Bull Environ Contam Toxicol (2012) 89:376–379
DOI 10.1007/s00128-012-0669-9

Air Quality Status During Diwali Festival of India: A Case Study

Padma S. Rao · D. G. Gajghate · A. G. Gavane · P. Suryawanshi · C. Chauhan · S. Mishra · N. Gupta · C. V. C. Rao · S. R. Wate

Received: 6 January 2012 / Accepted: 3 May 2012 / Published online: 13 May 2012

Abstract The $PM_{2.5}$ and PM_{10} samples were collected during Diwali celebration from study area and characterized for ionic concentration of four anions (NO_3^-, NO_2^-, Cl^-, SO_4^{2-}) and five cations (K^+, Mg^{2+}, NH_4^+, Ca^{2+}, Na^+). The results showed that the ionic concentrations were three times compared to those on pre and post Diwali days. Predominant ions for $PM_{2.5}$ were K^+ 33.7 μg/m^3, Mg^+ 31.6 μg/m^3, SO_4^{2-} 22.1 μg/m^3, NH_4^+ 17.5 μg/m^3 and NO_3^- 18 μg/m^3 and for PM_{10} the ionic concentrations were Mg^+ 29.6 μg/m^3, K^+ 26 μg/m^3, SO_4^{2-} 19.9 μg/m^3, NH_4^+ 16.8 μg/m^3 and NO_3^- 16 μg/m^3. While concentration of SO_2 and NO_2 were 17.23, 70.33 μg/m^3 respectively.

Keywords Ambient aerosol · Ions · Diwali · Crackers

In India, Diwali is one of the major festival and burning of crackers during this festival is an integral part of the celebrations. Cracker and fireworks contain large amount of nitrates and sulphates of lead, cadmium, potassium, ammonium and magnesium. During bursting of these, toxic metal fumes and gases like carbon dioxide, sulphur dioxide and nitrogen dioxide, as well as particulate matter (PM) are emitted. The particulate matter during cracker bursting has been a major concern for its short term and long-term health effects. Hirai et al. (2000) found that inhalation of smoke from firework causes cough, fever, and dyspnea and leads to acute eosinophilic pneumonia. Atmospheric ozone is produced from NOx in the presence of VOCs and sunlight. During these festivals O_3 is formed even in the absence of NOx due to burning of sparklers (Attri et al. 2001). Kulshrestha et al. (2004) reported that the high level of different trace elements in ambient air of Hyderabad (India) was due to fireworks during this festival. The smoke emitted from burning crackers contains potassium nitrate (75 %), charcoal (15 %) and Sulphur (10 %) (Liu et al. 1997; Kulshrestha et al. 2004; Drewnick et al. 2006). Measurement of water-soluble ions is important for determining compositions of atmospheric aerosols. An attempt was made to determine ionic chemical composition of atmospheric PM_{10} and $PM_{2.5}$ with the view to assess the impact of burning of crackers during Diwali festival celebrations in Nagpur, India.

Materials and Methods

The study region comprises of residential cum commercial area of NEERI colony (National Environmental Engineering Research Institute) in Nagpur city, which is situated, between 20°30′ N–21°30′ N latitudes and 78°30′ E–79°30′ E longitudes. National highway No-7, Godowns of Food Corporation of India, hotels, bakeries and railway station also exist in the vicinity of sampling area. The location has been depicted in Fig. 1a.

PM_{10} and $PM_{2.5}$ samples were simultaneously collected for pre- Diwali, during Diwali and post Diwali following the CPCB guidelines using Respirable Dust sampler (model APM 460 NL of M/s Envirotech) and Federal Reference Method Sampler (Partisol 2000 R&P), of which flow rates are 1.2 m^3/min and 16.7 L/min for PM_{10} and $PM_{2.5}$ respectively. The PM_{10} samples were collected on

P. S. Rao (✉) · D. G. Gajghate · A. G. Gavane · P. Suryawanshi · C. Chauhan · S. Mishra · N. Gupta · C. V. C. Rao · S. R. Wate
Air Pollution Control Division, National Environmental Engineering Research Institute, NEERI (CSIR), Nehru Marg, Nagpur 440020, India
e-mail: ps_rao@neeri.res.in

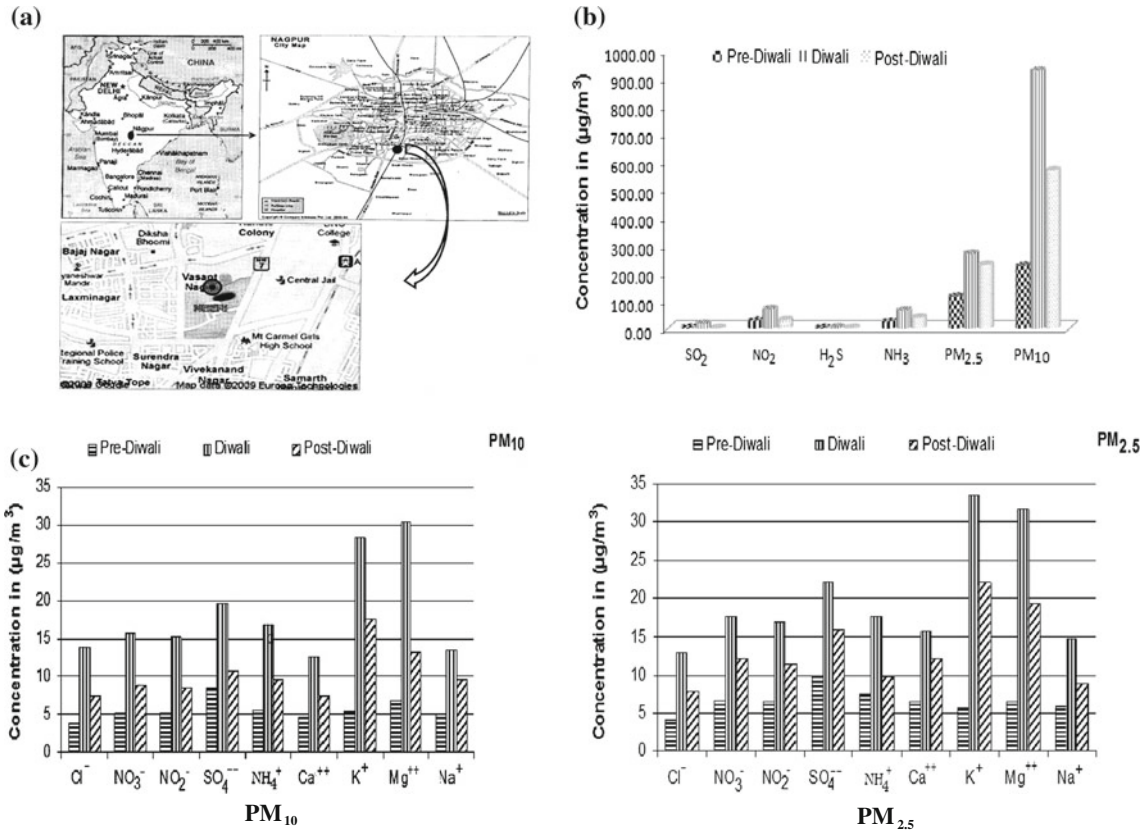

Fig. 1 Description of study area, air quality at Nagpur, concentration of inorganic species in PM_{10} and $PM_{2.5}$. **a** Location of sampling site. **b** Air quality at Nagpur. **c** Concentration of inorganic species in PM_{10} and $PM_{2.5}$

Whatman make glass fiber filters GR-A (200 × 250 mm^2) and $PM_{2.5}$ on Teflon filter (with PMP ring) of 47 mm diameter for 24 h each continuously. The glass fiber filters were equilibrated for 24 h in desiccators before and after collection of the samples and were stored at −18°C before out for further analysis.

The sample filter was extracted with 20 mL ultrapure water (AR grade) in an ultrasonic bath (Sonicator Model No.D-250/H) at 60°C for 1 h. The extracts were cooled down to ambient temperature and homogenized on shaker (Miclab instrument model No.03/16/24) for 1 h followed by the settling of particles over night. The extract was then filtered through cellulose acetate filter paper and residue was again extracted in 20 mL ultrapure water following the same procedure. The filtrate was analyzed using ion chromatograph (IC) model Dionex 100 for major inorganic ions. Operating conditions for the analysis of ions by ion chromatography has been given in Table 1. For reporting purposes, MDL is converted to the units (µg/m^3) based on the portion of the filter extracted, the volume of the extraction solution, and the volume of the sampled air. Matrix spikes are used to determine the effect of the matrix on a method's recovery efficiency as per Standard operating protocol for Ion chromatography analysis of ambient air particulate matter (2003) (DEQ03-LAB-0029-SOP).

Results and Discussion

In order to study the short term variation in air quality during pre Diwali, Diwali and post-Diwali, concentration of $PM_{2.5}$, PM_{10}, SO_2, NO_2, NH_3, H_2S have been shown in Fig. 1b. The average concentration of PM_{10} and $PM_{2.5}$ during Diwali days were found to be 930 and 271 µg/m^3 respectively which is nearly 2–3 times of those in pre Diwali days. Same result was found by (Ravindra et al. 2003) reported that fireworks during festival, lead to a short term variation of air quality and observed 2–3 times increase in TSPM concentration in Hisar city of India. While (Bach et al. 1975) found that firework activities on New Year's Eve on Oahu were responsible for an substantial increase in TSPM levels. This increased in PM mass concentration during Diwali period may be attributed to both the cracker emissions and stable atmospheric condition in winter. Interestingly, it was observed that

Table 1 Operating conditions for the analysis of ions by ion chromatography

Conditions	Anions	Cations
Sample loop volume	25 µL	25 µL
Analytical column	Ion Pac AS11	Ion Pac CS11
Eluent	5 mM Sodium Hydroxide (NaOH)	6 mM Methyl Sulphonic Acid (MSA)
Suppressor	ASRS ultra 4 mm suppressor	CSRS ultra 4 mm suppressor
Regenerant	Ultrapure water	Ultrapure water
Regenerant flow rate	0.8 mL/min	0.8 mL/min
Expected background conductivity	13–15 µs	13–15 µs

concentrations of PM_{10} and $PM_{2.5}$ in post Diwali days were higher than those during pre Diwali days. This shows that the finer particulates contributed by cracker burning remain suspended for long in the stable atmosphere even after Diwali days.

Concentration of inorganic species in $PM_{2.5}$ and PM_{10} has been shown in Fig. 1c, while correlation coefficients of these ions have been given in Table 2. The ionic concentration in $PM_{2.5}$ during Diwali days followed the order $K^+ > Mg^{2+} > SO_4^{2-} > NH_4^+ > NO_3^- > NO_2^- > Ca^+ > Na^+ > Cl^-$. Whereas in PM_{10} it followed the order $Mg^{2+} > K^+ > SO_4^{2-} > NH_4^+ > NO_3^- > NO_2^- > Ca^+ > Cl^- > Na^+$. Very strong correlations were observed amongst all these ions indicating that their source is the same, i.e. burning of crackers and sparkles. It may be noted that K^+, SO_4^{2-}, Na^+ and Mg^{2+} have higher correlation with many ions. This may be due to the abundant use of salts of these ions in the making of fireworks. Sr, Ba and Cu compounds are used to give red, green and blue fireworks, respectively (Kulshrestha et al. 2004; Wang et al. 2007; Moreno et al. 2007). Interestingly, it was observed that SO_4 ion is highly correlated with NH_4 ion in $PM_{2.5}$ as compared to PM_{10}. This may be attributed to ammonium sulphate which gets enriched in fine particulates more as compared to the coarser particles. The pre and post-Diwali days followed the same trends but the concentration was found lowest in pre-Diwali days. A slight increase during the post-Diwali days occurred due to long atmospheric residence time of fine particulates may be due to winter season, stable atmosphere and fog/smog formation. Throughout the study period, inorganic species were found enriched more in $PM_{2.5}$ than PM_{10} further suggesting burning of crackers and sparklers,

Table 2 Correlation matrix of ions in $PM_{2.5}$ and PM_{10} samples collected during Diwali festival at Nagpur, India

	Cl^-	NO_3^-	NO_2^-	SO_4^{2-}	NH_4^+	Ca^{2+}	K^+	Mg^{2+}	Na^+
Correlation matrix of ions in $PM_{2.5}$									
Cl^-	1.00								
NO_3^-	0.98	1.00							
NO_2^-	0.97	0.95	1.00						
SO_4^{2-}	0.94	0.91	0.91	1.00					
NH_4^+	0.93	0.90	0.92	0.91	1.00				
Ca^{2+}	0.89	0.90	0.92	0.93	0.86	1.00			
K^+	0.94	0.90	0.96	0.93	0.84	0.93	1.00		
Mg^{2+}	0.95	0.92	0.98	0.93	0.89	0.96	0.97	1.00	
Na^+	0.96	0.95	0.92	0.93	0.94	0.86	0.90	0.90	1.00
Correlation matrix of ions in PM_{10}									
Cl^-	1								
NO_3^-	0.97	1.00							
NO_2^-	0.97	0.95	1.00						
SO_4^{2-}	0.93	0.88	0.93	1.00					
NH_4^+	0.81	0.86	0.88	0.81	1.00				
Ca^{2+}	0.96	0.96	0.95	0.91	0.85	1.00			
K^+	0.93	0.93	0.94	0.84	0.92	0.92	1.00		
Mg^{2+}	0.94	0.91	0.96	0.98	0.86	0.93	0.88	1.00	
Na^+	0.92	0.89	0.93	0.90	0.89	0.89	0.95	0.95	1.00

as a strong source of emission of inorganic species in ambient air during this festival period.

Higher concentration of K^+, Mg^{2+}, SO_4^{2-}, NH_4^+, and NO_3^- observed during Diwali festival as sparklers and crackers mainly contain potassium nitrate, ammonium nitrate, charcoal and sulphur. K^+ is widely used as an indicator of agriculture biomass burning. However, K^+ was found to be elevated during the festival period due to burning of fireworks. The concentration of K^+ was found to be highest during Diwali days and post-Diwali days. Sixfold increase in K^+ concentration in $PM_{2.5}$ was observed during Diwali days and fourfold increase in PM_{10}. Therefore K^+ could also serve as an indicator of firework burning. This may not be misunderstood as caused by biomass burning especially during Diwali days. Second highest concentration was observed for Mg^{2+}, which was followed by SO_4^{2-} and NH_4^+. Significant increases in concentrations of cations were observed which may be due to the use of various salts for giving coloring effects. This study revealed that the burning of crackers and sparkles on the occasion of Diwali is a strong source of air pollution and may cause serious health hazardous. There is need of public awareness towards the ill effects of cracker burning. The crackers may be burnt in open areas away from city.

Acknowledgments The authors are grateful to Director, National Environmental Engineering Research Institute, Nehru Marg, Nagpur—440020, India, for providing encouragement and facilities to carry out this work and for permission to publish these findings.

References

Attri AK, Kumar U, Jain VK (2001) Formation of ozone by fireworks. Nature 411:1015

Bach W, Daniels A, Dickinson L, Hertlein F, Morrow J, Margolis S, Dinh V (1975) Fireworks pollution and health. J Environ Stud 7:183–192

Drewnick F, Hings SS, Cutius J, Eerdekens G, Williams J (2006) Measurement of fine particulate matter and gas-phasespecies during the new year's fireworks 2005 in Mainz Germany. Atmos Environ 40:4316–4327

Hirai K, Yamazaki Y, Okada K, Furuta S, Kubo K (2000) Acute eosinophilic pneumonia associated with smoke from fireworks. Intern Med (Japan) 39:401–403

Ion Chromatography Analysis of Ambient Air Particulate Matter (2003) Standard operating procedure (SOP), (DEQ03-LAB-0029-SOP) Version 2.1

Kulshrestha UC, Nageswara Rao T, Azhaguvel S, Kulshrestha MJ (2004) Emissions and accumulation of metals in the atmosphere due to crackers and sparkles during Diwali festival in India. Atmos Environ 38:4421–4425

Liu DY, Rutherford D, Kinsey M, Prather KA (1997) Real time monitoring of pyrotechnically derived aerosol particles in the troposphere. Anal Chem 69:1808–1814

Moreno T, Querol X, Alastuey A, Minguillon MC, Pey J, Rodriguez S, Miro JV, Felis C, Gibbons W (2007) Recreational atmospheric pollution episodes: inhalable metallic-ferrous particles from fireworks displays. Atmos Environ 41:913–922

Ravindra K, Mor S, Kaushik CP (2003) Short-term variation in air quality associated with fireworks events: a case study. J Environ Monit 5:260–264

Wang Y, Zhuang G, Xu C, An Z (2007) The air pollution is caused by the burning of fireworks during the lantern festival in Beijing. Atmos Environ 41:417–431