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Fine particles ($PM_{2.5}$) in ambient air of Lucknow city due to fireworks on Diwali festival

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Abstract: *People burn crackers world over on different occasions in different countries to express their happiness. Fireworks in large amounts aggravate the level of air pollutants and cause significant short-term air quality degradation with possible impact on human health. Fine particles ($PM_{2.5} \leq 2.5$ μm), which may pose detrimental effects on human health and ecosystems were monitored in a residential area of Lucknow city to assess the elevated level due to bursting of firecrackers during Diwali festival. The 24 hr mean $PM_{2.5}$ of normal day, pre Diwali day, Diwali day and post Diwali day was found to be 124, 154, 352 and 174 $\mu g\ m^{-3}$ respectively and much above the US-EPA limit (65 $\mu g\ m^{-3}$). The 12 hr mean concentration of $PM_{2.5}$ on Diwali night (591 $\mu g\ m^{-3}$) increased 3.9 fold than the respective night of normal day (159 $\mu g\ m^{-3}$) and was significantly higher ($p<0.01$) than normal day and pre and post Diwali night. Mean comparison showed that Diwali day was significantly ($p<0.01$) different from others (except post Diwali day) and for this high accumulation during night time, after fireworks (suspension) was found to be more responsible than the period of lighting of crackers (formation). This study indicated that there is high accumulation of $PM_{2.5}$ generated due to fireworks on Diwali festival which remains suspended in the air for upto 20 hr. During this period, extra mass burden of 289 $\mu g\ m^{-3}$ equivalent to 1.9 normal day (of this study) was imposed in the environment. The short-term high accumulation of $PM_{2.5}$ is a matter of serious concern for city dwellers as it can penetrate deep into the lungs and cause many respiratory and cardiovascular diseases.*

Key words: *Fireworks, Diwali festival, Fine particles ($PM_{2.5}$), Air pollution, Air quality*
PDF of full length paper is available online

Introduction

Diwali (Deepavali) is the festival of lights and is celebrated with great enthusiasm all over India every year with bursting of crackers as the most prominent activity of Diwali. There are few reports regarding the firework emitted trace gases and particulate matters (PM) including metals into the atmosphere, which causes generation of dense clouds of smoke, concentration of which depends on the composition of sparklers and crackers. Generally crackers contains potassium nitrate, charcoal, sulphur, potassium and trace elements, which severely affects environment as well as human health (Hirai *et al.,* 2000; Ravindra *et al.,* 2003; Kulshrestha *et al.,* 2004; Drewnick *et al.,* 2006; Tripathi and Gautam, 2007; Dwivedi *et al.,* 2008).

Bach *et al.* (1975) found that firework activities on New Year's eve in 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 range at one location. Ravindra *et al.* (2003) reported that fireworks lead to short term variation in air quality and observed 2 to 3 times increase in PM_{10} and TSPM concentrations in Hisar city (India) during Diwali festival. Kulshrestha *et al.* (2004) reported high level of different trace elements in ambient air of Hyderabad, (India) which was due to fireworks during Diwali festival. Attri *et al.* (2001) observed formation of ground level O_3 due to burning of colour emitting sparklers in Delhi (India) during Diwali festival. Wang *et al.* (2007) also reported higher level of air pollutants like SO_2, NOx, $PM_{2.5}$, PM_{10} in the ambient air of Beijing (China) and estimated five times higher levels for primary components of Ba, K, Sr, Cl^-, Pb, Mg and secondary components of $C_5H_6O_4^{2-}$, $C_3H_2O_4^{2-}$, $C_2O_4^{2-}$, $C_4H_4O_4^{2-}$, SO_4^{2-}, NO_3^- during fireworks of lantern days than on normal days. Moreno *et al.* (2007) reported spectacular increase in particulate matter SO_2, NO_x and metal concentration in ambient air during firework display in Spain.

During the same period (Diwali festival) we have monitored air pollutants and trace elements associated with PM_{10} in the ambient air at four different locations of Lucknow city and found 24 hr mean of PM_{10}, SO_2 and NOx were 753, 139 and 107 $\mu g\ m^{-3}$ respectively which were 5.7, 6.6 and 2.7 times higher than the normal day. The trace elements Cu, Co, Ni, Cr and Cd were found to be significantly associated with fireworks (Barman *et al.,* 2008a).

In general, PM (Particulate matter) is a complex mixture of elemental and organic carbon, ammonium, nitrates, sulphates,

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mineral dust, trace elements and water. Fine particles are one of the most important components of PM due to their properties and ubiquitous presence in the atmosphere (Hueglin *et al*., 2005; Salve *et al*., 2007; Singh *et al.,* 2008). Fine particles which are very small in size generally have long residence time in the atmosphere and tend to spread over a large geographic region and thus exert the greatest effect on vegetation and ecosystems by virtue of the mass loading of its chemical constituents and vegetation (Grantz *et al.,* 2003).

Health effects of particulate matters, are well documented. Exposure to short-term traffic pollution can trigger heart attacks. A German study reported that non fatal heart attacks due to risk of myocardial interaction increases 2.9 times more within one hour of exposure to traffic (Peters *et al.,* 2004). Dockery *et al.* (1993) and Pope *et al.* (1995) reported that an increase of 10 $\mu g\ m^{-3}$ $PM_{2.5}$ (as annual average) was associated with a relative risk for total mortality of 1.14 and 1.07% respectively. The high level of $PM_{2.5}$ increased sensitivity in asthmatic people. In India, 30 to 40% increased cases of wheezing, respiratory diseases, exacerbation of the bronchial asthma and bronchitis patients of all age and sex groups, irrespective of a family history of asthma or not, are reported during the Diwali festival (Clark, 1997). Hirai *et al.* (2000) found that inhalation of smoke from fireworks causes cough, fever, and dyspnoea and leads to acute eosinophilic pneumonia (AEP).

In general, the effect of fine particles on human health depends on their size, shape and number and mass concentration and also on the chemical composition. Particles smaller than 10 μm may reach the pulmonary alveoli and accumulate there. A consensus has been reached regarding adverse health impact of $PM_{2.5}$ (WHO, 2003; Peters *et al*., 2001). Ultrafine particles ($PM_{0.1}$) may even pass directly into the blood circulation and have vascular effects (Nemmar *et al.,* 2002; Maitre *et al.,* 2006). Experimental and clinical studies in man have shown that particles cause an inflammatory reaction of the lung which is related as much to their physical parameters as to the oxidative stress generated by organic and metallic compounds absorbed onto their surface (Donaldson *et al*., 2001; Salvi *et al.,* 1999). These compounds may then trigger a cascade of reactions; initial local production by macrophages and activated alveolar cells of pro-inflammatory cytokines, such as interleukin-6 (Van Eeden *et al*., 2001) and increased expression of endothelin (Bouthittier *et al.,* 1998; Maitre *et al.,* 2006).

A disturbance of the cardiac autonomic nervous activity due to harmful mechanism of a particular pollution is associated with decreased heart rate variability (Gold *et al.,* 2000; Liao *et al.,* 1999), elevated pulse rate (Pope *et al*., 1999) and increased incidence of cardiac arrhythmia (Peters *et al*., 2000). The relevance of these alveolar particles, which are mainly responsible for cardiovascular and respiratory diseases (Maynard and Kuempel, 2005; Curtis *et al.,* 2006) are increasing in importance to governments, regulators and research personnel due to their potential impact on human health and ecosystems.

Lucknow, the capital of Uttar Pradesh, situated in northern India with a population of 2.2 millions, (2001census) lies between $26^0 52'$N Latitude and $80^0 56'$E Longitude at 128 m above sea level. Vehicular traffic is the major source of air pollution in Lucknow city (Sharma *et al.,* 2006). Recently we have reported (Barman *et al*., 2008b) that $PM_{2.5}$ level in Lucknow city is greatly influenced by vehicular emissions and increases with increasing activity of vehicular population. We found significantly ($p< 0.01$) higher levels of $PM_{2.5}$ on weekdays than on weekend. There is no published data regarding $PM_{2.5}$ level in ambient air during festival days of Lucknow city. Maximum quantity of crackers and sparklers are burnt mainly on Diwali day followed by day before Diwali and day after Diwali. In India, there are legal controls on use of fireworks; according to which citizens can burn firecrackers only from 6 to 10 PM. In order to determine the effects of fireworks on $PM_{2.5}$, 4 days, 24 hr continuous monitoring of $PM_{2.5}$ was conducted in Vikas Nagar, a residential area of Lucknow city during Diwali festival (30th October to 2nd November, 2005).

Materials and Methods

Monitoring of $PM_{2.5}$: The monitoring of fine particles was carried out by the Haz-Dust, Environment Particulate Air Monitor (EPAM-5000), which is a high sensitivity (1 to 2000 $\mu g\ m^{-3}$) instrument, manufactured by Environmental Device Corporation, USA. The real time particulate monitor designed for ambient environment and indoor air quality applications is based on the principle of forwarding the scattering of an infrared light source position at 90-degree angle from a photo detector. The airborne particles enter the infrared beam, scatter the light and the amount of light received by the photo detector is directly proportional to the aerosol concentration.

To know the effect of '*Diwali episode'*, 24 hr continuous monitoring of $PM_{2.5}$ was done in Vikas Nagar in 2005 on 30th October (two days before Diwali), 31st October (day before Diwali), 1st November (Diwali day) and 2nd November (day after Diwali). For simplification, we named these days respectively as "normal day", "pre Diwali day", "Diwali day" and "post Diwali day". The Haz-Dust was adjusted to record single data per minute. For each day per minute data was recorded over a 24 hr period from 6 to 6 AM. We simplified the data by taking hourly average, which consist approximately 50-60 data points. Thus, for each day, total 24 data points were obtained. Data points of each day were again subdivided into two equal halves, the first half of 12 data points (6 AM to 6 PM) was named as *"day time"* and second half of 12 data points (6 PM to 6 AM) as "night time".

Table - 1: Comparison between days for each hour by Newman Keuls test

Comparisons			11 PM	12 PM	1 AM	2 AM	3 AM	4 AM
Normal day	vs.	Pre Diwali day	ns	ns	ns	ns	ns	ns
Normal day	vs.	Diwali day	**	**	**	**	**	ns
Normal day	vs.	Post Diwali day	ns	ns	ns	ns	ns	ns
Pre Diwali day	vs.	Diwali day	*	*	*	**	**	ns
Pre Diwali day	vs.	Post Diwali day	ns	ns	ns	ns	ns	ns
Diwali day	vs.	Post Diwali day	ns	ns	*	**	*	*

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

Statistical analysis: Data was analysed by one and two factor analysis of variance (ANOVA) and significance from ANOVA was done by Newman Keuls Post hoc test (pair-wise comparison of mean). Mean comparison was also done by Student's t-test. All statistical analysis was performed on transformed data (log_{10}). Interpretation and graphical representation was done on actual data. A two-tailed (α=2) probability (p) value less than 0.05 ($p<0.05$) was considered to be statistically significant.

Results and Discussion

Hourly concentration: The 24 hr (6 - 6 AM) 2 hourly $PM_{2.5}$ concentrations ($\mu g\ m^{-3}$) of all four days are shown graphically by Fig. 1. Irrespective of festival activities all four days show similar trend, low during day and high at night. All festival days (pre Diwali day, Diwali day and post Diwali day) showed high concentrations during night time than the normal day and showed increases with increasing activities of fireworks *i.e.* high on Diwali day followed by pre Diwali day and post Diwali day which clearly indicated the contribution of fireworks and gradual decrease after stopping suggests that their accumulation lasts for a short period of time (Fig. 1). Comparison of mean, night time mean $PM_{2.5}$ of Diwali day showed a significant difference level ($p<0.05$) from 11 PM - 4 AM than the respective concentrations of other observed days (Table 1) and in rest of the hours concentrations did not differ significantly ($p>0.05$) (results not shown). Similar trend and sharp peaks especially during night hours of all the observation days suggests that there was less dispersion of particulates during the festival period due to low wind conditions.

24 and 12 hr concentration: The 24 (6 - 6 AM) and 12 hr day time (6 AM - 6 PM) and night time (6 PM - 6 AM) $PM_{2.5}$ concentrations of all four days are summarised in Table 2. 24 hr mean $PM_{2.5}$ of Diwali day was the maximum (352 $\mu g\ m^{-3}$) followed by post Diwali day (174 $\mu g\ m^{-3}$), pre Diwali day (154 $\mu g\ m^{-3}$) and normal day (124 $\mu g\ m^{-3}$). Similarly, 12 hr day time mean concentration of post Diwali day was the maximum (127 $\mu g\ m^{-3}$) followed by Diwali day (112 $\mu g\ m^{-3}$), normal day (96 $\mu g\ m^{-3}$) and pre Diwali day (83 $\mu g\ m^{-3}$) and at night time it was maximum on Diwali day (591 $\mu g\ m^{-3}$) followed by pre Diwali day (225 $\mu g\ m^{-3}$), post Diwali day (221 $\mu g\ m^{-3}$) and normal day (151 $\mu g\ m^{-3}$). The maximum concentration during night time of Diwali day shows the day as affected the most by fireworks and maximum concentration during day time of post Diwali day which is a local holiday also suggests after effect of fireworks.

On comparison of 24 hr mean of $PM_{2.5}$ (Fig. 2) of normal day, pre Diwali day and post Diwali day, we observed more or less similar values but on Diwali day the values showed 2.8 and 2.3 times higher concentrations than the normal day and pre Diwali day respectively and was found to be significantly ($p<0.01$) different. The pre Diwali day and post Diwali day which showed an increase of 24 and 40% respectively than the normal day was also affected by the fireworks.

The 12 hr mean (Fig. 3) of all four days during day time and night time did not differ significantly ($p>0.05$) except night time of Diwali day which showed significantly ($p<0.01$) high concentration than other nights. Comparison of mean between day time and night time, mean $PM_{2.5}$ of all four days during night time was found to be significantly ($p<0.01$) higher than the respective day time. Higher concentration during night hours than the day hours was also reported in our separate study in Lucknow city (Barman *et al.,* 2008b). This similar trend has also been observed by others (Laakso *et al.,* 2003; Freiman *et al.,* 2006) in normal days. This variation is probably due to the consequences of dilution process as well as the thickening of urban boundary layers or decrease in the atmospheric stability and increase in the vertical mixing height. Furthermore, higher concentration during night hours in the normal day is due to the concentration process caused by the thinning of the mixing layer (Allegrini *et al.,* 1994; Querol *et al.,* 2001; Freiman *et al.,* 2006), due to increase of humidity (Barman *et al.,* 2008b).

Concentration during and after fireworks: Comparisons showed that Diwali day was significantly different from others days because of night time concentration. The night time (6 PM - 6 AM) difference of all four days was further evaluated by comparing concentrations during fireworks (6 - 10 PM) and after fireworks (10 PM - 6 AM) and is summarised in Table 3. Comparison between during fireworks and after fireworks (Fig. 4), mean $PM_{2.5}$ of all four days did not differ significantly ($p>0.05$) except Diwali day which showed significantly ($p<0.01$) higher

Table - 2: 24 hr (6 - 6 AM) and 12 hr day time (6 AM - 6 PM) and night time (6 PM - 6 AM) $PM_{2.5}$ ($\mu g\ m^{-3}$) statistics of normal day, pre Diwali day, Diwali day and post Diwali day

Statistics	24 hr (n=24)				12 hr (n=12)							
					Normal day		Pre Diwali day		Diwali day		Post Diwali day	
	Normal day	Pre Diwali day	Diwali day	Post Diwali day	Day time	Night time	Day time	Night time	Day time	Night time	Day time	Night time
Mean ± SD	124 ± 48	154 ± 98	352 ± 334	174 ± 95	96 ± 51	152 ± 21	83 ± 43	225 ± 85	112 ± 61	591 ± 324	127 ± 96	221 ± 70
Min	34	43	57	41	34	99	43	105	57	104	41	130
Max	184	352	963	360	170	184	163	352	222	963	360	327
Range = Max.-Min.	150	309	906	318	136	85	120	247	165	859	319	197

Table - 3: $PM_{2.5}$ ($\mu g\ m^{-3}$) statistics during fireworks (6 - 10 PM) and after fireworks (10 PM - 6 AM)

Statistics	During fireworks (n=4)				After fireworks (n=8)			
	Normal day	Pre Diwali day	Diwali day	Post Diwali day	Normal day	Pre Diwali day	Diwali day	Post Diwali day
Mean ± SD	153 ± 38	231 ± 124	284 ± 255	228 ± 99	152 ± 9	221 ± 69	745 ± 237	218 ± 59
Min	99	105	104	130	139	159	404	152
Max	184	352	658	327	166	334	963	308
Range = Max.-Min.	85	247	554	197	27	175	559	156

Table - 4: 20 hr (6 PM - 1 PM) $PM_{2.5}$ ($\mu g\ m^{-3}$) statistics* of pre Diwali day fireworks and post Diwali day fireworks

Statistics	Pre Diwali day fireworks (n=20)	Post Diwali day fireworks (n=20)
Mean ± SD	133 ± 39	422 ± 331
Min	49	71
Max	184	963
Range	135	892

*Significant at p<0.01

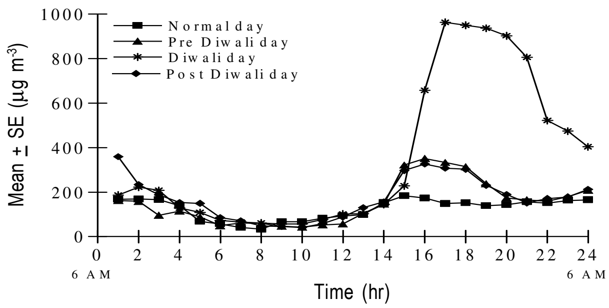

Fig. 1: 24 hr (6 - 6 AM) 2 hourly $PM_{2.5}$ ($\mu g\ m^{-3}$) of normal day, pre Diwali day, Diwali day and post Diwali day

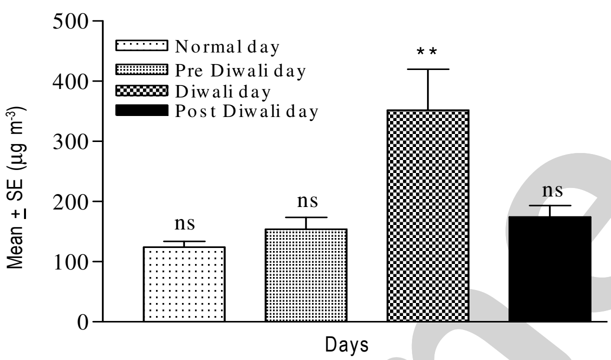

Fig. 2: 24 hr (6 - 6 AM) mean $PM_{2.5}$ ($\mu g\ m^{-3}$) of normal day, pre Diwali day, Diwali day and post Diwali day. ns - Not significant (p>0.05), ** - Significant (p<0.01)

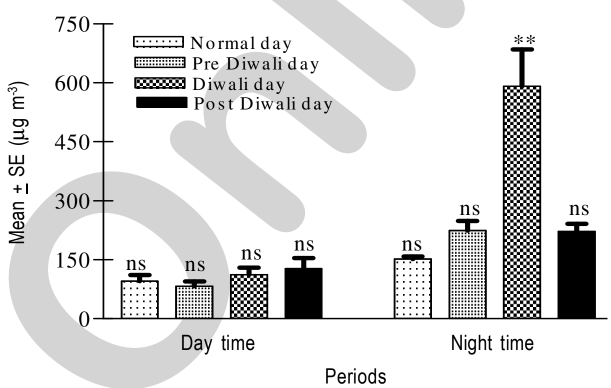

Fig. 3: 12 hr mean $PM_{2.5}$ ($\mu g\ m^{-3}$) during day time (6 AM - 6 PM) and night time (6 PM - 6 AM) of normal day, pre Diwali day, Diwali day and post Diwali day. ns - Not significant (p>0.05), ** - Significant (p<0.01)

concentration after fireworks (745 $\mu g\ m^{-3}$) than during fireworks (284 $\mu g\ m^{-3}$). Similarly, mean $PM_{2.5}$ of all four days during fireworks and after fireworks also did not differ significantly (p>0.05) except after fireworks of Diwali day which showed significantly (p<0.01) high concentration (745 $\mu g\ m^{-3}$) than normal day (152 $\mu g\ m^{-3}$), pre Diwali day (221 $\mu g\ m^{-3}$) and post Diwali day (218 $\mu g\ m^{-3}$).

48 hr concentration: The net effect of Diwali day (here after festival day) was evaluated by comparing 48 hr (2 days, 6 - 6 AM) $PM_{2.5}$ trend of pre Diwali day fireworks (normal day + pre Diwali day) and post Diwali day fireworks (Diwali day + post Diwali day) and is shown graphically by Fig. 5. On observation of 48 hr concentration, post Diwali day fireworks trend showed that concentrations slowly started rising at 6 PM (18 hr) on Diwali day when people generally start fireworks and increases up to 10 PM (22 hr) when people generally stop fireworks. After 1 hr the concentrations reach maximum (963 $\mu g\ m^{-3}$) at 11 PM (23 hr) and then start to decrease gradually within the following hours until they reach approximately pre Diwali day fireworks levels around 1 PM (13 hr) of next day of Diwali day *i.e.* day time of post Diwali day (Fig. 5). This suggests that accumulation of $PM_{2.5}$ in ambient air due to fireworks was for a short period of time (20 hr) and we considered these 20 hr concentrations (shaded area) as effect of fireworks (Fig. 5). The 20 hr concentrations of pre Diwali day fireworks and post Diwali day fireworks are summarised in Table 4. Comparison of mean $PM_{2.5}$ of post Diwali day fireworks (422 $\mu g\ m^{-3}$) was found significantly (p<0.01) higher than the pre Diwali day fireworks (133 $\mu g\ m^{-3}$) and the net effect *i.e.* mean difference (289 $\mu g\ m^{-3}$) was found equivalent to 1.9 normal day (152 $\mu g\ m^{-3}$) of this study.

For estimation of mass and duration we have observed 48 hr trend and merged the data of normal day and pre Diwali day and of Diwali day and post Diwali day. This type of merging may be considered statistically as we have found 24 hr mean $PM_{2.5}$ of normal day and pre Diwali day and of Diwali day and post Diwali day statistically the same. It was also considered while merging the data that if fireworks in huge amount was not be burnt on Diwali day, the 48 hr trend of post Diwali fireworks would also follow the same trend as of pre Diwali fireworks.

In our separate study during November, 2005 (Barman *et al.,* 2008b), reported 24 hr $PM_{2.5}$ concentrations of a weekend day (Sunday, 13th November) and weekdays *i.e.* Thursday (10th November) and Wednesday (16th November) and their respective mean were 76, 183 and 88 $\mu g\ m^{-3}$ at same location *i.e* Vikas Nagar. The mean concentrations of all days of this study were higher while less in comparison to Thursday except Diwali day. Mean $PM_{2.5}$ of normal day (124 $\mu g\ m^{-3}$) of this study which happened on Sunday shows 1.6 times higher concentration than the reported weekend Sunday (76 $\mu g\ m^{-3}$) and may be influenced

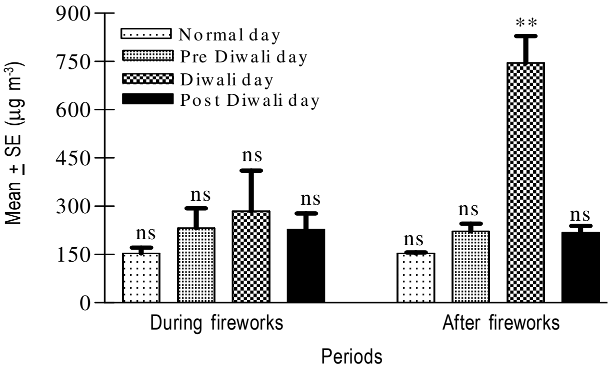

Fig. 4: Mean $PM_{2.5}$ ($\mu g\ m^{-3}$) during fireworks (6 - 10 PM) and after fireworks (10 PM - 6 AM) of normal day, pre Diwali day, Diwali day and post Diwali day. ns -Not significant ($p>0.05$), ** - Significant ($p<0.01$)

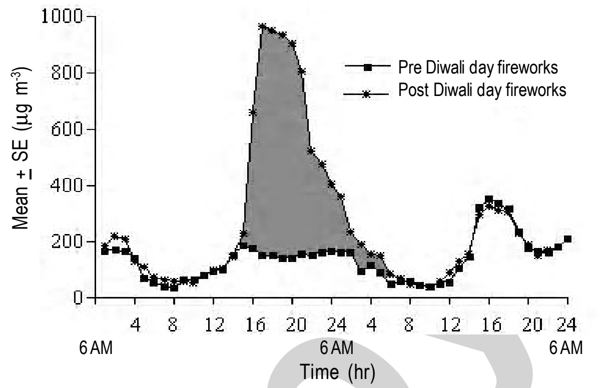

Fig. 5: 48 hr (6 - 6 AM) hourly $PM_{2.5}$ ($\mu g\ m^{-3}$) of pre Diwali day fireworks and post Diwali day fireworks

slightly by festival activities as lots of traffic movement and other activities take place (such as cleaning of houses) during this period but at the same time the maximum concentration during day time of post Diwali day (221 $\mu g\ m^{-3}$) even being a local holiday on that day with least traffic with least activities showed after effect of fireworks (Diwali night).

The concentrations of $PM_{2.5}$ in air vary considerably depending upon many factors including proximity to sources of emissions (primary) and formation (secondary), comparisons and hourly trend (Fig. 1, 5) of this study which suggests that during Diwali festival the variations in primary concentrations may be due to fireworks (episodal) rather than diurnal, and therefore probably rather associated with synoptic scale transport than with local emissions. Thus it can be considered that during festival the main impact on $PM_{2.5}$ concentrations was mainly from fireworks while local sources only complemented it.

For the first time, we were able to estimate the impact of fireworks on fine particles in terms of mass (289 $\mu g\ m^{-3}$) and duration (20 hr). These resultants may be much more if compared with other normal days (control day) as normal day of this study is influenced slightly by festival activities and thus can not be considered as a control day.

In our separate study (Barman *et al.,* 2008a) during the same period we have estimated air pollutants namely PM_{10}, SO_2 and NO_x and 10 trace elements associated with PM_{10} at four residential locations namely Gomti Nagar, Chowk, Aliganj and Alambagh which are 10-15 km apart from each other and situated all the four direction *i.e.* east, west, north and south directions of Lucknow city respectively. One of the locations, Aliganj is adjacent (approximately 1.5 km) to the present monitoring location.

On Diwali night average concentration of four locations for PM_{10}, SO_2 and NO_x were found to be 1206, 205 and 149 $\mu g\ m^{-3}$ respectively. These concentration were 4.0, 2.8 and 2.3 times higher than their respective daytime level and found to be significant ($p<0.01$) when compared with day time concentration of pre Diwali day. The 24 hr mean concentration of metals was found to be in the order of Ca (3169.4) > Fe (747.2) > Zn (548.6 > Cu (454.0) > Pb (307.5) > Mn (83.9) > Co (78.7) > Cr (42.1) > Ni (41.5) > Cd (34.7) ng m^{-3}. All these values were found to be higher than the pre Diwali (except Fe) and normal day (concentration measured during the month of May 2005; Sharma *et al.,* 2006). The concentrations of Co, Ni, Cr and Cd on Diwali night were found to be significantly higher than daytime concentration for pre Diwali day (control).

The nearest location Aliganj, the 12 hr concentration during Diwali night were found to be PM_{10} =1632, SO_2 = 223 and NOx = 144 $\mu g\ m^{-3}$ and total mean concentration of 10 metals were found 758 ng m^{-3} which was maximum among the four locations.

So, the particulate matter contains high levels of metals which are emitted from fireworks besides high concentration of other air pollutants. In our study area, Vikas Nagar showed significantly higher level of $PM_{2.5}$ during Diwali night. The elevated concentrations of all the metals are harmful to living being including humans. Exposure can occur through a variety of routes; inhalation of particles is one of the important routes. The high concentration of fine particles in Lucknow city which is above the prescribed limit (65 $\mu g\ m^{-3}$) of US-EPA (1997) is itself a matter of concern and addition of extra mass burden of fine particles in the environment due to fireworks is of serious concern as it may pose more detrimental short-term and long-term effects on human health and ecosystems.

In short, this study concluded that burning of crackers and sparklers *etc.* (fireworks) on Diwali festival are a very strong source of air pollution, which contributes significant amount of fine particles ($PM_{2.5}$) in ambient air and degrades air quality for 20 hr and during this period extra mass (concentration) burden of 289 $\mu g\ m^{-3}$ equivalent to 1.9 normal day (of this study) was imposed in the local environment. The same may be expected on other areas of Indian environment as Diwali festival is celebrated all over India. Therefore we strongly suggest use of fireworks be discouraged.

Acknowledgments

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