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Original article

Chemical speciation of aerosols and air quality degradation during the festival of lights (Diwali)

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ABSTRACT

Ambient $PM_{2.5}$ (particulate matter less than 2.5 μm) samples, collected in a 8-week wintertime sampling program in two residential sites of Bhilai, India during the Indian Diwali festival in November 2012, were chemically characterized for 38 chemical species including eight speciated carbonaceous fractions (SCFs) of elemental (EC) and organic carbon (OC), twenty one metallic elements, and nine water soluble ionic species. Our objectives were to investigate: 1) relative abundances of SCFs contained in $PM_{2.5}$during the Diwali festival period compared to normal days, and 2) enrichment pattern of potential inorganic markers of firework emission in ambient $PM_{2.5}$during the festival days. Eight-fold increase in$PM_{2.5}$mass concentrations were measured during the Diwali festival days compared to concentrations occurring in normal days. Bursting of firecrackers in the residential streets have shown significant contribution to the emission markers (K, Mg, Zn, S, EC and OC) along with crustal markers (Ca, Fe, Al) in ambient $PM_{2.5}$aerosol samples. Concentrations of water soluble ionic species were found to be 10 times greater than those found in normal days. Further, the anion/cation ratios were found to reach a factor of 2; indicating the acidic character of emissions resulting from fireworks. The relative abundance of SCFs and higher ratios of OC to EC during the Diwali episode suggested the significant formation of secondary organic carbon (SOC) aerosols. We estimate that aerosols emitted from firework bursting contribute up to 32% of total ambient $PM_{2.5}$ during the Diwali festival.

1. Introduction

Diwali is celebrated with great gusto all over India. The hallmark of celebrations of this festival is bursting of firecrackers by almost 80% of the Indian population in an unrestricted manner. This deteriorates the ambient air quality during the week-long celebrations every year. Several studies have shown that short term variation of atmospheric air quality caused by bursting of crackers can result in serious and acute health effects (Perry, 1999; Hirai et al., 2000; Murty, 2000; Ravindra et al., 2003; Pope III and Dockery, 2006) and reduction in atmospheric visibility (Curtis et al., 2006; Steinhauser et al., 2008; Sarkar et al., 2010; Tsai et al., 2012). Given its importance, there has been a surge of recent studies conducted to characterize the emissions resulting from fireworks during festivities such as New Year's Eve celebrations (Drewnick et al., 2006; Steinhauser et al., 2008; Zhang et al., 2010), the Lantern Festival in China (Wang et al., 2007; Tsai et al., 2012), and Diwali festival in India (Ravindra et al., 2003; Kulshrestha et al., 2004; Barman et al., 2008; Sarkar et al., 2010; Singh et al., 2010; Perrino et al., 2011; Chatterjee et al., 2013). These events involve extensive use of pyrotechnics on a regional and national scale, associated with elevated levels of gaseous pollutants such as O_3, SO_2 and NO_x (Ravindra et al., 2003), and high loadings of particulate matter, containing metallic elements and organic compounds (Steinhauser et al., 2008; Vecchi et al., 2008; Moreno et al., 2010; Sarkar et al., 2010; Tsai et al., 2012; Do et al., 2012). Firecrackers constitute a mixture of many metal salts,

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charcoal and sulfur and emit thick layers of smoke upon combustion. Recent noteworthy findings on impact of firework emissions on ambient air quality include elevated levels of ambient PM_{10} (particulate matter less than 10 μm) during Diwali festival days in comparison to normal days in Lucknow, India (Barman et al., 2008), a thousand times higher $PM_{2.5}$ mass concentration levels (1 0000 $\mu g/m^3$) during the 2007 Montreal International Fireworks Competition (Joly et al., 2010), and higher than normal concentrations of metallic elements in ambient PM_{10} and $PM_{2.5}$ (Kulshrestha et al., 2004; Moreno et al., 2010; Sarkar et al., 2010; Tsai et al., 2012). More recently, Tsai et al. (2012) showed that the fireworks during Taiwan's Lantern festival resulted in extremely high $PM_{2.5}$ levels (112.61 $\mu g/m^3$) with massive loadings between 2.2 and 33.1 times higher than normal mass concentrations of toxic inorganic elements such as Mg, K, Ca, Al, Zn and Fe. Similar elevation in PM_{10} and toxic metallic elements associated with firework burning in Delhi were also reported by Sarkar et al. (2010).

The work described in the present study is a systematic chemical characterization of ambient $PM_{2.5}$ including carbonaceous compounds and inorganic elements emitted during, and before-and-after the 2012 Diwali festival in India. To our knowledge, this paper is the first to report on the emitted inorganic marker species in aerosol form from firecracker bursting.

2. Methods

2.1. Study design and sampling plan

An 8-week long ambient air $PM_{2.5}$ monitoring program was carried out in the city of Bhilai, located in central India, during November 2012. The sampling sites were selected in residential areas, free from any direct contamination from traffic and industrial emissions (Fig. 1). As of 2011 census of India, the population of Bhilai was recorded at 0.56 million (Census, 2011). The overall climate is pleasant and mild in the winter (minimum temperature 10 °C, 50 °F). There is medium rainfall in the monsoon season. The summers are very hot and dry, with maximum temperature reaching 48 °C (118.4 °F), and minimum humidity falling to 18–20% (IMD, 2012).

In the year 2012, Diwali was celebrated on 13th November in India. Three sampling episodes designated as Pre-Diwali days (18th, 25th day of October, and 5th, 9th, 11th day of November 2012), Diwali days (13th, 14th and 15th day of November 2012) and Post-Diwali days (22nd, 25th, 28th day of November 2012 and 3rd, 10th, 16th day of December 2012) were selected for ambient $PM_{2.5}$ monitoring. Firework began in the evening (around 6:00 PM) and continued till late night (11:00 PM) with peak activities taking place between 8:00 PM and 10:00 PM. Eight consecutive sampling runs, each an hour long, was started at 4:00 PM on each of the sampling days and continued till12:00 AM to maintain the uniformity in sampling period across the monitoring days. Detailed description of sampling schedule and meteorological parameters are given in Table 1. Ambient $PM_{2.5}$ samples were collected at the rooftop of a residential property (18 ft height) in each of two selected residential zone of Bhilai by installing and operating three sets of fine particulate samplers (Envirotech Model, APM550), simultaneously, with an average flow rate of 16.7 lpm. Samples were collected on quartz fiber filters (QFFs) of 47 mm (QM/A, Whatman Make) (prefired at 450° C for 6 h). All sampled QFFs were placed in cassettes, sealed in polyethylene bags, transported to laboratory and desiccated for 48 h before and after sampling. After weighing measurements, QFF were stored in a refrigerator (4 °C) until performing comprehensive chemical analysis on them at the Desert Research Institute (DRI, 2011).

2.2. Chemical analysis of $PM_{2.5}$ filter samples

The sampled QFFs were analyzed for elemental species, soluble ions, and temperature-resolved organic (OC1, OC2, OC3, OC4, OP) and elemental (EC1, EC2, EC3) carbonaceous sub-fractions, collectively abbreviated as speciated carbonaceous fractions (SCFs). Triplicates of 0.5 cm^2 punches from each QFF were analyzed for

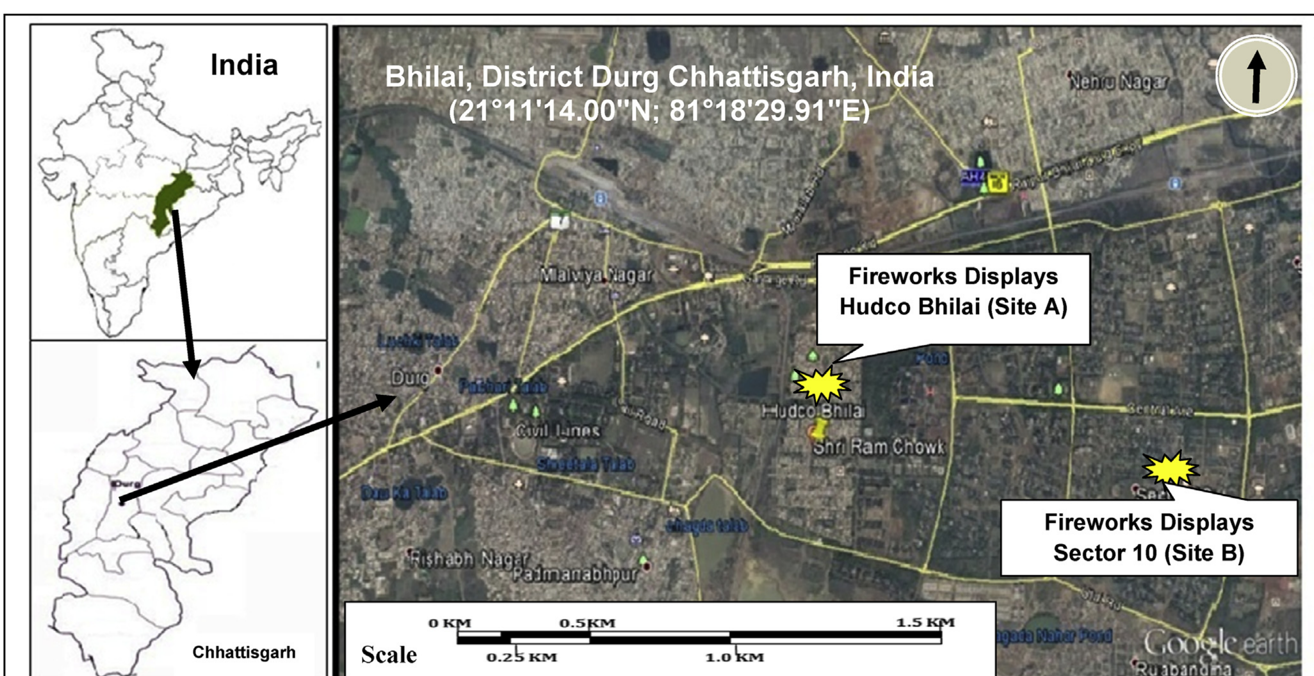

Fig. 1. Map of the sampling site.