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Ambient air quality of Lucknow City (India) during use of fireworks on Diwali Festival

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Abstract The present study deals with the effect of fireworks on ambient air quality during Diwali Festival in Lucknow City. In this study, PM_{10}, SO_2, NO_x and 10 trace metals associated with PM_{10} were estimated at four representative locations, during day and night times for Pre Diwali (day before Diwali) and Diwali day. On Diwali day 24 h average concentration of PM_{10}, SO_2, and NO_x was found to be 753.3, 139.1, and 107.3 μg m^{-3}, respectively, and these concentrations were found to be higher at 2.49 and 5.67 times for PM_{10}, 1.95 and 6.59 times for SO_2 and 1.79 and 2.69 for NO_x, when compared with the respective concentration of Pre Diwali and normal day, respectively. On Diwali day, 24 h values for PM_{10}, SO_2, and NO_x were found to be higher than prescribed limit of National Ambient Air Quality Standard (NAAQS), and exceptionally high (7.53 times) for PM_{10}. On Diwali night (12 h) mean level of PM_{10}, SO_2 and NO_x was 1,206.2, 205.4 and 149.0 μg m^{-3}, respectively, which was 4.02, 2.82 and 2.27 times higher than their respective daytime concentrations and showed strong correlations ($p<0.01$) with each other. The 24 h mean concentration of metals associated with PM_{10} was found to be in the order of Ca (3,169.44)>Fe (747.23)>Zn (542.62)>Cu (454.03),>Pb (307.54)>Mn (83.90)>Co (78.69)>Cr (42.10)>Ni (41.47)>Cd (34.69) in ng m^{-3} and all these values were found to be higher than the Pre Diwali (except Fe) and normal day. The metal concentrations on Diwali day were found to be significantly different than normal day (except Fe & Cu). The concentrations of Co, Ni, Cr and Cd on Diwali night were found to be significantly higher than daytime concentrations for Pre Diwali (control). The inter correlation of metals between Ca with Pb, Zn with Ni and Cr, Cu with Co, Co with Mn, Ni with Cd, Mn with Cd, Ni with Cd and Cr, and Cr with Cd showed significant relation either at $p<0.05$ or $P<0.01$ levels, which indicated that their sources were the same. The metals Cu, Co, Ni, Cr and Cd showed significant ($p<0.01$) association with PM_{10}. These results indicate that fireworks during Diwali festival affected the ambient air quality adversely due to emission and accumulation of PM_{10}, SO_2, NO_x and trace metals.

Keywords Diwali · Fireworks · Air pollutants · Trace metals

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Introduction

Diwali (or Deepawali) is the festival of lights and is celebrated with great enthusiasm all over India every year. Firing crackers is an integral activity of the celebrations during Diwali. Fireworks and crackers are used world over for different occasions in different countries. Fireworks emit trace gases and particulates including metals into the atmosphere, which generate dense clouds of smoke that contain black powder containing potassium nitrate, charcoal and sulphur (Liu et al. 1997; Dutcher et al. 1999; Mandal et al. 1997; Kulshrestha et al. 2004; Drewnick et al. 2006). Attri et al. (2001) showed that the formation of O_3 without participation of NO_x is due to burning of sparklers.

Bach et al. (1975) found that firework activities on New Year's Eve on Oahu was responsible for an increase in TSPM by an average of 300% at 14 locations and by about 700% in the lung penetrating size ranges at one location. Ravindra et al. (2003) reported that fireworks during Diwali Festival, lead to a short term variation of air quality and observed the 2–3 times increased PM_{10} and TSPM concentration in Hisar City (India). Kulshrestha et al. (2004) reported that the high level of different trace elements in ambient air of Hyderabad, (India) was due to fireworks during Diwali Festival. Hirai et al. (2000) found that inhalation of smoke from firework causes cough, fever, and dyspnoea and leads to acute eosiophilic pneumonia (AEP).

The urban population is mainly exposed to high levels of air pollution including metals because of motor vehicle emissions, which is also the main source of fine and ultrafine particles (Morawska et al. 2002; Ristovski et al. 1998; Fang et al. 2005; Sharma et al. 2006), which influence the air quality. These particles can penetrate deep into the respiratory system, and studies indicate that the smaller the particle, more severe the health impacts (Dockery et al. 1993; Pope et al. 1995; Schwartz et al. 1996). Ambient particulate matter may be carriers of acidic or toxic species (e.g., heavy metals, acids and carcinogenic organic compounds) and may have detrimental effects on human health and ecosystems. Besides particulate matter, literature also suggests that there is a strong relationship between higher concentration of SO_2 & NO_x and several health effects (Curtis et al. 2006), like cardiovascular diseases (Peters et al. 2004; Chen et al. 2005; Zanobetti and Schwartz 2002; Dockery et al. 2005), respiratory health effects such as asthma and bronchitis (Ye et al. 2001; Barnett et al. 2005), reproductive and developmental effects such as increased risk of preterm birth (Liu et al. 2003).

At elevated concentrations all the metals are harmful to living beings including humans (Yasutake and Hirayama 1997). Exposure can occur through a variety of routes; inhalation of particles (<10 μm) is one of the important routes. The inorganic components constitute a small portion by mass of the particulates, however, it contains some trace elements such as As, Cd, Co, Cr, Ni, Pb and Se which are human or animal carcinogens even in trace amounts (ATSDR 2003; Wang et al. 2006). There are several reports that high level of Pb can induce severe neurological and hematological effects on the exposed population especially children, whereas Cd and Ni are known for inducing carcinogenic effects in humans through inhalation, occupational level of Cd exposure is a risk factor for chronic lung diseases (Benoff et al. 2000). Cr (VI) is known to have toxic and carcinogenic effect on the bronchial tree (Manalis et al. 2005; Hu 2002). Mn exposure leads to increased neurotoxic impairments (Santos-Burgoa et al. 2001). The increased level of Cu can lead to respiratory irritance (ATSDR 2002; Manalis et al. 2005).

Vehicular traffic is the main source of particulate air pollution in Lucknow city (Kisku et al. 2003; Sharma et al. 2006). Continuous emission of pollutants from vehicular traffic, is itself a matter of concern and in addition, fireworks during Diwali festival generate huge amount of PM as well as gaseous pollutants including metals and ultimately aggravate the pollution level. Diwali festival is celebrated in Lucknow city along with rest of India with great enthusiasm. Huge amount of crackers and sparklers are burnt mainly on the day of festival (Diwali day) and also on the day before Diwali (Pre Diwali day) but less in comparison to Diwali day. During the year 2005, the main day of Diwali happened on 1st November. In order to determine the short-term effects of fireworks on the local environment, monitoring of PM_{10}, SO_2, NO_x, was conducted at four residential areas of Lucknow City during Pre Diwali and Diwali days. Ten trace metals, which are associated with PM_{10}, were also estimated.

Materials and methods

Site and sample collection

Lucknow is the capital of Uttar Pradesh, India, situated in northern India with a population of 2.245 million, (2001 census) and lies between 26° 52′ Latitude and 80° 56′ Longitude at 128 m above sea level. Monitoring of PM_{10}, SO_2, and NO_x were done simultaneously in the ambient air at four residential areas namely Alambagh, Aliganj, Chowk and Gomti Nagar, for 12 h continuously during day and night time of pre Diwali (day before Diwali) and Diwali day and trace metals namely Fe, Ca, Zn, Cu, Pb, Co, Mn, Ni, Cr, Cd associated with PM_{10} were estimated. The residential areas namely Gomti Nagar, Chowk, Aliganj and Alambagh are 10–15 km apart from each other and are situated in all the four east, west, north and south directions of Lucknow city, respectively.

Monitoring and analysis

Monitoring of PM_{10} was carried out using Respirable Dust Sampler (Model-415, Envirotech, New Delhi) at a flow of 1.0–1.2 m^3/min for 12 h day (6.0 A.M.–6.0 P.M.) and night time (6.0 P.M.–6.0 A.M.). The sampling instruments were fixed at a breathing height of 1.5 m above the ground level. Preweighed cellulose filters, Whatman (EPM-2000) of 20×25 cm size were used and reweighed after sampling in order to determine the mass of the particles collected. The concentration of the particulate matter in ambient air was then computed on the net mass collected divided by the volume of air sampled.

The analysis of SO_2 and NO_x was done by Bureau of Indian Standard (BIS) methods Indian Standard (2001): IS: 5182 (Part II) and Indian Standard (1975): IS: 5182 (Part VI), respectively. A known quantity of air was passed through the impinger containing known volume of absorbing solution; SO_2 is absorbed in absorbing solution, sodium tetrachloromecurate. A dichlorsulphitomercurate complex is formed which made to react with para rosaniline and methysulphonic acid. The absorbance of the solution was measured at a wavelength of 560 nm on spectrophotometer (Spectronic-20). Whereas, Nitrogen oxides (NO_x) as nitrogen dioxide was absorbed in absorbing solution, sodium hydroxide which formed a stable solution of sodium nitrite. The nitrite ion produced was determined colorimetrically at a wavelength 540 nm by reacting the exposed absorbing reagent with phosphoric acid, sulphanilamide and N (1-naphthyl) ethylenediamine dihydrochloride.

Metal analysis

Total 60 circles of 1" diameter (4 locations + 1 control/blank) were punched out in triplet from the sampled filter paper and digested with concentrated nitric acid on hot plate till white fumes arose and reduced to 2–3 ml. The content was filtered through Whatman Filter no. 42 and final volume made-up to 25 ml by double distilled water. The filtrate was examined for the concentration of, Ca, Fe, Zn, Cu, Pb, Co, Mn, Ni, Cr and Cd by AAS (Varian Spectra AA-250 Plus). The AAS values of blank filter papers of each metal was deducted for the sample value for final calculations. The AAS was calibrated for each metal using known CRM (Qualigens make) before analysis and the details of Atomic Absorption Spectrophotometer (AAS) for analysis is given in Table 1.

Statistical analysis

Pollutant concentrations in four different periods (12 h), three different days (24 h) and four different locations were compared separately by one factor analysis of variance (ANOVA) and their significance by Dunnett's test and Newman Keuls multiple range test (Zar 1974). While comparing group means between periods and days, non Diwali period i.e. day time concentrations of Pre Diwali day (background no. 1) and non Diwali days (Normal) i.e. concentrations measured in May 2005 (background no. 2) were taken

Table 1 Details of atomic absorption spectrophotometer (AAS)

Metal	Wavelength (λ)	Slit (nm)	OWRD (μg/ml)
Ca	422.7	0.5	0.01–3.0
Fe	248.3	0.2	0.06–0.15
Zn	213.9	1.0	0.1–2.0
Cu	324.7	0.5	0.03–10
Pb	121.7	1.0	0.1–30
Co	240.7	0.2	0.05–15
Mn	279.5	0.2	0.02–5
Ni	232.0	0.2	0.1–20
Cr	357.9	0.2	0.06–15
Cd	228.8	0.5	0.02–3

OWRD=Optimum Working Range of Detection

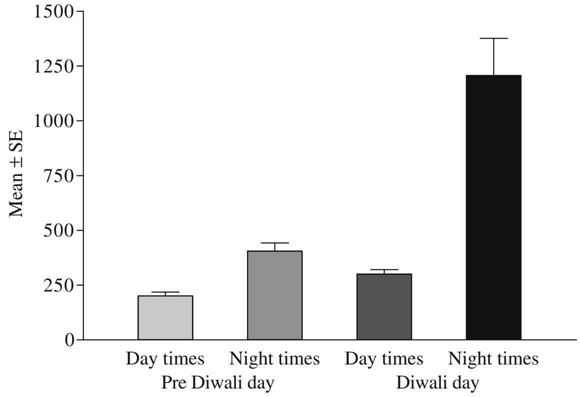

Fig. 1 Mean concentrations (μg m^{-3}) of PM_{10} in ambient air of Lucknow City during day and night times of Pre Diwali and Diwali day

as control group, respectively. Instead of defining all the 10 metals every time, we have used the average of all the 10 metals (Metals_M). Pearson correlation coefficient (r) was also calculated between metals, PM_{10}, SO_2 and NO_X. Before analyzing, to make data more homogenous, all the data were first $\log_{10}$ transformed. Statistical analysis was done on transformed data. Interpretation and graphical representation were done on actual data.

Results and discussion

Air pollutants – PM_{10}, SO_2 and NO_x

Day and night concentration

On Diwali night average concentration of four locations for PM_{10}, SO_2, and NO_x were found to be

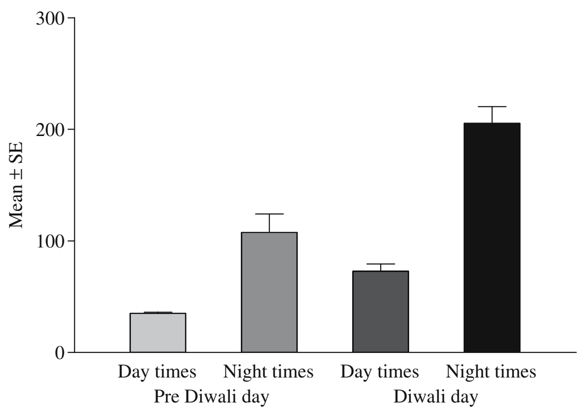

Fig. 2 Mean concentrations (μg m^{-3}) of SO_2 in ambient air of Lucknow City during day and night times of Pre Diwali and Diwali day

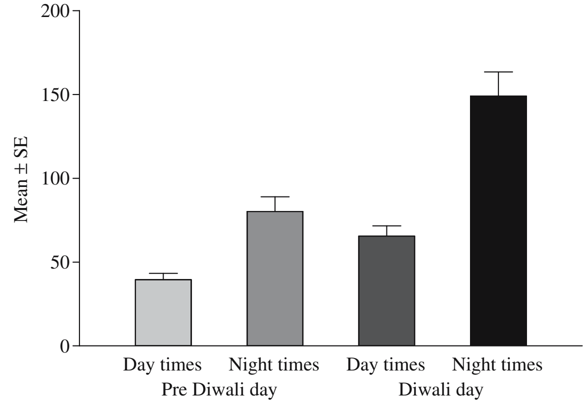

Fig. 3 Mean concentrations (μg m^{-3}) of NO_x in ambient air of Lucknow City during day and night times of Pre Diwali and Diwali day

1,206.2 (807.5–1,632.4), 205.4 (176.9–238.3) and 149.0 (126.7–190.8) μg m^{-3}, respectively, (Figs. 1, 2 and 3). These concentrations were 4.02, 2.82 and 2.27 times higher than their respective daytime level and found to be significant (P<0.01) when compared with day time concentrations of Pre Diwali (Table 2).

Whereas in case of Pre Diwali night same trend were observed which was 405.1 (307.8–488.2), 107.6 (74.0–147.9) and 80.1 (63.9–104.9) μg m^{-3} (Figs. 1, 2 and 3) and were 2.02, 3.07 and 2.02 times higher than their respective daytime concentration, respectively, and found to be significant (P<0.01) (Table 2).

Furthermore, the daytime concentrations of PM_{10}, SO_2 and NO_x on Diwali day was found to be significantly higher than the previous daytime (Pre Diwali) concentrations (Figs. 1, 2 and 3), which was found to be increased by 49.49, 107.85 and 65.61% for PM_{10}, SO_2 and NO_x, respectively. In general, there were no fireworks during daytime and besides due to a public holiday the source of vehicular pollution might have been less than the Pre Diwali day. Even then, the increase in concentration indicated a longer time stay of these pollutants in the ambient air accumulated on Pre Diwali night due to fireworks.

24 hours concentration

The 24 h concentration of PM_{10}, was found in the range of 527.5 (Gomti Nagar) to 963.3 (Aliganj) with an average value of 753.3 μg m^{-3} (Fig. 4). The 24 h concentration of SO_2 ranged from 119.5 (Gomti Nagar) to 163.7 (Alambagh) with an average value of 139.1 μg m^{-3} (Fig. 5) and NO_x ranged from 91.6

Table 2 Comparison between periods by Dunnett test (DF=12)

Comparisons	Fe	Ca	Zn	Cu	Pb	Co	Mn	Ni	Cr	Cd	PM_{10}	SO2	NO_x
Pre Diwali day vs. Pre Diwali night	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	**	**
Pre Diwali day vs. Diwali-day	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	**	**
Pre Diwali day vs. Diwali-night	ns	ns	ns	ns	ns	*	ns	*	*	*	**	**	**

ns=not significant ($p>0.05$), *=significant ($p<0.05$), **=significant ($p<0.01$)

(Gomti Nagar) and 134.0 (Alambagh) with an average value of 107.3 μg m^{-3} (Fig. 6) and the concentrations was found to be 5.67 & 7.53 for PM_{10}, 6.59 & 1.74 for SO_2 and 2.69 & 1.34 for NO_x times higher than the normal day and the prescribed National Ambient Air Quality Standard (NAAQS), respectively.The normal day values at same locations during May 2005 are reported in ITRC report June 2005; Sharma et al. (2006). On Diwali day the maximum concentration increased in order of PM_{10} (248.59%) > SO_2 (195.09%) > NO_x (179.22%) to Pre Diwali day and showed significantly higher (PM_{10} & SO_2 at $p<0.01$ and NO_x for $p<0.05$ level) and PM_{10} (567.50%) > SO_2 (659.77%) > NO_x (269.13%) to normal day and all the values showed significantly higher ($p<0.01$) (Table 3).

Mean concentrations of PM_{10} and SO_2 on Diwali day and Pre Diwali day were found significantly ($p<0.01$) higher than the normal day (background no. 2) and the mean concentrations of the same pollutants during Diwali day were also found to be significantly higher ($p<0.01$) than the Pre Diwali day.While comparing NO_x, Pre Diwali day values were insignificant ($p>0.05$) than the normal day (background no. 2) but during Diwali day it increased significantly ($p<0.05$) than the background no. 2 and the Pre Diwali day (Table 3). Several times increase of PM_{10}, SO_2 and NO_x than the normal day values were reported by Central Pollution Control Board (CPCB), New Delhi, with maximum 300 times increase of SO_2 during Diwali in Delhi, India and exposure to this deadly gas is responsible for the incidence of severe respiratory diseases (http://cseindia.org/campaign/apc/dark_trends.htm).

The elevated concentration of PM_{10}, SO_2 and NO_x and trace metals with particulate matters have direct relation with adverse human health as well as on the environment (Gupta et al. 2003; Wang et al. 2006; Maynard and Kuempel 2005). Generally, higher concentration of PM_{10}, SO_2, NO_x is responsible for respiratory diseases, asthma, cardiovascular effects, lung cancer, disorder in reproductive and development, neurological and neuropsychiatric effects (Curtis et al. 2006). With these reference levels of concentration observed in our study, the short-term increase of air pollutants especially the PM_{10} on the Pre Diwali and Diwali day, are a cause of major concern due to their human health effects.

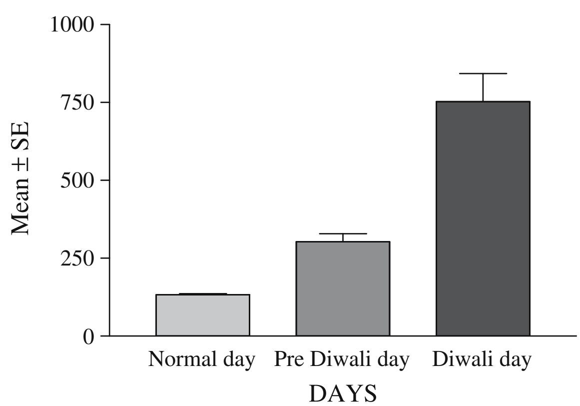

Fig. 4 Average PM_{10} concentrations (μg m^{-3}) in ambient air of Lucknow City during Normal, Pre Diwali and Diwali day

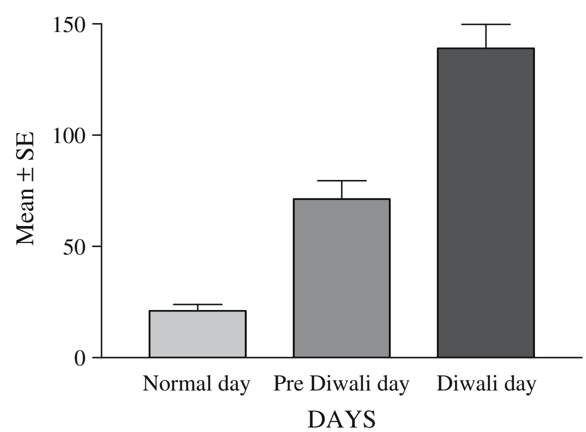

Fig. 5 Average SO_2 concentrations (μg m^{-3}) in ambient air of Lucknow City during Normal, Pre Diwali and Diwali day

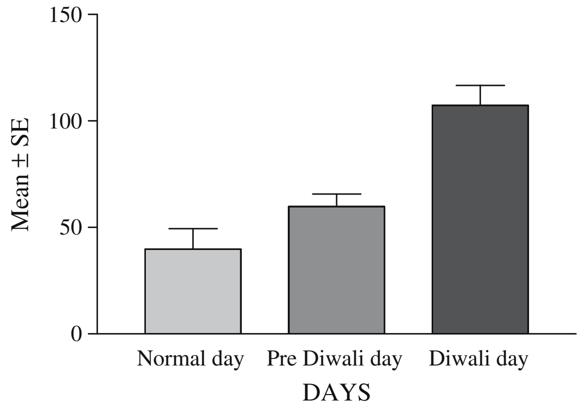

Fig. 6 Average NO_x concentrations ($\mu g\ m^{-3}$) in ambient air of Lucknow City during Normal, Pre Diwali and Diwali day

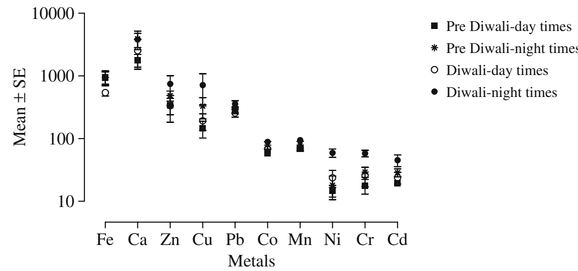

Fig. 7 Mean concentrations ($\mu g\ m^{-3}$) of different metals in ambient air of Lucknow City during day and night times of Pre Diwali and Diwali day

Metal concentration

Day and night time metal concentration

On Diwali night, the concentration of metals were found to be Ca=3,807.01, Fe=952.89, Zn=748.68, Cu=715.64 Pb=358.79, Co=88.64, Mn=94.88, Ni=59.19, Cr=58.21 and Cd=45.47 ng m^{-3} (Fig. 7) and which were Ca=1.50, Fe=1.73, Zn=2.22, Cu=3.72, Pb=1.40, Co=1.29, Mn=1.30, Ni=2.49, Cr=2.24 and Cd=1.90 times higher than the respective day time concentration. During Diwali night the mean comparison of metals (Table 2) showed that Co, Ni, Cr, and Cd significantly ($P<0.05$) increased from the day time of Pre Diwali (background no. 1). Other metals also increased but were found statistically not significant ($p>0.05$) which suggests that fireworks do not influence these metals (Fe, Ca, Zn, Cu, Pb, Mn) significantly due to high variations. Similarly Cu and Fe concentration levels for Diwali night show the maximum and minimum increase of 4.90 and 1.00 times, respectively, than the background no. 1.

Fireworks also influenced the metal level on Pre Diwali night and their mean concentration were found to be Ca=3,912.50, Fe=947.32, Zn=486.30, Cu=329.40, Pb=307.27, Co=78.87, Mn=79.11, Ni=18.04, Cr=29.47 and Cd=28.76 ng m^{-3}, respectively, and found Ca=1.91, Fe=0.99, Zn=1.43, Cu=2.26, Pb=1.07, Co=1.35, Mn=1.12, Ni=1.22, Cr=1.67 and Cd=1.47 times higher than the respective day time concentration.

The concentration of trace metals estimated on day time of Pre Diwali was not sourced from the fireworks and could be considered as normal concentration and the rest of the analysis result showed that the metal accumulation in air from the fireworks as well as normal source and maximum level was found in the Diwali night when the maximum fireworks were burnt. The mean concentration of the 10 trace metals during day and night time of Pre Diwali and Diwali festivals is as shown (Fig. 7) and their average (average of 10 metals) concentration (ng m^{-3}) in night of Pre Diwali and Diwali are of:

Night Pre Diwali (621.70) < Night Diwali (692.94)

The above order clearly indicates that the firecrackers were the source of elevated metal concentration on Diwali night. Overall the concentration of

Table 3 Comparison between days by Newman Keuls test (DF=9)

Comparisons	Fe	Ca	Zn	Cu	Pb	Co	Mn	Ni	Cr	Cd	PM_{10}	SO_2	NO_x
Normal vs. Pre Diwali	ns	*	**	ns	**	**	**	ns	*	**	**	**	ns
Normal vs. Diwali	ns	*	**	ns	*	**	**	*	*	**	**	**	**
Pre Diwali vs. Diwali	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	**	*

ns=not significant ($p>0.05$), *=significant ($p<0.05$), **=significant ($p<0.01$)

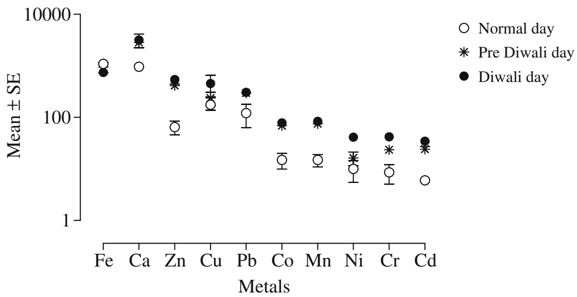

Fig. 8 Average metal concentrations (μg m^{-3}) in ambient air of Lucknow City during Normal, Pre Diwali and Diwali day

trace metals increased in PM_{10} due to fireworks on Diwali and the percentage of increase varied from metal to metal, which is presented below in the descending order.

Night :
Diwali to Pre Diwali: Ni (228.1%)>Cu(117.3%)> Cr (97.5%)> Cd (58.1%)> Zn (54.0%)>Mn (19.9%)>Pb(168%)>Co (12.4%)> Fe (0.6%)> Ca (−2.7%)
Pre Diwali :
Night to day: Cu (125.7%) > Ca (117.9%) > Cr (66.8%) > Cd (46.5%) >Zn (42.6%) > Co (34.6%) > Ni (22.4%) >Mn (12.1%)>Pb(7.4%) >Fe (−26.0%).
Diwali:
Night to day : Cu (271.9%) > Ni (149.1%)> Cr (123.9%) > Zn (122.5%)> Cd (90.1%) >Fe (75.9%)> Ca (50.4%) >Pb (40.0%) > Mn (30.1%) > Co (28.9%).
24 h:
Diwali to Pre Diwali : Ni (153.0%) > Cu (91.0 %) > Cr (78.6%) > Cd (43.4%) > Zn (31.2%) > Co (14.5%)> Mn (12.1%) >Ca (11.1%) > Pb (3.7%) > Fe (−21.3%).

24 hours metal concentration

On Diwali day the metal concentration (ng m^{-3}) increase with respect to Pre Diwali day (time increase within bracket) for 24 h were found to be Ca= 3,169.44 (1.11), Fe=747.23 (0.79), Zn=542.62 (1.31), Cu=454.03(1.91), Pb=307.54 (1.04), Co=78.69 (1.15), Mn=83.90 (1.12), Ni=41.47 (2.53), Cr=42.10 (1.39) and Cd=34.69 (1.43), respectively, (Fig. 8) and the concentration of metals was found in the order of Ca > Fe >Zn > Cu > Pb > Mn > Co > Cr > Ni > Cd.

On normal day (background no. 2) mean of Fe is the maximum and Cd the minimum, during Pre Diwali day Ca the maximum and Ni the least. Similarly on Diwali day, Ca the maximum and Cd the least. On comparing mean (Table 3), concentrations of Ca ($p<0.05$), Zn ($p<0.01$), Pb ($p<0.01$), Co ($p<0.01$), Mn ($p<0.01$), Cr ($p<0.05$) and Cd (($p<0.01$) of Pre Diwali day and Ca ($p<0.05$), Zn ($p<0.01$), Pb ($p<0.05$), Co ($p<0.01$), Mn ($p<0.01$), Ni ($p<0.05$), Cr ($p<0.05$) and Cd ($p<0.01$) on Diwali day the levels were found to be significantly higher than the normal day (background no. 2). Though the concentrations of all the metals (except Fe) on Diwali day showed an increase over Pre Diwali day but none of the increases were found to be statistically significant ($p>0.05$) which might be due to high variation in concentrations.

Metal Zn and Fe of Diwali day showed the highest and the least increase of 8.35 and 0.68 times, respectively, than the normal day (background no. 2). Similarly PM_{10}, SO_2 and NO_x were found to be 5.68, 6.60 and 2.69 time higher on Diwali day, respectively, than the background no. 2.

Spatial variation of pollutants

During fireworks on Diwali night, the concentration of pollutants (PM_{10}, SO_2 and NO_x in μg m^{-3}) including metals (ng m^{-3}) was found to be higher than the Pre Diwali night at all the four locations i.e. Alambagh, Aliganj, Chowk and Gomtinagar. The details are summarized below in descending order:

PM_{10} : Aliganj (1,632.4) > Alambagh (1,237.4) > Chowk (1,147.4) > Gomti Nagar (807.5)
SO_2 : Alambagh (238.3) > Aliganj (222.9) > Chowk (183.5) > Gomti Nagar (176.9)
NO_x : Alambagh (190.8) > Aliganj (143.7) > Gomti Nagar (134.8) > Chowk (126.7)
Total Metal: Aliganj (758.5) > Chowk (729.9) > Alambagh (708.2) > Gomti Nagar (575.1)

During the festival, comparative mean shows that PM_{10} and its trace elements affected Aliganj the most and Gomtinagar the least, both the gaseous pollutants SO_2 & NO_x affected Alambagh the most and Chowk and Gomtinagar the least. The variation of pollutants including total metals at four different locations might be due to the variation in compositions and quality of fireworks.

Table 4 Correlation among metals, PM_{10}, SO_2 and NO_x (n=1fs6, DF=14)

Pollutants	Fe	Ca	Zn	Cu	Pb	Co	Mn	Ni	Cr	Cd	PM_{10}	SO_2	NO_X
Fe	1.00												
Ca	−0.24	1.00											
Zn	0.46	−0.26	1.00										
Cu	0.40	−0.02	0.44	1.00									
Pb	−0.06	0.70**	−0.02	0.27	1.00								
Co	−0.08	0.30	0.48	0.59*	0.29	1.00							
Mn	0.32	0.22	0.41	0.41	0.35	0.64**	1.00						
Ni	0.15	0.10	0.50*	0.38	0.15	0.54*	0.48	1.00					
Cr	0.09	0.44	0.50*	0.05	0.44	0.33	0.43	0.64**	1.00				
Cd	−0.09	0.35	0.35	0.22	0.36	0.69**	0.76**	0.65**	0.63**	1.00			
PM_{10}	0.05	0.43	0.38	0.62**	0.48	0.68**	0.42	0.71**	0.64**	0.65**	1.00		
SO_2	0.13	0.46	0.41	0.64**	0.36	0.71**	0.47	0.64**	0.63**	0.60*	0.93**	1.00	
NO_x	0.12	0.34	0.51*	0.63**	0.31	0.68**	0.38	0.72**	0.66**	0.58*	0.94**	0.95**	1.00

*=significant (p<0.05), **=significant (p<0.01)

Correlations of metals

Inter correlations of metals (Table 4), Ca with Pb (r=0.70, p<0.01); Zn with Ni (r=0.50, p<0.05) and Cr (r=0.50, p<0.05)); Cu with Co (r=0.59, p<0.05); Co with Mn (r=0.64, p<0.01); Ni (r=0.54, p<0.05) and Cd (r=0.69, p<0.01); Mn with Cd (r=0.76, p<0.01); Ni with Cr (r=0.64, p<0.01) and Cd (r=0.65, p<0.01); Cr with Cd (r=0.63, p<0.01) were found to be significant with each other indicating that their sources are the same. Similarly PM_{10}, SO_2 and NO_X also show very strong correlations (p<0.01) with each other. Metal Cu (r=0.62, p<0.01), Co (r=0.68, p<0.01), Ni (r=0.71, p<0.01), Cr (r=0.64, p<0.01), and Cd (r=0.65, p<0.01) were found to have a significant association with PM_{10} which suggests that these are linearly dependent on PM_{10} and the proximity of the emission source during Diwali period i.e. burning of crackers and sparklers.

Sharma et al. (2006) estimated metals concentration in ambient air of Lucknow city during non Diwali days, in the same year in May 2005, and found a significant correlation of Fe (r=0.71), Mn (r=0.66) and Mg (r=0.71) with the PM_{10} and in significant (p>0.05) rather poor association with Cu, Co, Ni, Cr and Cd.

During Diwali period the insignificant association of Fe, and Mn and significant association of Cu, Co, Ni, Cr and Cd with PM_{10} (Table 4) clearly indicates that the burning of crackers and sparklers are the main sources of these significantly associated metals.

Mean comparisons and correlations both suggest that burning of crackers and sparklers on Diwali festival is a very strong source of air pollution which contributes significantly high amount of metals especially Cu, Co, Ni, Cr, and Cd; particulates (PM_{10}) and gaseous pollutants (SO_2 and NO_x) in the environment.

Conclusion

The quantitative results of PM_{10}, SO_2, NO_x and trace metals indicate that fireworks on Pre Diwali and Diwali night were found to be responsible for the elevated concentrations.

During Diwali night, increase of PM_{1O} (446.8%) SO_2 (289.3%) and NO_x (121.3%) clearly indicated that fireworks were the source of these pollutants.

All the 24 h average concentrations of PM_{10}, SO_2, and NO_x were found to be higher than the NAAQS which are 100, 80 and 80 $\mu g/m^3$, respectively. The higher level of air pollutants, especially the many fold (7.53 times) increase of PM_{10} concentration is of great concern with regard to the health effects.

Fireworks on Diwali night resulted in the increase of the metal level in ambient air and maximum percentage of increase was found in case of Cu (271.9%), Ni (149.1%), Cr (123.9%), Zn (122.5%), Cd (90.1%) which suggests that use of fireworks be discouraged.

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