health and environmental hazards (Perrino et al. 2011; Rao et al. 2012).

Studies have been made in several parts of the world to determine the effects of firework activities on the ambient air quality. Fleischer et al. (1999) revealed that highly toxic pollutants like furans and polychlorinated dioxins are produced during the display of fireworks like "Fountains" and "Blue lightning rockets". Firecracker activities on New Year's Eve on Oahu (USA) was contributing for an enhancement of total suspended particulates with an average of 300% at 14 locations and with approximately 700% in the lung-penetrating size ranges at a particular location (Bach et al. 1975). An increase of about 57, 25 and 123% in SO₂, NO₂ and PM₁₀ levels respectively has been reported during Lantern festival in Beijing by the fireworks display over the previous day. The effect of firework activities on aerosol concentrations in the air during the celebration of New Year's Eve 2005 in Germany has been shown by some studies (Liu et al. 1997; Drewnick et al. 2006). During the FIFA World Cup

2006 celebration, fireworks increased the concentration of metals like Mg, Sr, Ba, Cu and K by 22, 120, 12, 6 and 11 times respectively in the ambient air of Italy (Vecchi et al. 2008). A number of studies have also reported with a rise in trace gases and particulate matter pollution during Diwali period in Delhi, Lucknow, Hisar and Howrah (Attri et al. 2001; Barman et al. 2009; CPCB 2010; Ganguly 2009; Perrino et al. 2011; Khaiwal et al. 2003; Thakur et al. 2010; Kulshrestha et al. 2004; Singh et al. 2010).

In the present study, the variations of trace gases and particulate matter at one of the residential and representative site of Delhi during Diwali festival in 2016 and 2017 were reported. Moreover, the role of transboundary movements was also discussed in and around Diwali festival during selected years.

4.2 Methodology

4.2.1 Monitoring Sites and Data Sources

Measurements of air pollutants viz. nitrogen oxides (NO_x), particulate matter ($\text{PM}_{2.5}$ and PM_{10}) and ozone (O_3) in 2016 and 2017 in background, pre, during and post Diwali at one of the residential and representative site in Delhi were analyzed. The location of the site is shown in Fig. 4.1. Hourly concentrations of PM_{10} , $\text{PM}_{2.5}$, NO_x and O_3 at selected site were obtained from the Central Pollution Control Board



Fig. 4.1 Map of Delhi showing sampling site

(CPCB) (<http://cpcb.nic.in/real-time-air-quality-data/>) website. O_3 and NO_x were measured using Chemiluminescence method and PM_{10} and $PM_{2.5}$ using tapered element oscillating microbalance (<http://cpcb.nic.in/air-quality-standard/>). The selected air pollutants were analyzed during the given periods as: (a) background (control days i.e. 25th October, 2016 and 14th October, 2017), (b) Pre Diwali (before the onset of Diwali festival i.e. 26–29th October, 2016 and 15–18th October, 2017), (c) Diwali (on the day of festival i.e. 30th October, 2016 and 19th October, 2017) and Post Diwali (after the Diwali festival i.e. 31st October to 3rd November, 2016 and 20th to 23rd October, 2017).

4.2.2 Description of Study Site

Ashok Vihar (latitude: 28.6910° N, longitude: 77.1765° E) is one of residential site of Delhi surrounded by commercial complexes and nearby to an industrial area. There are around four major market places and 2 major commercial complexes. It is also nearby to a metro station, Keshavpuram and 3 major arterial roads. It has also various traffic intersections which are well connected with ring roads and outer ring roads. The passenger per unit (PCU) at Ashok Vihar has been registered 3,267 per hour. One of the famous industrial area of Delhi is located nearby Ashok Vihar i.e. Wazirpur Industrial area which is a hub of many large scale and small scale industries.

4.2.3 Back Trajectory Analysis

Back trajectory analysis have been widely used for the identification of the air mass movement and long-range transport in the Asian as well as in western countries (Stein et al. 2015; Su et al. 2015; Deka et al. 2015; Escudero et al. 2006; Langford et al. 2018). The online Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) (Draxler and Rolph 2014) was used to calculate the trajectories. The transport of pollutants like trace gases or atmospheric aerosols generally analyzed by Lagrangian-based particle trajectory models (White et al. 2007; Stein et al. 2015). In the present study, five day air mass back trajectories using the NOAA-HYSPLIT model over Delhi during the selected period of Diwali and nearby Diwali days along with background period in the year 2016 and 2017 is used.

4.3 Results and Discussion

4.3.1 Air Mass Back Trajectory Analysis

Figures 4.2a–j and 4.3a–j show the five day air mass back trajectories using the NOAA-HYSPLIT model over Delhi at elevation of 500, 1000, 1500 m above mean sea level (AMSL) during the selected period of Background, Pre Diwali, Diwali and post Diwali days in years 2016 and 2017 both. Figure 4.2a–j depicts the selected

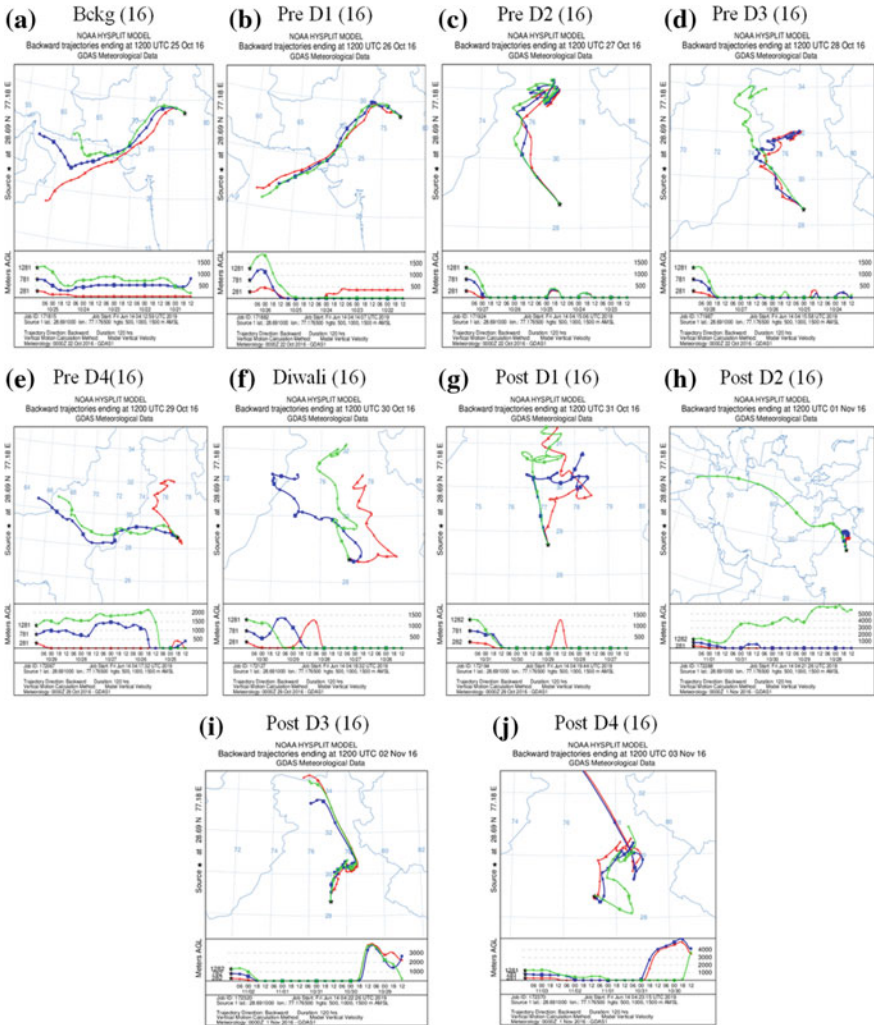


Fig. 4.2 a–j Back trajectory plots during selected period in 2016

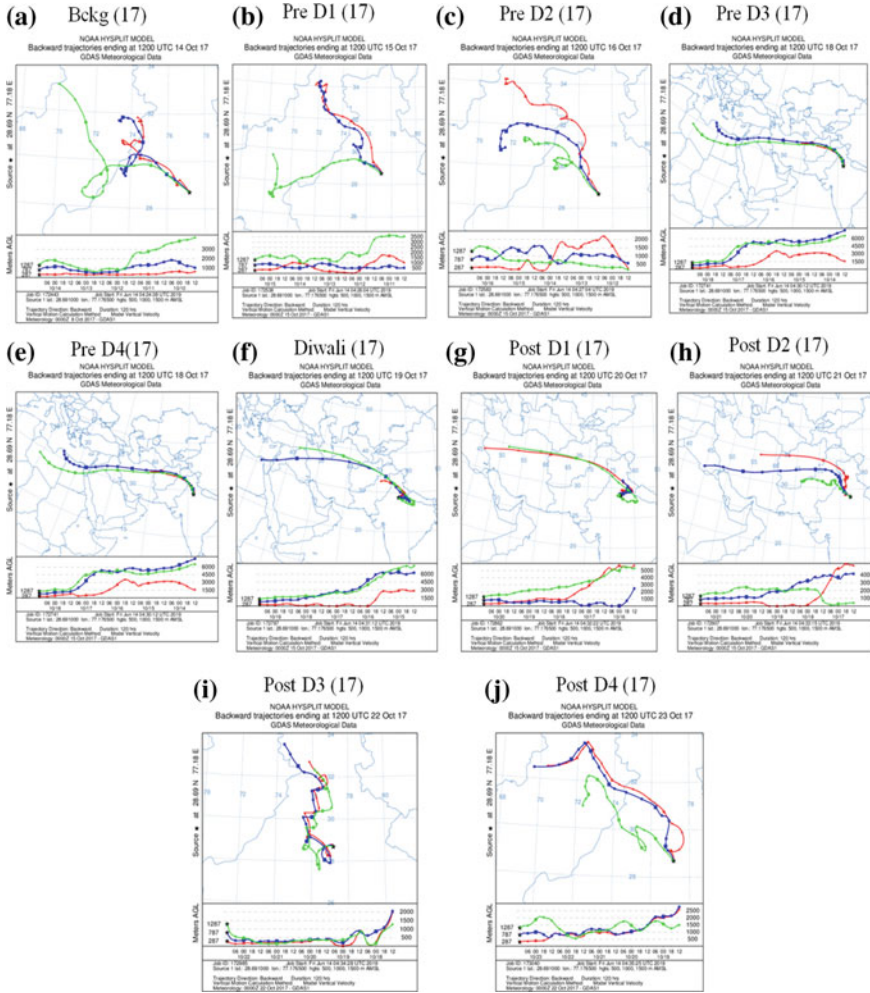


Fig. 4.3 a–j Back trajectory plots during selected period in 2017

periods as (a) Background Day, 25th Oct 2016, (b–e) Pre-Diwali day, 26–29th Oct 2016, (f) Diwali Day, 30th Oct 2016 and (g–j) Post Diwali Day, 31st to 3rd Nov 2016. Likewise, Fig. 4.3a–j depicts the selected periods as (a) Background Day, 14th Oct 2017, (b–e) Pre-Diwali day, 15–18th Oct 2017, (f) Diwali Day, 19th Oct 2017 and (g–j) Post Diwali Day, 20th to 23rd Oct 2017. Hysplit back trajectory (ARL Laboratory, NOAA, USA) have been widely used for the identification of the air mass movement and long-range transport in the Asian as well as in Western countries (Stein et al. 2015; Su et al. 2015; Deka et al. 2015; Escudero et al. 2006; Langford et al. 2018). A detailed analysis of these trajectories depicted in Fig. 4.2a. Background Day, 25th Oct 2016, the trajectories are originating from Pakistan and Arabian Sea

during 2016, whereas neighboring state of Delhi such as Punjab and Haryana and country like Pakistan were identified as origin of air mass during Background Day, 14th Oct 2017 as plotted in Fig. 4.3a. During Pre Diwali period (Fig. 4.2b–e) 26–29th Oct 2016, it was observed that most of the air masses originated from the neighboring states such as Punjab, Himachal Pradesh, Jammu & Kashmir, apart from this some of the air masses were also originated from Pakistan and some part of Arabian Sea. Moreover, during the Pre Diwali days (Fig. 4.3b–e), 15–18th Oct 2017 the air masses were coming from Punjab and some part of Pakistan, whereas it was also noticed that some of the air mass originated from distant countries in Middle East Countries, and Africa. These regions contain high emission sources of pollutants which may carry forward with the help of winds over Delhi region. On the day of Diwali (30th Oct 2016), apart from the local sources air masses originating from neighboring states such as Punjab, Uttar Pradesh, Uttarakhand, it is also clear from the trajectory that some of the air masses also coming from the Pakistan at same day in 2016. In Diwali Day, 19th Oct 2017 (Fig. 4.3f) the major air masses were coming from neighboring states such as Punjab, Uttar Pradesh and countries like Pakistan and some Middle East countries, which may increase the pollutant load during Diwali day in Delhi region. In the analysis of the trajectories during Post Diwali Day, 31st to 3rd Nov 2016 (Fig. 4.2g–j) the most of the air masses were originated from Punjab, Haryana, Uttarakhand and several part of the Middle East countries including Pakistan. Moreover, the Post Diwali trajectories of 20th to 23rd Oct 2017 (Fig. 4.3g–j) showed similar source origin like in 2016.

Overall, the analysis of the air mass back trajectory conclude that the study period in 2016 and 2017 in and around Diwali period was found under the influence of the air masses coming from the nearby states and countries, which may increase the pollution load during the study period in Diwali in both the years.

4.3.2 Annual Variation in Trace Gases and Particulate Matter Concentrations

Figures 4.4a, b and 4.5a, b show the annual variations of trace gases and particulate matter concentrations at selected residential site which is assumed as typical a representative of emission scenario in Delhi city. To analyze the role of emissions in and around Diwali period, the following days are divided per se in two selected years: (a) background (control days i.e. 25th October, 2016 and 14th October, 2017), (b) Pre Diwali (before the onset of Diwali festival i.e. 26–29th October, 2016 and 15–18th October, 2017), (c) Diwali (on the day of festival i.e. 30th October, 2016 and 19th October, 2017) and Post Diwali (after the Diwali festival i.e. 31st October to 3rd November, 2016 and 20th to 23rd October, 2017). The variations among different periods in different years and varies as per different air pollutants are shown in Figs. 4.4a, b and 4.5a, b.

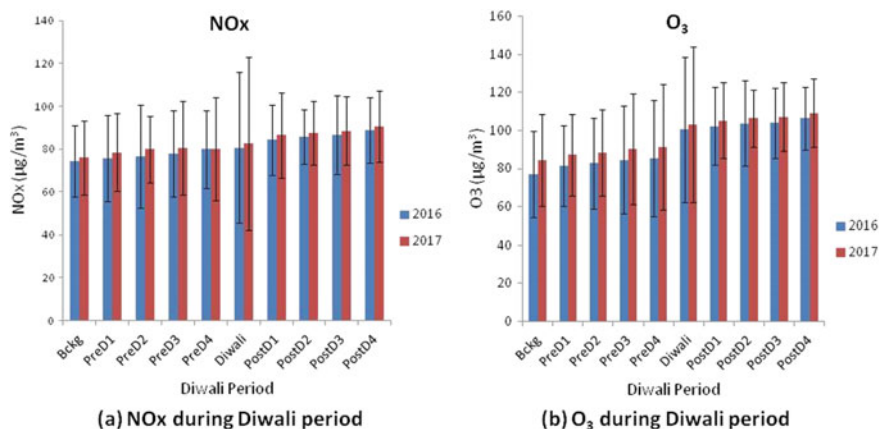


Fig. 4.4 a, b Annual variation of trace gases during selected period of 2016 and 2017

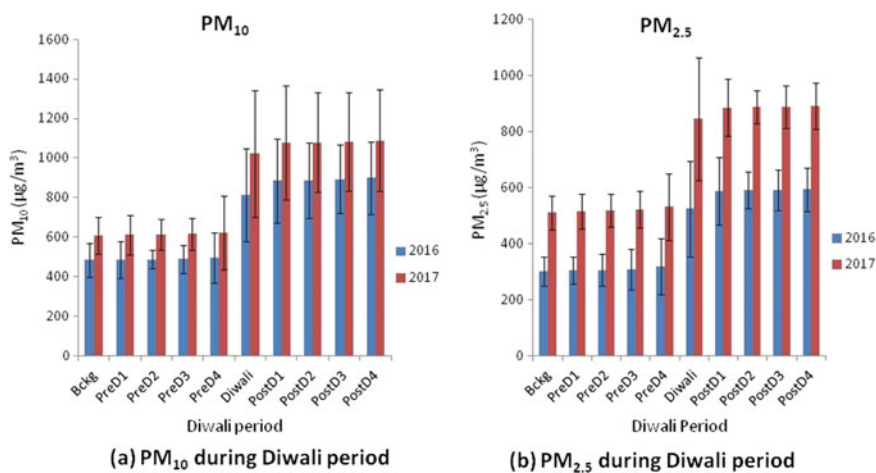


Fig. 4.5 a, b Annual variation of particulate matter during selected period of 2016 and 2017

4.3.3 Trace Gases

Annual average variations of NO_x and O₃ of selected residential site during all the selected periods viz. Background, Pre Diwali, Diwali and Post Diwali are shown in Fig. 4.4a, b. The concentrations found during different selected in and around festive periods were also being compared with National Ambient Air Quality Standards (NAAQS). In case of NO_x, during the year 2016, in background and Pre-Diwali days, the concentrations were found in the range of 74.3 ± 16.6 to 79.8 ± 18.2 µg/m³ which is slightly near to NAAQS permissible limit. However, the background NO_x concentration of 74.3 ± 16.6 µg/m³ is showing significantly lesser than NAAQS permissible

limit but the last and fourth day of Pre-Diwali (PreD4), insignificant difference of NO_x concentration ($79.8 \pm 18.2 \mu\text{g}/\text{m}^3$) was found as compared to NAAQS permissible limit. This is may be due to the reason that, in general, just before the day of Pre-Diwali (PreD4), the firework activities have relatively increased than other days of Pre Diwali (PreD1, PreD2 and PreD3). In addition to that, the selected site is residential site, having about more than 40 major colonies, which will also contribute the high concentrations of NO_x on fourth and last day of Pre Diwali period (PreD4). Interestingly, as shown in Fig. 4.4a, b, there is insignificant difference between the concentrations of background ($74.3 \pm 16.6 \mu\text{g}/\text{m}^3$) and first 3 days of Pre-Diwali (75.5 ± 20.1 ; 76.4 ± 24.1 and $77.8 \pm 20.3 \mu\text{g}/\text{m}^3$). This is may be due to the fact that fireworks activities generally becomes higher just before one day of Diwali as compared to previous days of Pre Diwali and since Ashok Vihar is a residential area and connected to ring roads, are responsible for high concentrations of NO_x just before one day of Diwali, as more of shopping and transportation activities becomes relatively higher at that day as compared to other previous days of Pre-Diwali period. Hence, insignificant change was observed during background and first three days of Pre Diwali period. On Diwali day, $80.65 \pm 35.5 \mu\text{g}/\text{m}^3$ of NO_x was found which is insignificantly different from NAAQS permissible limit, may be due to, firework activities were started from the last day of Pre Diwali, therefore, there is no significant difference between just before one day of Diwali and on the day of Diwali. However, significant difference was found between average value of Pre Diwali period ($77.37 \pm 15.67 \mu\text{g}/\text{m}^3$) and the day of Diwali ($80.65 \pm 35.5 \mu\text{g}/\text{m}^3$). During Post Diwali period, in all the days (PostD1–PostD4), higher concentrations of NO_x (84.32 ± 16.5 – $88.76 \pm 15.3 \mu\text{g}/\text{m}^3$) were found that are higher than NAAQS permissible limit. This may be due to the lower boundary layer and low temperature during October month which trapped the air pollutants and resulted in higher concentrations (Srinivas et al. 2015; Sonwani and Saxena 2016; Saxena and Naik 2018). Higher concentrations of NO_x were found in the year 2017 as compared to 2016 during all the selected days of Diwali period. Similar trend was also reported in 2017, in background and Pre-Diwali days, that the concentrations were found in range of 75.9 ± 17.2 to $80.08 \pm 24.2 \mu\text{g}/\text{m}^3$ which is also slightly near to or at the threshold level of NAAQS limit. In this year too, the background NO_x concentration of $75.9 \pm 17.2 \mu\text{g}/\text{m}^3$ is showing significantly lesser than NAAQS permissible limit while the 3 days of Pre-Diwali i.e. PreD2, PreD3 and PreD4 were at the threshold or very near to NAAQS permissible limit. On Diwali day, higher concentration of NO_x was found to be $82.65 \pm 40.5 \mu\text{g}/\text{m}^3$ in 2017 as compared to 2016 which is just crossing the NAAQS permissible limit. Moreover, significant difference was observed between mean value of Pre Diwali period ($79.70 \pm 22.4 \mu\text{g}/\text{m}^3$) and the day of Diwali ($82.65 \pm 40.5 \mu\text{g}/\text{m}^3$). During Post Diwali period, in all the days (PostD1–PostD4), higher concentrations of NO_x (86.43 ± 20.1 – $90.54 \pm 16.7 \mu\text{g}/\text{m}^3$) were found that are higher than NAAQS permissible limit and also reported to higher than 2016. This is may be due to the transboundary movements of air masses from adjoining states and neighboring countries for the increasing pattern of air pollutants found to be more prevalent than 2016 as already shown in Figs. 4.2a–j and 4.3a–j.

In case of O_3 , significantly lower concentrations were found during background and Pre Diwali period in both the years of 2016 (77.13 ± 22.8 – $85.43 \pm 30.5 \mu\text{g}/\text{m}^3$) and 2017 (84.34 ± 24.1 – $91.22 \pm 33.0 \mu\text{g}/\text{m}^3$) as compared to NAAQS permissible limit. This may be due to the fact that, ozone formation is a non linear process, therefore its precursor-product relationship is not dependent on only precursor (e.g. NO_x , VOCs or CO) rather other precursors too (Sonwani et al. 2016). On the day of Diwali, in both the years, ozone concentrations in 2016 ($100.54 \pm 38.2 \mu\text{g}/\text{m}^3$) as well as in 2017 ($103.23 \pm 41.0 \mu\text{g}/\text{m}^3$) were just crossing the threshold limit of NAAQS. This may be due to that firework activities are found to be more on the day of Diwali as compared to other previous days. Moreover, vehicular activities just before the day of Diwali are generally high and due to lower boundary layer and stable atmospheric conditions, ozone concentrations were found to be high at the day of Diwali (Thakur et al. 2010; Singh et al. 2010; Saxena et al. 2019). During post Diwali period, ozone concentrations were found to be significantly higher than NAAQS permissible limit in both 2016 (102.43 ± 20.0 to $106.54 \pm 16.5 \mu\text{g}/\text{m}^3$) and 2017 (105.32 ± 20.1 to $109.34 \pm 18.1 \mu\text{g}/\text{m}^3$). This may be due to the lower boundary layer and low temperature during October month which trapped the air pollutants and resulted in higher concentrations (Srinivas et al. 2015; Sonwani and Saxena 2016). In case of O_3 too, higher concentrations were found to be more in 2017 as compared to 2016 due to the transboundary movements of air masses from adjoining states and neighboring countries for the increasing pattern of air pollutants found to be more prevalent than 2016 as already shown in Figs. 4.2a–j and 4.3a–j.

4.3.4 Particulate Matter

Figure 4.5a, b shows the changes in the annual mean $\text{PM}_{2.5}$ and PM_{10} concentrations at the selected residential site during in and around Diwali period. The concentrations found during different selected in and around Diwali periods were also being compared with National Ambient Air Quality Standards (NAAQS), India. In case of $\text{PM}_{2.5}$, the background ($301.22 \pm 50.30 \mu\text{g}/\text{m}^3$) and Pre Diwali period concentrations (304.55 ± 48.60 to $318.76 \pm 100.50 \mu\text{g}/\text{m}^3$) are 5 times higher than the permissible limit of NAAQS in the year 2016. Moreover, significant difference was found between background concentration ($301.22 \pm 50.30 \mu\text{g}/\text{m}^3$) and all days of Pre Diwali period (PreD1 to PreD4). This may be due to the fact that Ashok Vihar is very near to one of the main industrial area of Delhi i.e. Wazirpur Industrial area which is a hub of construction as well as electroplating industries. These industries may emit a large number of particulate matter which got suspended in the atmosphere. Moreover, in late October month, low temperature and lower boundary layer trapped the particulate matter more firmly as compared to trace gases like NO_x and O_3 (Nishanth et al. 2012; Sonwani and Kulshrestha 2019). Hence, very high concentrations of $\text{PM}_{2.5}$ were found during the background and Pre Diwali period. On the day of Diwali, alarmingly high concentration of $\text{PM}_{2.5}$ ($524.23 \pm 170.30 \mu\text{g}/\text{m}^3$) was reported which is 7 times higher than NAAQS permissible limit. Firework activities

and lower boundary layer and low temperature can be the major reason for such high concentrations. During Post Diwali, $PM_{2.5}$ concentrations were found to be 8–9 times higher than NAAQS permissible limit in all the four days of Post Diwali period (589.32 ± 120.50 to $594.22 \pm 78.30 \mu\text{g}/\text{m}^3$). The high loading of atmospheric particulate matter particularly during winter months due to low temperature leads to the low mixing height and stable atmospheric conditions and transportation of emission coming from biomass burning or crop residue burning activities in nearby states and countries as already shown in Figs. 4.2a–j and 4.3a–j. During the year 2017, $PM_{2.5}$ concentrations were also found to very high and about 8–13 times higher than NAAQS permissible value, which is higher than the values reported in year 2016. Significant difference was found between background concentration ($511.23 \pm 60.20 \mu\text{g}/\text{m}^3$) and all days of Pre Diwali period (516.22 ± 63.0 to $531.28 \pm 120.50 \mu\text{g}/\text{m}^3$). On the day of Diwali, $845.34 \pm 220.50 \mu\text{g}/\text{m}^3$ of concentration was found which is almost 13 times higher than NAAQS permissible limit. Moreover, during post Diwali period, in all the days, concentrations (886.12 ± 102.70 to $891.23 \pm 83.90 \mu\text{g}/\text{m}^3$) were found be 13–14 times higher than NAAQS permissible value. Higher concentrations of $PM_{2.5}$ was found in all the days of background and in and around Diwali period in the year 2017 as compared to 2016 may be due to increased firework activities, transboundary movements of air masses from neighboring states and countries as already discussed in Figs. 4.2a–j and 4.3a–j, increased biomass burning and crop residue burning (Ambade and Ghosh 2013; Sonwani et al. 2016; Sonwani and Kulshreshtha 2016; Sonwani and Kulshreshtha 2018).

Similarly, in case of PM_{10} , during the year 2016, concentrations were found to be 5–8 times than NAAQS permissible limit in all the days of Diwali period and background day and 6 to 10 times higher in the year 2017. During the year 2016, significant difference was found between background day ($484.56 \pm 85.2 \mu\text{g}/\text{m}^3$) and all the days of Pre Diwali period (486.55 ± 91.5 to $497.65 \pm 126.2 \mu\text{g}/\text{m}^3$). In the year 2017 too, very high concentrations of PM_{10} during the period of background ($609.76 \pm 92.50 \mu\text{g}/\text{m}^3$) as well as Pre Diwali period (612.33 ± 99.3 to $623.24 \pm 185.80 \mu\text{g}/\text{m}^3$) was found which clearly depicted the significant difference between them. This may be due to the fact that likely in the case of $PM_{2.5}$ too, industrial emissions from nearby industrial area of Ashok Vihar emitted a large amount of particulate matter which got suspended in the atmosphere. Moreover, in October month, low temperature and lower boundary layer trapped the particulate matter more firmly as compared to trace gases like NO_x and O_3 (Nishanth et al. 2012). Hence, very high concentrations of $PM_{2.5}$ were found during the background and Pre Diwali period. On the day of Diwali, $813.23 \pm 233.70 \mu\text{g}/\text{m}^3$ in 2016 and $1023.13 \pm 320.90 \mu\text{g}/\text{m}^3$ in 2017 PM_{10} concentrations were found which are 8 and 10 times higher than NAAQS standard. Moreover, during Post Diwali period concentrations were found in the range of $885.43 \pm 211.78 \mu\text{g}/\text{m}^3$ to $899.65 \pm 182.80 \mu\text{g}/\text{m}^3$ in 2016 and $1077.43 \pm 287.20 \mu\text{g}/\text{m}^3$ to $1089.23 \pm 255.80 \mu\text{g}/\text{m}^3$ in 2017. These were also found to be 8–11 times higher NAAQS permissible limit. This is also due to the similar reason as mentioned in the above section of $PM_{2.5}$.

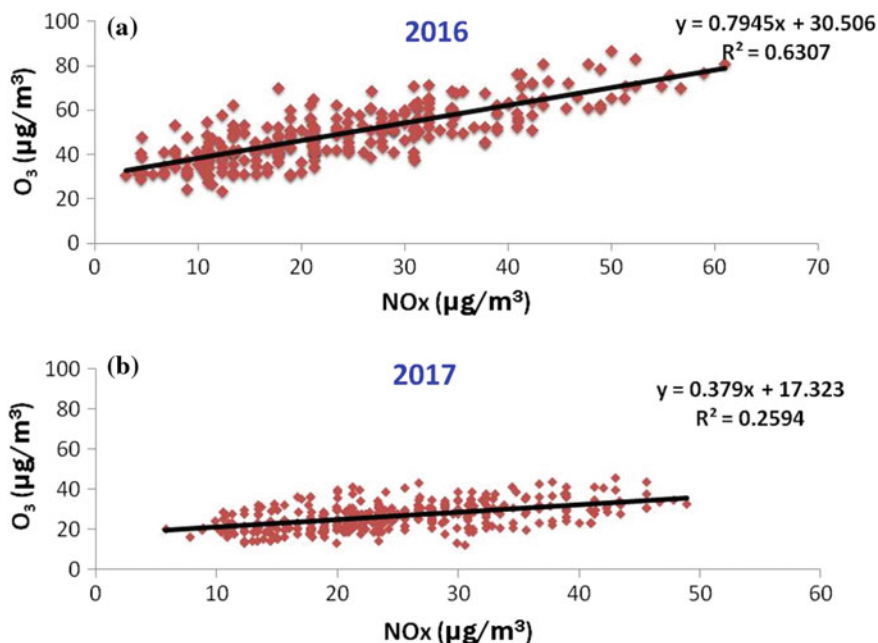


Fig. 4.6 a, b Correlation plots of NO_x and O₃ during selected period of 2016 and 2017

4.3.5 Relationship Between NO_x and O₃ in and Around Fireworks Festival

Figure 4.6a shows a positive moderate correlation with a correlation coefficient of 0.63 in 2016. This shows that O₃ was formed from the photolysis of NO_x during the selected period of Diwali but can be produced from other sources too. Similar observation was found in the study of Nishanth et al. (2012). While a weak correlation was found between O₃ and NO_x as shown in Fig. 4.6b with a correlation coefficient of 0.25 in 2017. This depicts that O₃ and NO_x are not well correlated and the O₃ may be produced from other sources during Diwali period.

4.4 Conclusion

The present study concludes that the levels of particulate matter as well as trace gases stay near or above the NAAQS threshold level for the “very healthy” and in some cases “severe” category at one of the residential site of Delhi in 2016 and 2017 for most of the selected period of in and around Diwali. Generally, a significant rise in the concentrations of selected air pollutants (trace gases and particulate matter) from 4 days back from Diwali, considering during Pre Diwali period onwards reveals

the impact of high background emissions and transported component behind their high concentrations. Moreover, the transboundary movements of air masses from adjoining states of Delhi along with nearby neighboring countries like Pakistan and Middle East countries have also contributed to a larger extent in the form of biomass burning. The concentrations of trace gases and particulate matter also showed an increasing trend year after year. Therefore, higher concentrations of trace gases and particulate matter were found in 2017 as compared to 2016. In Diwali-2016, the highest PM_{10} and $PM_{2.5}$ concentrations were about 8 times and 7 times higher than National Ambient Air Quality Standards (NAAQS) limits respectively. For Diwali-2017, there was rapid increase in PM_{10} and $PM_{2.5}$ concentrations that were about 10 times and 13 times higher than NAAQS threshold value respectively. Moreover, PM_{10} and $PM_{2.5}$ concentrations in 2017, higher than 2016 were found to be 5–8 times more as compared to background concentrations. Moreover, particulate matter (PM_{10} and $PM_{2.5}$) seems similar during Diwali and post Diwali period. The relatively similar concentration (no significant difference) of PM even after Diwali period pointed towards some transported component along with the air-masses coming from the neighboring states and countries, which contribute high load of PM during and after Diwali period in Delhi. Thus, the heavy background emissions due to biomass burning/agricultural-waste burning may contribute significantly to the total pollution load (especially PM) in and around firework festival in Delhi.

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