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Ambient Air Quality during Diwali Festival over Kolkata – A Mega-City in India

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ABSTRACT

The effects of fireworks on air quality was assessed from the ambient concentrations of PM_{10}, water soluble ionic species, metals and SO_2 over Kolkata metropolis, India during Diwali festival in November 2010. PM_{10} concentrations on Diwali night were found to be ~5 times higher than the normal day night-time average. The increase in night-time concentrations of the metals on Diwali night spanned over a wide range (Al, Zn, Pb and Cd showed 5–12 times increases, Cu, Fe and Mn showed 25–40 times and Co and V showed 70–80 times) compared to normal night-time concentrations. The water soluble ionic species showed 1.5–6 times higher concentrations on Diwali night than on normal days. The most significant increases were found for K^+, $Ca^{2+,}$ Mg^{2+} and SO_4^{2-}. The diurnal variations in PM_{10} and SO_2 were also studied at one of the sites, and the results showed that their maximum concentrations were on Diwali night between 8 P.M.–3 A.M., indicating maximum firework activities during this period. PM_{10} and SO_2 concentrations increased by ~5 times compared to those on normal days during this period at this site. The extensive use of firecrackers during Diwali festival thus leads to significant increases in these air pollutants, and since they are associated with serious, adverse health impacts, the use of fireworks during in this kind of festival in a highly populated city, like Kolkata, India, needs to be controlled.

Keywords: Fireworks; Diwali, PM_{10}, Ionic species; Metals.

INTRODUCTION

Diwali is the festival of lights and is celebrated with great enthusiasm all over India every year during October/ November. Firing crackers is an integral activity of the celebrations during Diwali. Fireworks emit trace gases and particulates including metals into the atmosphere, which generate dense clouds of smoke, concentration of which depends on the composition of sparklers and crackers (Barman *et al.*, 2009). Generally crackers contains potassium nitrate, charcoal, sulphur, potassium and trace elements, which severely affects environment as well as human health (Barman *et al.*, 2009 and several references therein).

Several studies have been made all over the world based on the effect of firework activities on the air pollutants like particulate matter and its components and trace gases during various festivals. Bach *et al.* (1975) found that firework activities on New Year's Eve on Oahu were responsible for an increase in TSPM (Total suspended particulate matters) by an average of 300% at 14 locations and by about 700% at one location. Drewnick *et al.* (2006) showed the effect of firework activities on fine aerosol particle during New Year's Eve in Mainz, Germany. Vecchi *et al.* (2008) observed high loading of some heavy metals due to firework activities during the celebration of win of FIFA world Cup in the year of 2006 over Italy. Moreno *et al.* (2007) also observed the high loading of heavy metals during "Las Fallas", a 6-day celebration famous for its firework displays in Spain. Wang *et al.* (2007) reported higher level of air pollutants like SO_2, NO_x, $PM_{2.5}$, PM_{10} in the ambient air of Beijing (China) and estimated five times higher levels for primary and secondary components of aerosols during fireworks of lantern days than on normal days.

In Indian context, studies have also been reported on the air quality degradation for the firework activities during Diwali festival but they are few. 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, which was due to fireworks during Diwali festival. Barman *et al.* (2008, 2009) reported the remarkable increase in $PM_{2.5}$ concentration in Lucknow city due to firework activities during Diwali festival. Effect of firework activities during Diwali on surface Ozone has also been reported in Delhi (Ganguly *et al.*, 2009; Attri *et al.*, 2001).

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Health effects of particulate matters and their components are well documented. A consensus has been reached regarding adverse health impact of PM_{10} (WHO, 2003; Peters *et al.*, 2001). 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). Besides particulate matter, there is a strong relationship between higher concentration of SO_2 and several health effects like cardiovascular diseases (Chen *et al.*, 2005; Dockery *et al.*, 2005), respiratory health effects such as asthma and bronchitis (Barnett *et al.*, 2005), reproductive and developmental effects such as increased risk of preterm birth (Liu *et al.*, 2003). Short-term but high emissions of trace elements from fireworks can induce severe health effects like neurological and hematological effects on the exposed population for Pb, carcinogenic effects in humans through inhalation and chronic lung diseases for Cd and Ni, carcinogenic effect on the bronchial tree for Cr, neurotoxic impairments for Mn, respiratory irritance for Cu etc. (Barman *et al.*, 2008 and several references therein).

Kolkata, situated in the eastern part of India-amidst world's largest Ganges delta is one of the important Indian megacities. With rapid pace of industrialization and urbanization, high vehicular density plying on insufficient road space and dumping of municipal/industrial solid waste disposal, air quality over this region is severely affected resulting heavy PM loading in Kolkata. Diwali festival is celebrated also in Kolkata 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 (pre-Diwali day) and after (post-Diwali day) Diwali. There is no published data regarding the effect of firework activities on aerosol and its several components during Diwali festival over Kolkata. However a study was made on the air pollution during Diwali festival over a city Howrah adjacent to Kolkata metropolis (Thakur *et al.*, 2010). Along with trace metals and trace gases, we also have investigated the effect of firework activities on the water soluble ionic components of aerosols which have not been reported in any studies made earlier in India during Diwali to the best of our knowledge. This study is thus the first-time study made over Kolkata during Diwali festival in order to find out the effect of firework activities on PM_{10} and its components (water soluble ionic species and metals) and SO_2. To do this, a short-term sampling program was conducted during November 3–10, 2010 over two residential-cum-commercial locations in Kolkata. Thus this study is an attempt to assess the additional burden on air quality due to Diwali festival over Kolkata, where air pollution is already an acute problem through-out the year.

STUDY AREA AND PREVAILING METEOROLOGY

Kolkata formerly known as Calcutta (22°33′N and 88°20′E) is the second most populous city of India after Mumbai. According to 2011 census report, the city population is 4,486,679 (~4.5 million) and the urban agglomeration (spread over 1750 km^2) had a population of about 13.5 million. The city is bounded to the west and north-west by Hooghly river spread along 80 km. The core area is flat with elevation ranging from 6 m above the mean sea level. Sundarban mangroves forest, the world's largest mangrove eco-region at the land-ocean boundary of the Ganges delta is situated at about 100 km from Kolkata.

The study was carried out at two residential-cum-commercial sites at northern Kolkata (Fig. 1). The first site (KKG) is situated in our institute campus (Bose Institute) at Kankurgachi and the second site (STH) is situated in Rabindra Bharati University campus at Sinthi. Both the sites are within 100 meters from the busy roads where the densities of all types of vehicles (light, medium and heavy) plying on these roads are quite high. The site STH is situated at ~7 km west to the site KKG.

Sampling was done at the terrace of the buildings at these two campuses which are ~15 m (KKG site) and ~10 m (STH site) from the ground level. The samplers were mounted on a wooden platform at a height of 1.5 m from the roof level.

The micro-meteorological parameters like temperature (°C), relative humidity (%), wind speed (m/s) and solar radiative flux (watt/m^2) over Kolkata (averaged of 16 stations) during the study period have been shown in Fig. 2. for normal, pre-Diwali, Diwali and post-Diwali day. These data have been taken from West Bengal Pollution Control Board (WBPCB), Govt. of West Bengal, India and averaged based on day-time (6 A.M.–6 P.M.) and night-time (6 P.M.–6 A.M.) except solar radiative flux, which has been shown for the day-time only. It was found that the temperature, relative humidity, wind speed and radiative flux varied from 18–33°C, 45–98%, 0.8–3.3 m/s and 35–740 watt/m^2 respectively over Kolkata during the entire study period. It can be seen from Fig. 2 that the mean temperature and relative humidity on normal days were almost same as on festival days. The mean wind speed was found to be slightly lower on Diwali night and post-Diwali day-time compared to other days. The day-time mean solar radiative flux on post-Diwali day was higher (366 watt/m^2) compared to other days (260–290 watt/m^2).

METHODOLOGY

Sample Collection at KKG Site

For the collection of respirable suspended particulate matter (PM_{10}) from ambient air, a respirable dust sampler was used. The sampler (model APM 460BL) was manufactured by Envirotech Instrument Pvt Ltd, India which pioneered the development of indigenous air monitoring instruments all over India. The sampler collected the samples with a flow rate of 1.4 m^3/min. The sampler was fitted with a cyclone, which was used for fractioning the dust into two fractions. PM_{10} was collected on the filter paper (EPM 2000 filter paper from Whatman of 8 × 10 inch dimension) while particulate matter of aerodynamic diameter more than 10 μm was collected in a cup placed under the cyclone.

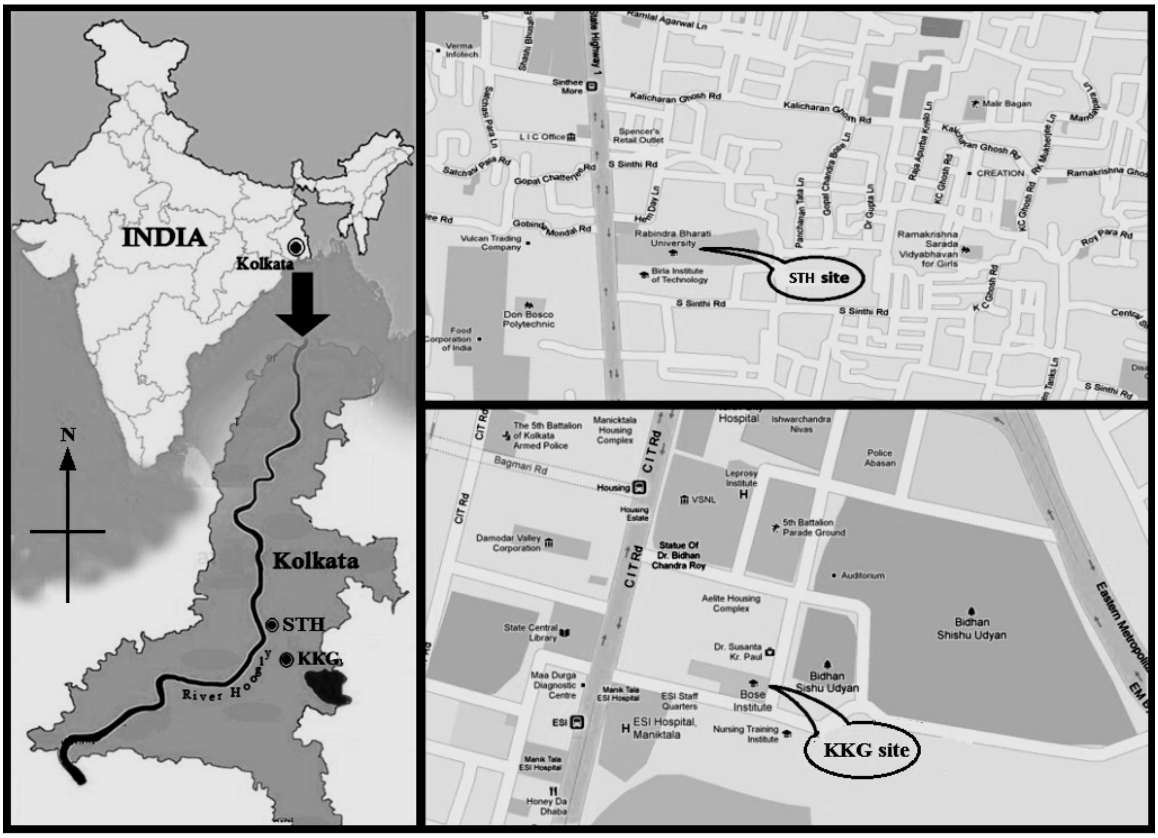

Fig. 1. Map showing the sampling locations.

The mass concentration of aerosol was determined by the gravimetric measurement. The filters were placed in desiccators for 24 hrs before and after the sampling to remove the absorbed water and weighed in a controlled environment chamber after taking the filters out of the desiccators before and after the sampling using an analytical balance (Sartorius, Model ME 235 P). The aerosol mass (µg) was determined by the differences between initial and final weight of the filters and the concentration (µg/m^3) was determined dividing the aerosol mass by total volume of air (m^3).

Sample Collection at STH Site

Respirable Suspended Particulate Matter (RSPM) analyzer (MP101M, Environment S.A., France) was used to measure PM_{10} concentration at this site. It consists of a carbon 14 radioactive source (^{14}C) which emits Beta radiation, filter ribbon which collects the particles suspended in the air and a radioactive detector. The detector is mounted at a downstream of the filter ribbon. The ribbon filter is made of glass fibre and collection efficiency of the particle is more than 99%. The low-energy Beta rays are absorbed by the matter by collision with the electrons whose number is proportional to the density of dust collected on the glass filter and the filter material. The absorption is governed by exponential law and is independent of the physical-chemical nature of the matter.

To measure SO_2 concentration at this site, an on-line SO_2 analyzer (AF21M-LCD, Environment S.A., France) was used. The analyzer is equipped with a low pressure zinc vapour lamp which emits ultraviolet radiation at a wavelength λ = 213.9 nm and measures the concentration of SO_2 based on fluorescent technique.

The instruments at STH site have been provided by West Bengal Pollution Control Board (WBPCB), Govt. of West Bengal, India.

Sampling Schedule and Data Sets

The PM_{10} sampler was run continuously from November 3 to November 10, 2010 and the samples were collected for 12 hour day (6 A.M.–5 P.M.) and night (6 P.M.–5 A.M.) time basis at KKG site. Thus a total of 16 samples (8 day and 8 night samples) were collected during this period. On the other hand, aerosol sampler and on-line SO_2 analyzer run continuously during this period at STH site.

The main festival day (Diwali day) was on November 5, 2010. Thus November 4 and November 6 were considered as Pre-Diwali and Post-Diwali day respectively and November 3 and November 7–10 were considered as normal day.

Chemical Analysis of Water Soluble Ionic Species in PM_{10} at KKG Site

Ion Chromatography was used for the analysis of water soluble ions in PM_{10}. One-half of the filters were soaked in 20 ml Milli-Q water (18.2 MΩ resistivity) for 30 min and ultrasonicated for 20 min. The solutions were made up to known volume (100 mL) using Milli-Q water. The solutions were then kept in polypropelene bottles and kept at 4°C

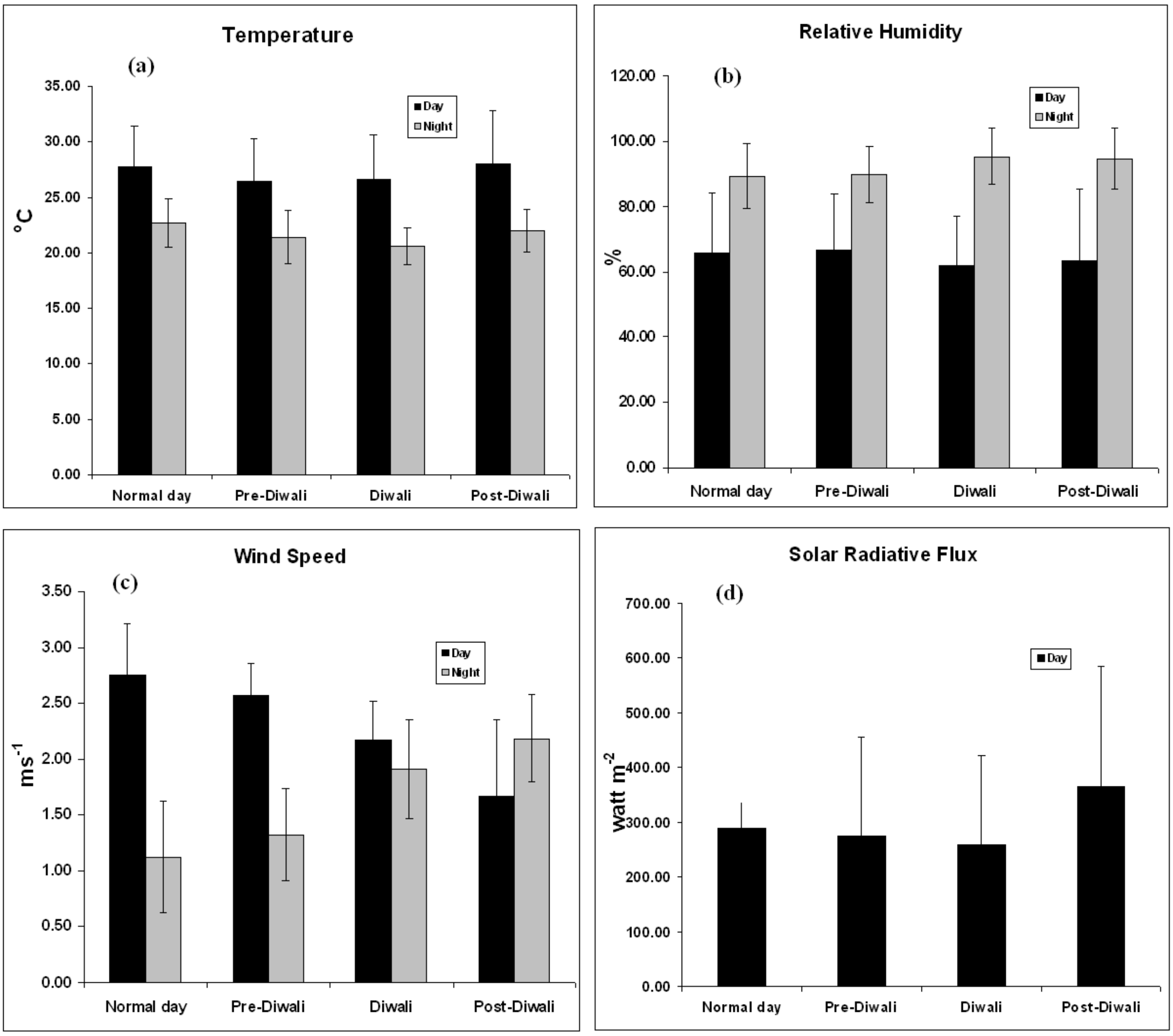

Fig. 2. Day and Night time average of micro-meteorological parameters over Kolkata on normal, pre- Diwali, Diwali and post- Diwali days. Solar radiative flux (d) is shown for day time only.

until analysis. Prior to their use, the bottles were cleaned repeatedly using distilled water and soaked for ~72 hrs. The major ions, namely anions (Cl^-, NO_3^- and SO_4^{2-}) and cations (K^+, Ca^{2+} and Mg^{2+}) were quantitatively determined by Ion Chromatograph (Metrohm, 861 Advanced Compact IC). The analytical column METROSEP A SUPP 5 (250/4 mm) was used for anions where the mixture of 3.2 mM Na_2CO_3 and 1.0 mM $NaHCO_3$ was used as eluent 0.7 mL/min. Similarly the analytical column METROSEP C2 250 (250/4 mm) was used for cations where the mixture of 4.0 mM L-Tartaric Acid and 0.75 mM PDCA (Pyridene 2,6 Dicarboxylic Acid) was used as the eluent with a flow rate of 1 mL/min. We used the standard reference materials for different ions for calibration purpose. They are TraceCERT standards from Sigma-Aldrich, USA with NIST traceability. Detection limits of the ionic species, concentrations corresponding to three times the standard deviation of five replicate blank level measurements for K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^- and SO_4^{2-} were 1.3, 3.0, 5.0, 9.0, 5.0, 8.0 ng/m^3. The precision estimated from the standard deviation of repeat measurements of standard samples was 2% for K^+ and Ca^{2+}; 5% for Mg^{2+}; 2% for Cl^-, SO_4^{2-} and 4% for NO_3^-. The concentrations of ions in blank filter paper were found to be less than 10% of the minimum concentration of the respective ions in aerosol samples.

Chemical Analysis of Metals in PM_{10} at KKG Site

Half of the filter paper was digested with concentrated nitric acid (Fluka Trace Select Ultra Grade) on hot plate till white fumes arose and reduced to 2–3 mL (APHA, 1977). The content was filtered through Whatman Filter no. 42 and final volume made-up to 25 mL by double distilled water. The filtrate was analyzed for the concentration of Fe, Al, Zn, Pb, Cu, Co, Cd, Mn, and V by Atomic Absorption Spectrophotometer (AAnalyst 700, Perkin Elmer, USA) equipped with graphite furnace. The AAS value of blank filter papers of each metal was deducted for the sample value for final calculations. We used different standard reference materials for different metals for the calibration purpose. They are AccuTrace Reference Standard (AAS standard) from Rankem, Germany with NIST traceability. The analysis of metals has been performed at West Bengal Pollution Control Board (WBPCB), Govt. of West Bengal, India.

RESULTS AND DISCUSSION

PM_{10} Aerosol during Normal and Festival Days at KKG Site

The 12 hrs average day-time (6 A.M.–5 P.M.) and night-time (6 P.M.–5 A.M.) concentrations of PM_{10} aerosols during normal, pre-Diwali, Diwali and post-Diwali day have been shown in Fig. 3. On normal day, the night-time PM_{10} concentration (153 ± 34 μg/m^3) was found to be higher than day-time (122 ± 24 μg/m^3). During night, the mixing height decreases with the decrease in temperature by ~6°C which allows the aerosol particles to be accumulated near the surface. The lower wind speed during night does not allow the particles to be dispersed which in turn enhances the surface concentration of aerosol particles. On the other hand, during day-time, the higher thermal convection increases the mixing height and higher wind speed allows the aerosol particles to be dispersed which in turn lowers the surface aerosol concentrations. The day-time concentration of PM_{10} on pre-Diwali day (125 μg/m^3) was almost equal to that on normal day (122 μg/m^3) as there was not any difference in usual day-time anthropogenic activities between a normal day and pre-Diwali day. The maximum night-time concentration of PM_{10} aerosol was found on Diwali (711 μg/m^3) followed by post-Diwali (507 μg/m^3) and pre-Diwali (397 μg/m^3) day. The night-time concentrations of PM_{10} on pre-Diwali, Diwali and post-Diwali day were respectively 4, 7, and 5 times higher than the permissible standard of PM_{10}, 100 μg/m^3 over a residential area as given by National Ambient Air Quality Standards (NAAQS). It is to be noted here that maximum firework activities occurred on Diwali-night followed by post-Diwali-night and pre-Diwali-night. Thus PM_{10} concentration was found to follow the same order which clearly indicates the effect of firework activities on the atmospheric loading of night-time PM_{10} aerosol during those days. The maximum day-time concentration of PM_{10} aerosol was found on post-Diwali (468 μg/m^3) followed by Diwali (338 μg/m^3) and pre-Diwali (125 μg/m^3) day. Thus it is clear that there was a strong effect of night-time firework activities on the next day day-time aerosol concentration. As the firework activities during Diwali night were higher than that during pre-Diwali night, the day-time aerosol concentration on post-Diwali day was also higher than that on Diwali day.

Metals in PM_{10} during Normal and Festival Days at KKG Site

The day-time and night-time concentrations of the metals during normal, pre-Diwali, Diwali and post-Diwali day have been shown in Fig. 4. Zn, Fe, Pb and Al were found to be the most abundant elements in the atmosphere and their concentrations exceeded 100 ng/m^3 and were much higher than other elements even on normal day. Their day-time concentrations followed the same order (Zn > Fe > Pb > Al) on normal, pre-Diwali and Diwali day which was different from post-Diwali day (Fe > Zn > Pb > Al) where Fe dominated over other metals. The similar order was also found for their night-time concentrations. On normal and pre-Diwali night it was Zn > Fe > Pb > Al whereas on Diwali and post-Diwali night it was Fe > Zn > Pb > Al. The same order on Diwali-night and post-Diwali day-time clearly indicates the effect of firework activities during night-time on the next day day-time concentrations. It has been found that the day-time concentrations of the metals on normal days were almost equal to that on pre-Diwali day. On the other hand, the night-time concentrations of the metals on the pre-Diwali day were much higher (2–10

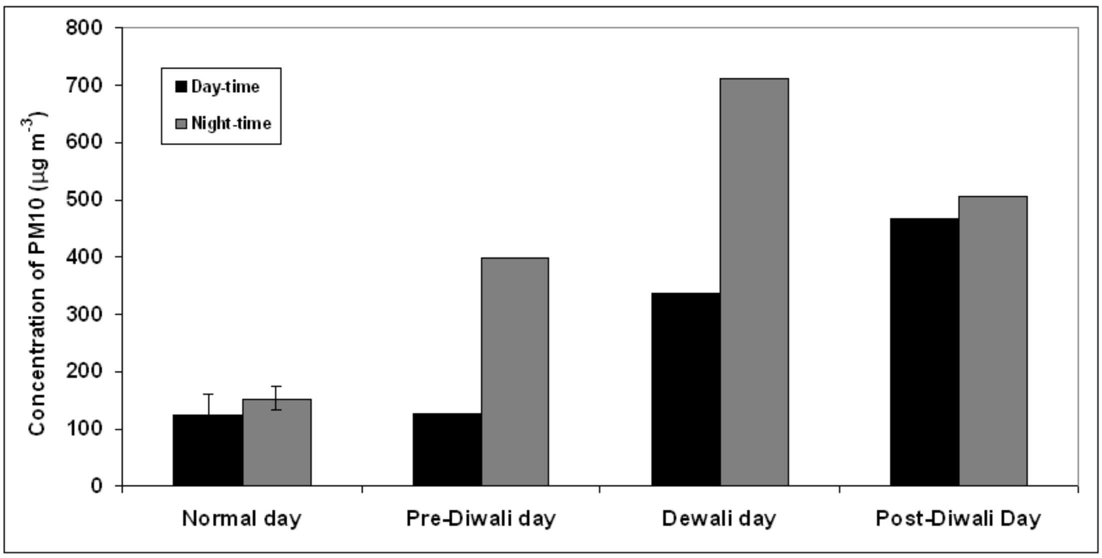

Fig. 3. Variation of PM_{10} concentration on normal, Pre- Diwali, Diwali and post-Diwali days at KKG site.

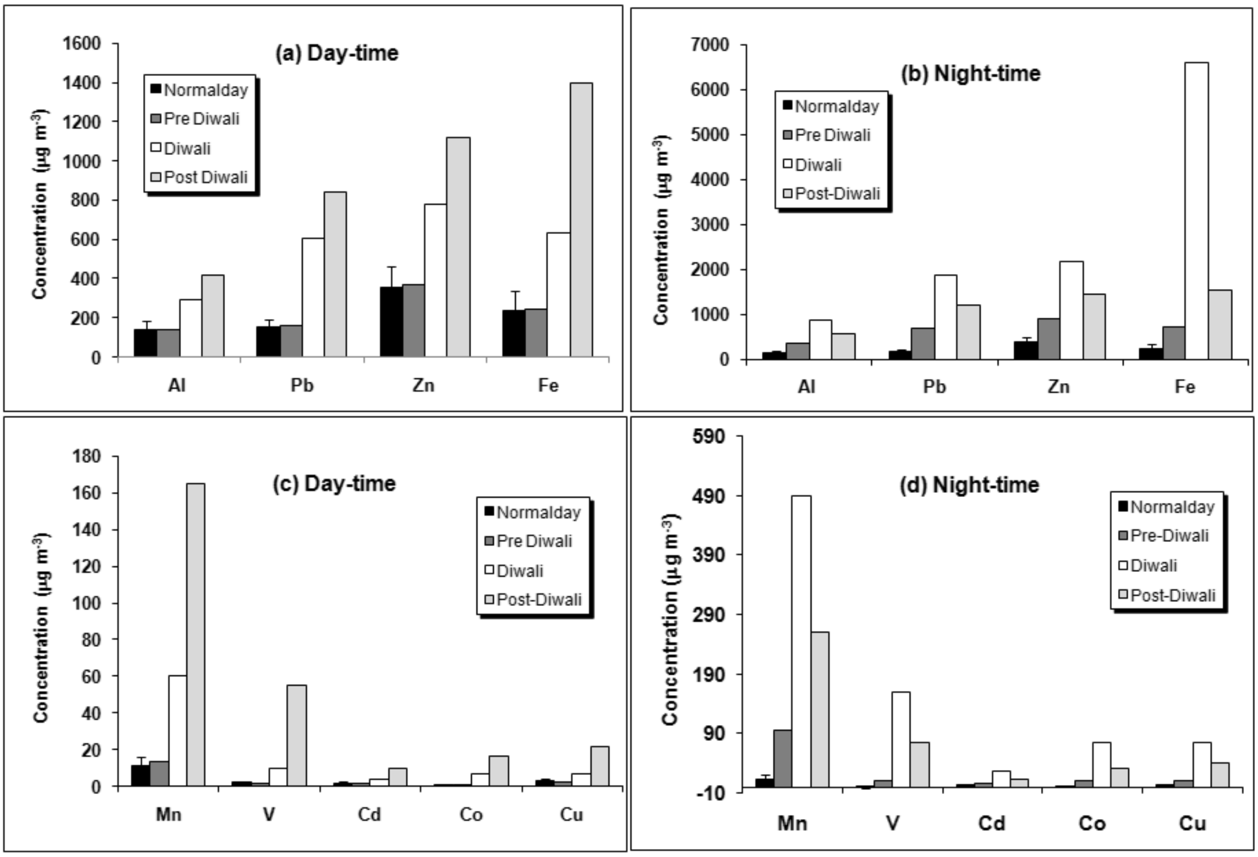

Fig. 4. Day time and night time concentration of Al, Pb, Zn, Fe (a,b) and Mn, V, Cd, Co, Cu (c,d) on normal, pre- Diwali, Diwali, and post- Diwali days at KKG site.

times) than that on normal days. Firework activities usually start from pre-Diwali night and thus there was a strong influence of the firecrackers on the metal concentrations during pre-Diwali night. However, a gradual increase in the day-time concentrations of the metals was observed from pre-Diwali to post-Diwali day. The higher day-time concentrations of all the metals on post-Diwali day were due to the effect of firework activities on Diwali night which sustained till next morning (post-Diwali day). The day-time concentrations of all the metals on post-Diwali day showed 1.5–3 times increase than that on Diwali day and 3–16 times increase (3 times for Al and Zn; 5–7 times for Pb, Cd and Fe; 10–16 times for Cu, Mn and Co) than that on pre-Diwali day. The day-time concentration of V on post-Diwali day was found to be exceptionally higher than pre-Diwali day (~50 times). The night-time concentrations of the metals was found to follow the order of Diwali > post-Diwali > pre-Diwali. The increase in night-time concentrations of the metals on Diwali than that on normal day spanned over a wide range (5–80 times). The night-time concentrations of Al and Zn showed 5–6 times, Pb and Cd showed 10–12 times, Cu and Fe showed 25 times, Mn showed 40 times, Co showed 70 times and V showed 80 times higher than normal day. On the other hand, the night-time concentrations of the metals on Diwali showed 1.5–3.5 times higher than post-Diwali and 2.5–15 times (2.5 times for Al, Zn and Pb; 5–7 times for Cd, Mn, Co and Cu; 9 times for Fe and 15 times for V) higher than pre-Diwali day.

There are several sources emitting trace metals in to the atmosphere. Fossil fuel combustion (for Al, Fe, Ca, Mg, K, Na, As, Pb, Cd, Sc, Hg etc.), wood burning (Pb, Zn etc.), soil dust (Fe, Al etc.), vehicular traffic (Cd, Cr, Cu, Ni, Pb, Zn etc.), electroplating industries, metal alloy industries (Cd, Cr, Al, Fe, Ni, Zn, Pb, Cu etc.) are the major sources over an urban atmosphere (Kulshrestha *et al.*, 2004). Karar *et al.* (2007) identified the sources of some metals in PM_{10} over a residential and an industrial location in Kolkata, India. They identified four possible sources of trace metals comprising solid waste dumping, vehicular traffic with the influence of road dust and soil dust at residential site, while vehicular traffic with the influence of soil dust, road dust, galvanizing and electroplating industry, and tanning industry at industrial site. Gupta *et al.* (2007) also identified major sources of heavy metals in PM_{10} over a residential and an industrial location over Kolkata. The identified major sources were field burning, wood combustion, diesel combustion, soil dust and road dust at residential site, while metal industry, solid waste, tyre wear, road dust and soil dust at industrial site. In this study Zn, Fe, Al, Pb were found to be the most abundant elements in the atmosphere even on normal days indicating their source of soil and road dust, industrial and vehicular emissions.

Other than the stationary and mobile sources mentioned above, the burning of crackers and sparkles during Diwali festival also emit a huge amount of metals in the atmosphere. To make the crackers more bright and colourful and to produce white flames and sparks Al is used. Zn is used in the crackers to create smoke effects. Fe, Cu, Co are used as colouring agents and to produce sparks. The oxides, nitrates and nitrites of some elements like Pb, Mn, Cd, and V are used as the ready source of oxygen for the process of combustion of the firecrackers. Most of the heavy metals are used to give colouring effects and flash. However it is hard to find out the exact sources of these elements in the atmosphere of Kolkata during Diwali unless a long-term data is generated.

Comparison of Aerosol, Trace Metals and Trace Gases between Kolkata and Other Indian Locations during Diwali Festival

The enhancement in the concentrations of aerosol and its components (compared to normal days) during Diwali festival over Kolkata (this study) has been compared with the other Indian locations and shown in Table 1. One of those locations, Howrah, is adjacent to Kolkata metropolis. It has been found that the increase in PM_{10} over Howrah is higher than Kolkata. The increase in Al was found to be exactly equal to that over Kolkata (6 times) whereas the increases in Pb and Cd concentrations over Howrah were slightly higher than Kolkata. But the increase in Cu concentration over Howrah showed remarkably higher (79 times) than Kolkata (25 times). It can be seen from the table that over Kolkata, the increase in PM_{10} concentration was much higher (4.6 times) compared Delhi, Hyderabad and Hisar (1.5–2.8 times). However, Lucknow showed higher increase (5.7 times) in PM_{10} than Kolkata. But the interesting observation is that the increase in trace metal concentrations was several times higher over Kolkata compared to other locations. This indicates that trace metal pollution over Kolkata during Diwali festival was much higher than other Indian locations. Over Kolkata, the increase in SO_2 during Diwali-night compared to normal days (5 times) was found to be less than Lucknow city (7 times) and higher than Hisar (4 times). The micro-meteorological factors, usage of firecrackers could make the difference in the enhancement of aerosol and its components loading in the atmosphere during Diwali festival between several locations.

Ionic Species in PM_{10} during Normal and Festival Days at KKG Site

The day-time and night-time concentrations of the ionic species have been shown in Fig. 5. SO_4^{2-} was found to have the highest and Mg^{2+} was found to have the lowest abundance in the atmosphere. The day-time concentrations of the ionic species on normal day were almost equal to that on pre-Diwali day and the order of the abundance of the ionic species is $SO_4^{2-} > NO_3^- > Ca^{2+} \sim Cl^- > K^+ > Mg^{2+}$ during day-time and $SO_4^{2-} > NO_3^- > Cl^- > K^+ > Ca^{2+} > Mg^{2+}$ during night-time on normal day. This indicates that the secondary anthropogenic ionic species (SO_4^{2-} and NO_3^-) dominated over primary ionic species both during day and night-time on normal day. It was also observed that the night-time concentrations of SO_4^{2-}, NO_3^-, Cl^- and K^+ were higher than day-time concentrations whereas Ca^{2+} showed higher concentrations during day-time than night-time on normal day. Ca^{2+} mainly comes from the resuspension of soil-dust aerosols and from construction activities favoured by higher wind speed during day-time and enriched in coarse mode (aerodynamic diameter greater than 2.5 microns) aerosol which can settle down quickly. On the other hand, the other species are anthropogenic in nature (biomass and fossil fuel burning and vehicular emission etc.) and mostly enriched in fine mode (aerodynamic diameter less than 2.5 microns) which can stay in the atmosphere for a long time and get accumulated near the surface because of the decrease in boundary layer height during night-time. The day-time concentrations of all the ionic species increased gradually from pre-Diwali to post-Diwali whereas the night-time concentrations were highest on Diwali day followed by post-Diwali and pre-Diwali. The reason for highest day-time concentrations of the ionic species on post-Diwali and highest night-time concentrations on Diwali is the same as discussed for metals. The day-time concentrations of the ionic species on post-Diwali day were 1.5–3 times higher

Table 1. The number of times increases in aerosol components and trace gases concentrations compared to normal days over Kolkata and other Indian locations during Diwali.

	Kolkata (This Study)	Delhi (Perrino *et al.*, 2011)		Hyderabad (Kulshrestha *et al.*, 2004)	Hisar (Ravindra *et al.*, 2003)	Lucknow (Barman *et al.*, 2008)	Howrah (Thakur *et al.*, 2010)
Year of study	2010	2008	2009	2002	1999	2005	2008
PM_{10}	4.6	2.8	1.6	NA	1.5–2.0	5.7	7.2
Al	6.0	3.3	3.8	18.0	NA	NA	6.0
Pb	11.0	2.1	1.7	NA	NA	1.4	15.0
Zn	5.5	4.2	2.6	NA	NA	2.2	NA
Fe	26.0	1.1	1.2	2.0	NA	1.7	NA
Mn	40.0	2.9	2.8	2.0	NA	1.3	NA
V	80.0	7.5	6.6	1.5	NA	NA	NA
Cd	12.0	NA	NA	NA	NA	2.0	17.0
Co	70.0	NA	NA	NA	NA	1.3	NA
Cu	25.0	NA	NA	9.0	NA	3.7	79.0
SO_2	5.0	NA	NA	NA	4.0	7.0	1.7

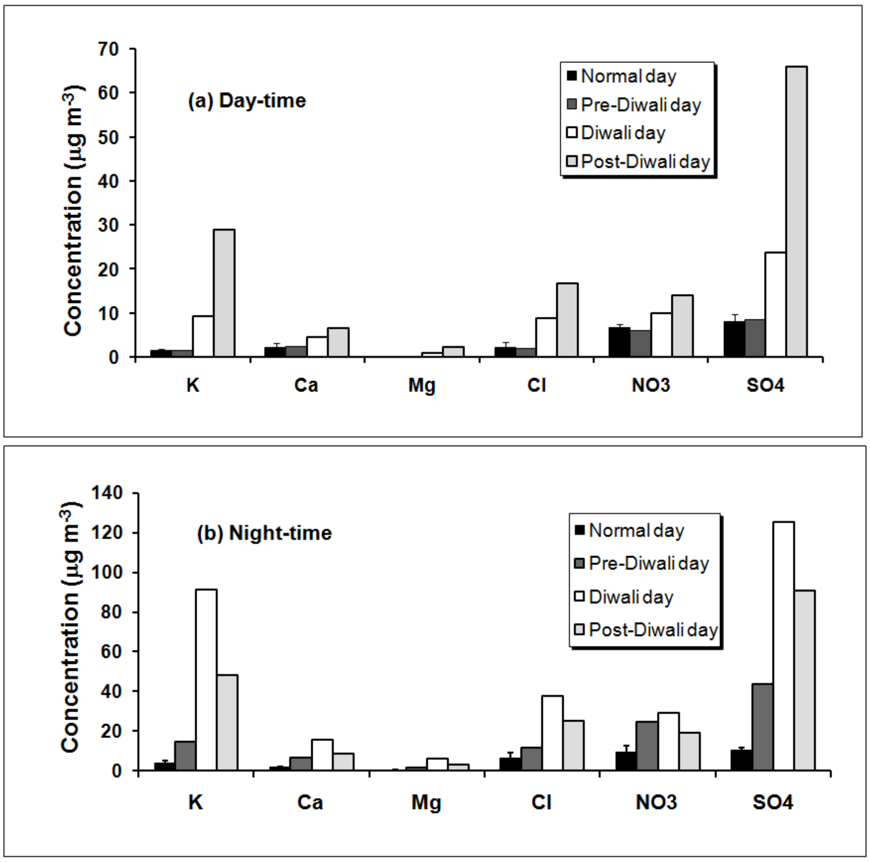

Fig. 5. a) Day time b) Night time concentration of K^+, Ca^{+2}, Mg^{+2}, Cl^- NO_3^-, SO_4^{2-} on normal, Pre-Diwali, Diwali and post-Diwali days at KKG site.

than that on Diwali and normal (and pre-Diwali) day. The notable feature is that the day-time concentrations of K^+ showed 20 times and Cl^- and SO_4^{2-} showed 8 times higher on post-Diwali day than normal and pre-Diwali day. On the other hand, the night-time concentrations of the ionic species on Diwali day were 1.5–2 times higher than that on post-Diwali day and 1.5–6 times higher than pre-Diwali and normal day. The remarkable increases in night-time concentrations on Diwali day than normal day were found for K^+ (30 times), Mg^{2+} (20 times), Ca^{2+} (14 times) and SO_4^{2-} (12 times). Interestingly it was observed that the order of the abundances of the ionic species during pre-Diwali night-time and Diwali day-time were same, $SO_4^{2-} > NO_3^- > K^+ > Cl^- > Ca^{2+} > Mg^{2+}$. The abundance order was also same for Diwali night-time and post-Diwali day-time, $SO_4^{2-} > K^+ > Cl^- > NO_3^- > Ca^{2+} > Mg^{2+}$. This clearly indicates the strong effect of firework activities during night-time on the next day day-time. Sparkles and fire crackers mainly contain black powder that contains potassium nitrate, charcoal and sulphur. Potassium chlorate and perchlorate are used in fire crackers to supply oxygen necessary for the combustion of the mixture which under heat generated by the burning of crackers decomposes to produce Cl^-. Calcium and magnesium salts are used to make the crackers more bright and colourful. The burning of fire crackers and sparkles produce SO_2. SO_2 can get converted to particulate SO_4^{2-} easily and rapidly either by photochemical oxidation in presence of higher solar radiative flux in day-time or by aqueous phase oxidation (by O_3/H_2O_2) catalysed by metal like Fe. Although we have not studied O_3, but high O_3 production by firecracker burning during Diwali has been reported by Attri *et al.* (2001) in India. We also observed the high Fe concentration and high relative humidity during Diwali night. Thus conditions were favourable for aqueous phase oxidation of SO_2 to SO_4^{2-} which resulted high SO_4^{2-} concentration during Diwali night (125 µg/m^3). The high day-time SO_4^{2-} concentration during post-Diwali day (66 µg/m^3) could be contributed by the particulate SO_4^{2-} produced in previous Diwali night and/or photochemical oxidation of SO_2 (from previous Diwali night) in presence of higher solar radiative flux (Fig. 2) on clear-sky sunny post-Diwali day. In addition to that, some sulphate salts are also used as colouring agents in sparkles and crackers which directly emit sulphate in the atmosphere.

Interestingly it was observed that PM_{10}, metals and ionic species concentrations followed a same trend during the study period and which is,

Diwali-night-time > Post-Diwali-night-time > Post-Diwali-day-time > Pre-Diwali-night-time > Diwali-day-time > normal day night-time > normal day day-time ~pre-Diwali-day-time.

The most important observation in this trend is that the post-Diwali day-time concentration (with no firework activities) was higher than pre-Diwali night-time concentration (with firework activities) of the aerosol components. This indicates that the effect of Diwali-night firework activities was so high on next day (post-Diwali) day-time concentrations that the later exceeded the pre-Diwali night-time concentrations.

Diurnal Variation of PM_{10} and SO_2 at STH Site

The diurnal variation (6–6 A.M.) of PM_{10} and SO_2 on normal, pre-Diwali, Diwali and post-Diwali day have been shown in Fig. 6. In all cases, the night-time concentrations of PM_{10} showed higher concentrations than day-time. The average day (6 A.M.–5 P.M.) and night-time (6 P.M.–5 A.M.) concentrations of PM_{10} were 81.5 ± 22 and 119.5 ± 39 µg/m^3 respectively on normal, 77 ± 27 and 152 ± 52 µg/m^3 respectively on pre-Diwali, 110 ± 40 and 526 ± 210 µg/m^3 respectively on Diwali and 139 ± 84 and 359 ± 154 µg/m^3 respectively on post-Diwali day. It is clear that the day-time concentrations of PM_{10} on normal and pre-Diwali day do not show much difference and are lower than that on Diwali and post-Diwali day. On normal day, a peak was observed during morning hours (8–10 A.M.) which could be attributed to the maximum vehicular emission during this peak office hours. During afternoon, concentrations were much lower which could be due to the increase in boundary layer height due to enhanced convection which allows the aerosol particles to be dispersed favoured by higher wind speed. Another peak was observed during evening (8–10 P.M.) followed by a slow and steady decrease till morning. The higher night-time concentration could be due to the thinning of the boundary layer at low temperature which allows the particles to be accumulated near the surface favoured by lower wind speed. On pre-Diwali day, the day-time concentration showed a morning peak during the same period (8–10 A.M.) as observed on normal day. The night-time PM_{10} concentrations showed peaks during 8 P.M.–3 A.M. on pre-Diwali, Diwali and post-Diwali days which clearly indicates that most of the firework activities happened during this period. The average PM_{10} concentrations during this period (8 P.M.–3 A.M.) were 190 µg/m^3 on pre-Diwali day which were ~1.5 times, 678 µg/m^3 on Diwali day which were 5 times and 477 µg/m^3 on post-Diwali day which were ~3.5 times higher than that during the same period on normal day. PM_{10} concentrations during the period of 8 P.M.–3 A.M. at this site on pre-Diwali, Diwali and post-

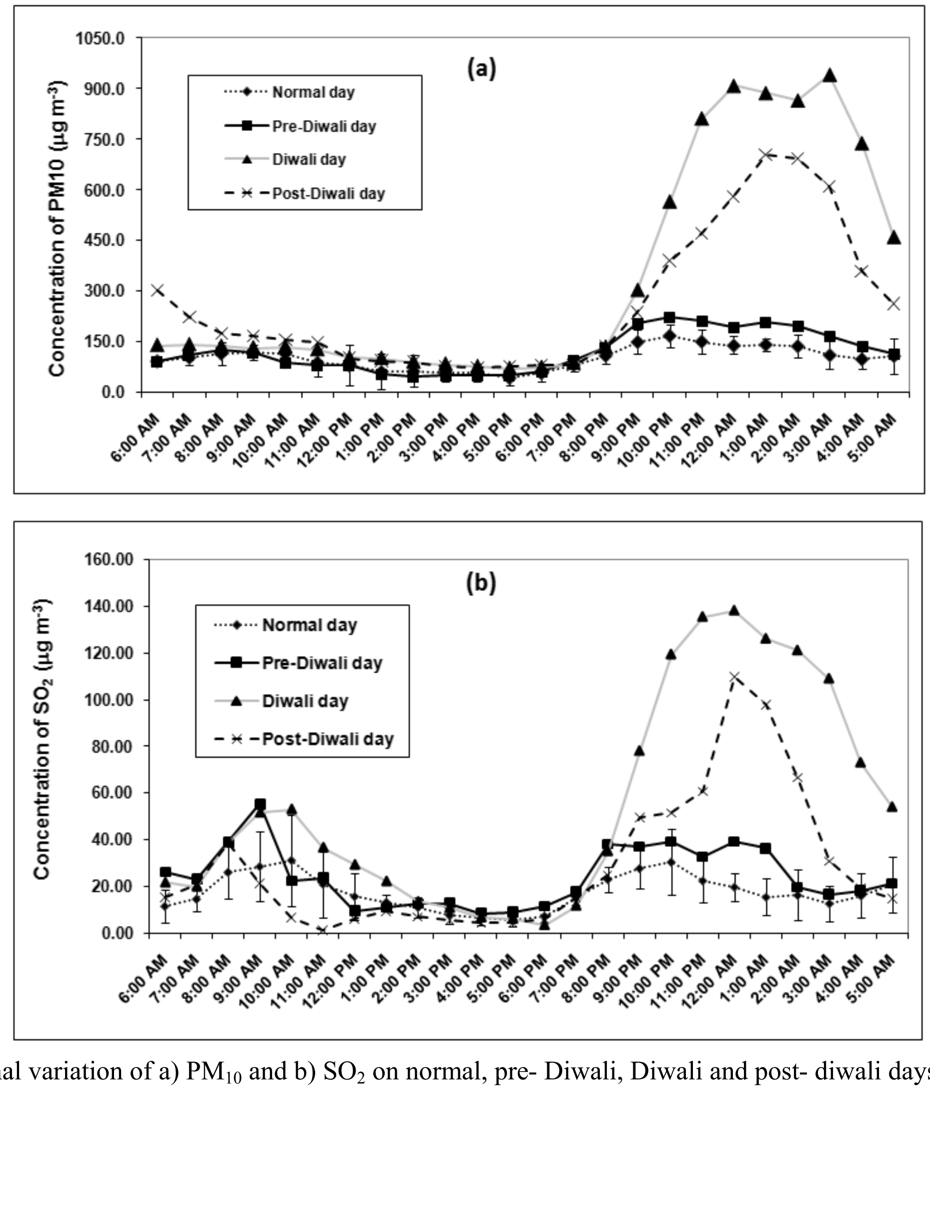

Fig. 6. Diurnal variation of a) PM_{10} and b) SO_2 on normal, pre- Diwali, Diwali and post- diwali days at STH site.

Diwali day were found to be ~2, ~7 and ~5 times higher than the permissible standard of PM_{10} (100 μg/m^3) as given by NAAQS. It can also be seen from the figure that the effect of firework activities during night-time lingered till late morning hours on the next day as we observed higher PM_{10} concentrations on Diwali and post-Diwali day during 6 A.M.–11 A.M. compared to normal and pre-Diwali day. But the effect was not found to last long as afternoon started probably due to the ventilation of the particles with higher boundary layer height and higher wind speed as PM_{10} concentrations during afternoon on Diwali and post-Diwali day were found to be comparable with that on normal and pre-Diwali day.

The average day and night-time concentrations of SO_2 were found to be almost equal on normal day (17.2 ± 8.3 μg/m^3 during day-time and 17.8 ± 7.5 μg/m^3 during night-time). During day-time, the anthropogenic activities (fossil fuel burning from vehicular and industrial activities, biomass burning etc.) are higher resulting higher emission of SO_2 than night-time. But higher solar radiative flux also plays the role in the photochemical oxidation of gas phase SO_2 to particulate SO_4^{2-} which in turn lowers the SO_2 concentration during day-time. During night-time, the emitted SO_2 from various sources (although lower than day-time) is remained as gas phase SO_2 as photochemistry does not play any role and also the thinning of boundary layer enhances its surface concentrations. Due to these mixed effects, the day-time and night-time concentrations of SO_2 probably became equal. However the night-time concentrations of SO_2 were higher than day-time concentrations on festival days (pre-Diwali, Diwali and post-Diwali). The maximum night-time concentration was observed on Diwali day (84 μg/m^3 which was ~5 times higher than normal day night-time) followed by post-Diwali day (46 μg/m^3 which was ~3 times higher than normal day night-time) and pre-Diwali day (27 μg/m^3 which was ~1.5 times higher than normal day night-time). On normal day, the diurnal variation of SO_2 showed two peaks, one during morning (8–10 A.M.) and one during evening (7–10 P.M.) with the minimum concentrations during afternoon. On pre-Diwali night, SO_2 showed higher concentrations (32 μg/m^3) during 8 P.M.–1 A.M. and on Diwali and post-Diwali night it was higher (102 and 74 μg/m^3 respectively) during 8 P.M.–3 A.M. indicating firework activities during respective periods. SO_2 concentrations were 1.6, 5 and 3.7 times higher on pre-Diwali, Diwali and post-Diwali night respectively than that during the respective periods on normal day. The effect of firework activities during Diwali night on early morning hours on post-Diwali day was found to be higher than the effect of pre-Diwali night on early morning hours on Diwali day.

Comparison of Aerosol (PM_{10}) between KKG and STH Site during Diwali

In general, during normal days, the night-time PM_{10} concentration was found to be higher than day-time concentration for both the locations. But, both the day and night-time PM_{10} concentrations over KKG show 35–50% higher than STH site. The site KKG is situated between two busy roads with very high traffic density. One is around 75 m to the east and the other one is around 25 m to the west to the site (Fig 1). Another road which is joining these two roads is also adjacent to the KKG site towards south with moderate traffic density. On the other hand, there is only one busy road adjacent to STH site with less traffic density compared to roads near KKG site. Also, KKG is a residential-cum-commercial site whereas STH is a residential site with minimum commercial activities. Thus based on vehicular and other anthropogenic activities, the site KKG shows higher aerosol concentrations compared to STH.

During Diwali night, the increase in PM_{10} concentration was 558 μg/m^3 over KKG whereas it was 406 μg/m^3 over STH as compared to the normal day night-time concentrations at respective sites. Also, PM_{10} concentration over KKG was found to be 1.3 times higher than STH site during Diwali night. It was also observed that during pre-Diwali and post-Diwali night, PM_{10} concentrations over KKG were higher by 2.6 and 1.4 times respectively as compared to STH site. This clearly indicates the higher firework activities over KKG than STH during the festive period. The residents of KKG site are in fact economically richer than the residents of STH site. Thus the use of expensive firecrackers and the frequency of their usage during Diwali night are much higher over KKG than STH. This could be the reason for higher aerosol loading during Diwali at KKG compared to STH.

Probable Impact of Air Pollution during Diwali Festival over Kolkata

Diwali festival does not only enhance the loading of aerosol and its components in the atmosphere over Kolkata but it could also have the impact on remote marine areas adjacent to Kolkata metropolis. There is a close proximity (~90 km south of Kolkata) of Sundarban mangrove forest to Kolkata. Sundarban mangrove forest at the north-east coast of Bay of Bengal is the major ecosystem of the biosphere in India and represents a stressed chemical environment because of the increased pollutant emission advected from the adjacent urban atmosphere (Raes *et al.*, 2000). In order to find out the possibility of the transport of pollutants (during Diwali) from Kolkata to this remote marine area at the coast of Bay of Bengal, frequency distribution of the wind direction during festive period has been studied. The firework activities for Diwali festival actually started from pre-Diwali evening and ended on post-Diwali night except the day-time of pre-, post- and Diwali day. Hence, wind direction was studied from the evening (6 P.M.) of pre-Diwali day till the morning (6 A.M.) of the day after post-Diwali. It was found that during the entire festive period, 72% of the wind trajectories correspond to southern and south-eastern sectors. This indicates that there was a high probability for the transport of air pollutants from Kolkata and adjacent urban atmosphere towards the remote marine atmosphere at the coast of Bay of Bengal during the festive period of Diwali. The aerosols with several ionic and carbonaceous components along with highly enriched heavy metals could interact with the fresh or less polluted aerosols of mostly marine origin and thus could degrade the forest/marine air quality. Thus, the effect of

Diwali festival, though of short-period but could have an adverse impact on an area of a rich and unique biodiversity like Sundarban.

CONCLUSION

This study shows that the firework activities i.e. burning of crackers, sparkles etc had a strong effect in increasing the concentration of PM_{10}, water soluble (ionic species), water insoluble (metals) and trace gas (SO_2) components over two study sites; Kankurgachi (KKG) and Sinthi (STH) at northern Kolkata.

At KKG, PM_{10} concentration reached at 711 μg/m^3 on Diwali night which was ~5 times than the average night-time concentration on normal day. The increase in night-time concentrations of the metals on Diwali than normal day spanned over a wide range. Al, Zn, Pb and Cd showed 5–12 times, Cu, Fe and Mn showed 25–40 times and Co and V showed 70–80 times increase in concentrations on Diwali night than normal day night-time. The water soluble ionic species showed 1.5–6 times higher concentrations on Diwali night than normal day. The remarkable increases were found for K^+, Ca^{2+}, Mg^{2+} and SO_4^{2-}. Strong effect of firework activities was observed for SO_4^{2-} concentration which reached at 125 μg/m^3 on Diwali night. PM_{10}, metals and ionic species concentrations were found to follow a same trend at KKG during the study period and which was, Diwali-night-time > Post-Diwali-night-time > Post-Diwali-day-time > Pre-Diwali-night-time > Diwali-day-time > normal day night-time > normal day day-time ~pre-Diwali-day-time. Thus, there was a strong effect of night-time firework activities on the next day day-time concentrations.

At STH, the diurnal variation of PM_{10} and SO_2 showed their maximum concentrations on Diwali night during 8 P.M.–3 A.M. indicating maximum firework activities during this period. PM_{10} and SO_2 concentrations increased by ~5 times than normal day during this period at this site. The diurnal variation of pollutants at this site shows that the effect of Diwali night activities lasted for ~12 hr (8 P.M. on Diwali night to 8 A.M. on post-Diwali day).

The short-term exposure of these pollutants and the high increase in their concentrations during Diwali festival can increase the likelihood of acute health effects. As Diwali is the festival of light and celebrated during night-time, the unfavourable meteorological conditions (lower wind speed, lower boundary layer height etc.) for the dispersion of pollutants during night-time helps them to be accumulated near the earth surface till next day day-time. The same may be expected in other cities in India as this festival is celebrated all over the country. Hence, for the benefit of society, it is necessary to formulate proper strategy to control the emission and subsequent dispersion of the pollutants. Following measures may be considered:

- Promotion of firecracker display as a community entertainment
- Prohibition of firecracker burning on roads/lanes and earmarking of large open spaces, away from residential area, for firecracker display
- Crackers, exploding at a higher elevation (higher than the normal skyline of the locality) may be encouraged for a better dispersion

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REFERENCES

Attri, A.K., Kumar, U. and Jain, V.K., (2001). Formation of Ozone by Fireworks. *Nature* 411: 1015.

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

Barman, S.C., Singh, R., Negi, M.P.S. and Bhargava, S.K. (2008). Ambient Air Quality of Lucknow City (India) during Use of Fireworks on Diwali Festival. *Environ. Monit. Assess.* 137: 495–504.

Barman, S.C., Singh, R., Negi, M.P.S. and Bhargava, S.K. (2008b). Fine Particles ($PM_{2.5}$) in Residential Areas of Lucknow City and Factors Influencing the Concentration. *Clean-Soil Air Water* 36: 111–117.

Barman, S.C., Singh, R., Negi, M.P.S. and Bhargava, S.K. (2009). Fine Particles ($PM_{2.5}$) in Ambient Air of Lucknow City due to Fireworks on Diwali Festival. *J. Environ. Biol*. 30: 625–632.

Barnett, A.G., Williams, G.M., Schwartz, J., Nekker, A.H., Best, T.L., Petriescgevsjt, A.L. and Simpson, R.W. (2005). Air Pollution and Child Respiratory Health: A Case-Crossover Study in Australia and New Zealand. *Am. J. Respir. Crit. Care Med.* 171: 1272–1278.

Chen, L.H., Knutsen, S.F., Shavlik, D., Beeson, W.L., Peterson, F., Ghamsary, M. and Abbey, D. (2005). The Association between Fatal Coronary Heart Disease and Ambient Particulate Air Pollution: Are Females at Greater Risk? *Environ. Health Perspect.* 113: 1723–1729.

Clark, H. (1997). Air Pollution from Fireworks. *Atmos. Environ.* 31: 2893–2894.

Dockery, D.W., Luttnabb-Gibson, H., Rich, D.Q., Link, M.L., Mittleman M.A., Gold, D.R., Koutrakis, P., Schwartz, J.D. and Verrier, R.L. (2005). Association of Air Pollution with Increased Incidence of Ventricular Tachyarrythmias Recorded by Implanted Cardioverter Defibrillators. *Environ. Health Perspect.* 113: 670–674.

Drewnick, F., Hings, S.S., Curtius, J., Eerdekens, G. and Williams, J. (2006). Measurement of Fine Particulate and Gas-Phase Species during the New Year's Fireworks 2005 in Mainz, Germany. *Atmos. Environ*. 40: 4316–4327.

Ganguly, N.D. (2009). Surface Ozone Pollution during the Festival of Diwali, New Delhi, India. *Earth Sci. (India)* 2: 224–229.

Gupta, A.K., Karar, K. and Srivastava, A. (2007). Chemical Mass Balance Source Apportionment of PM_{10} and TSP in Residential and Industrial Sites of an Urban Region of Kolkata, India. *J. Hazard. Mater.* 142: 279–287.

Hirai, K., Yamazaki, Y., Okada, K., Furuta, S. and Kubo, K. (2000). Acute Eosinophilic Pneumonia Associated with Smoke from Fireworks. *Intern. Med. (Japan)* 39: 401–403.

Karar, K. and Gupta, A.K. (2007). Source Apportionment of PM_{10} at Residential and Industrial Sites of an Urban Region of Kolkata. *Atmos. Res.* 84: 30–41.

Kulshrestha, U.C., Nageswara Rao, T., Azhaguvel, S. and Kulshrestha, M.J., (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, S., Knewski, D., Shi, Y., Chen, Y. and Burnett, R. T. (2003). Association between Gaseous Ambient Air Pollutants and Adverse Pregnancy Outcomes in Vancouver, British Columbia. *Environ. Health Perspect.* 111: 1773–1778.

Moreno, T., Querol, X., Alastuey, A., Minguillon, M.C., Pey, J., Rodriguez, S., Miro, J.V., Felis, C. and Gibbons, W. (2007). Recreastional Atmospheric Pollution Episodes: Inhalable Metalliferous Particles from Firework Displays. *Atmos. Environ*. 41: 913–922.

Peters, A., Dockery, D.W., Muller, J.E. and Mittlemean, M.A. (2001). Increased Particulate Air Pollution and the Triggering of Myocardial Infarction. *Circulation* 103: 2810–2815.

Raes, F., Wilson, J., Putaud, J.P., Seinfeld, J.H., Adams, P., Van Dingenen, R. and Vignati, E. (2000). Formation and Cycling of Aerosols in the Global Troposphere. *Atmos. Environ*. 34: 4215–4240.

Ravindra, K., Mor, S. and Kaushik, C.P. (2003). Short-term Variation in Air Quality Associated with Firework Events: A Case Study. *J. Environ. Monit.* 5: 260–264.

Thakur, B., Chakraborty, S., Debsarkar, A., Chakraborty, S. and Srivastava, R.C. (2010). Air Pollution from Fireworks during Festival of Lights (Deepawali) in Howrah, India - A Case Study. *Atmosfera* 23: 347–365.

Vecchi, R., Bernardoni, V., Cricchio, D., D'Alessandro, A., Fermo, P., Lucarelli, F., Nava, S., Piazzalunga, A. and Valli, G. (2008). The Impact of Fireworks on Airborne Particles. *Atmos. Environ.* 42: 1121–1132.

Wang, Y., Zhuang, G., Xu, C. and An, Z. (2007). The Air Pollution Caused by the Burning of Fireworks during the Lantern Festival in Beijing, China. *Atmos. Environ.* 41: 417–431.

WHO (2003). Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide, Available on WHO website, Bonn, Germany.

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