

Short Term Air Quality Degradation by Firecrackers Used during Diwali Festival in Varanasi, India

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ABSTRACT: This study is mainly focussed on adverse environmental impact of fireworks performed during the Diwali Festival which is celebrated with great enthusiasm across the Indian subcontinent. Air pollutants prevailing during this period have been assessed which reveals large amount of aggravation in the level of these air pollutants. Pollutants cause short term degradation in air quality and in some cases long term effects have also been noticed. In this study 24 hr mean of PM_{2.5}, PM₁₀ has been taken into account and elemental as well as ionic component has also been analysed. The analysis was done by using scanning electron microscope (SEM) coupled with energy dispersive X-ray microanalyzer (EDX) and ion-chromatography (IC). The PM_{2.5} concentration was found increased up to 185 $\mu\text{g}/\text{m}^3$ and PM₁₀ concentration increased up to 258 $\mu\text{g}/\text{m}^3$ which is 3 to 4 times higher as stated by NAAQS limits. SEM-EDX reveals strong prevalence of Carbon, Oxygen, Sodium, Magnesium, Aluminium, Silicon, Potassium and Ferrous in the atmosphere. Ion chromatography results show enhanced concentration of Fluoride, Potassium, Sulphate, Nitrate and Chlorides on Diwali day or post Diwali days which in turn resulted in degraded environment. Short term increase in these particulate matters imposes serious health issues on persons dwelling in these cities. So this issue has to be taken into account in a serious manner to act upon and minimise its impact.

KEYWORDS: Fireworks, Diwali, PM₁₀, PM_{2.5}, Air Quality.

I. INTRODUCTION

Diwali is one of the most pompously celebrated festivals (falls mainly in the month of October or November) in India, which is accompanied by extensive bursting of fire crackers. These fireworks contributes in generating dense clouds of smoke which in turn results in short term degradation in air quality, due to increase in total suspended particulates (TSP) in the atmosphere. Generally crackers contain potassium, nitrate, charcoal, sulphur and trace elements, which severely affect environment as well as human health [1]. Atmospheric pollutants such as SO₂, NO₂ and particulate matters (PM₁₀ and PM_{2.5}) and water soluble ions [2-3], heavy metals like Aluminium, Manganese and Cadmium etc. are released in significant quantity [4] due to extensive use of fire crackers. It is evident from the study that short term exposure to PM₁₀ affects respiration health but as a consequence of long term exposure to PM_{2.5} is a great threat to our respiratory system (WHO Regional Office for Europe, 2013). This fire work also results in increased number concentrations of particles in the size range of 100nm-500nm [5]. These atmospheric pollutants not only cause adverse effects on health [6], but it also affects meteorological parameters such as aerosol optical depth (AOD), air temperature, relative humidity and lapse rate. In addition to this it may cause lower visibility for short duration of time. Effect on surface ozone has also been reported in association with these firework activities [7]. Studies have shown that continuous exposure to these particles is associated with a high percentage of death from respiratory and cardiovascular disease [8]. Particles of diameter 10 μm (PM₁₀) and 2.5 μm (PM_{2.5}) have been found to be associated with cardio-respiratory problem and mortality [9]. These health effects lead to need for better understanding of physical and chemical characteristic of particles (chemical composition, shape, size and distribution), their types and origin.

Bach et al. [10] reported that firework activities on New Year's eve in different parts of the world was responsible for an increase in total suspended particulates by an average of 300% at 14 locations and by about 700% in the lung penetrating size ranges at one location. Ravindra et al. [4] reported that fireworks during the Diwali festival in Hisar

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city, India lead to a short-term variation of air quality and two to three times increase in PM₁₀ and total suspended particulate concentration. Fine particles prevails for long time in the atmosphere and tend to spread over a large geographical region and thus affects vegetation and ecosystem on a large scale by virtue of its mass loading. Barman et al. [1] reported the remarkable increase in PM_{2.5} concentration in Lucknow city due to firework activities during Diwali festival. Out of various techniques Scanning Electron Microscope (SEM) coupled with energy dispersive X-ray microanalyzer (EDX) is a powerful tool to understand aerosols morphology, elemental composition and their particle density to give us a better insight about the origin of particles [11-12].

In this study, we have monitored Particulate matters (PM 2.5 and PM 10) suspended in the air and its chemical composition viz. metal ions and elemental composition at Varanasi located in Indo-Gangetic basin. We have collected suspended particulate matter in the atmosphere by using two high volume air samplers PM 10 and PM 2.5. We have also obtained AOD data from ground measurements using MICROTOPS-II sunphotometer and also by MODIS on board Terra satellite. We have collected data for recent Diwali event of year 2016 from 24th October to 8th November 2016. The collecting data 7 days before the Diwali date is considered as pre-Diwali event data, the Diwali day and the next day data is considered as Diwali event data and 7 days after this is considered as post-Diwali event data.

II. INSTRUMENTATION AND METHODOLOGY:

The study was conducted at an urban site Varanasi, located in Uttar Pradesh, a state of India situated in the heart of Indo-Gangetic basin (IGB) from 24 October 2016 to 8 November 2016. IGB is one of the largest basins in the world and highly polluted due to the various sources of the anthropogenic aerosol. Nearly 20% of geographical area and approximately 40% of food production of India is covered by IGB and also 40% population of India live in IGB. IGB is bounded by Himalaya to the North, Vindhyana – Satpura range to the south, Thar Desert and Arabian Sea in western part while eastern part is surrounded by the Bay of Bengal. So IGB has a unique topography due to which natural and anthropogenic both aerosols show the strong seasonal variability [12-13]. Its climate is semi-arid and consist of pre-monsoon or summer (March -May), monsoon (June- August), post- monsoon (Sept. – Nov.) and winter (Dec. - Feb.) seasons. The daily mean maximum and minimum temperature over Varanasi during sampling period of October-November, 2016 was 34.5⁰ C and 25.2⁰ C respectively.

Two high volume dust samplers of sizes PM_{2.5} and PM₁₀ were used for collection of suspended particulate matter in the atmosphere. The sampler has been manufactured by Envirotech Instrument Pvt. Ltd, India which is one of the pioneers in the development of indigenous air monitoring instruments. The sampler collected the samples with an average flow rate of 1.0 m³/min. The PM₁₀ sampler has been fitted with a cyclone, which is used for fractioning the dust into two fractions. PM₁₀ was collected on Quartz filter paper (Whatman of 8 × 10 inch dimension) while particulate matter of diameter more than 10 μm was collected in a cup placed under the cyclone. The filters were placed in desiccators for 24 hrs before and after the sampling to remove the absorbed humidity. The desiccated filter papers were weighted using electronic microbalance (Model GR202, A&D Company Ltd, Japan) with 0.01 mg resolution. The aerosol mass (μg/m³) was determined by the differences between initial and final weight of the filters and the concentration (μg/m³) was calculated by dividing the aerosol mass by total volume of air (m³). Similarly particulate matter of size up to 2.5μm was collected from PM_{2.5} repairable sampler. The details of sampling schedules and mass concentrations of PM₁₀ and PM_{2.5} particles are shown in Table 1. It is clearly observed from the table that the mass concentrations of both PM₁₀ and PM_{2.5} particles increased during Diwali days compared to pre-Diwali days.

The sample was (dry filter papers) randomly cut in size of about 1 mm² out of the main filter. A very thin film of carbon was deposited on the surface of the samples to make electrically conductive using vacuum coating unit. These samples were mounted on electron microprobe stubs. The SEM - EDX analyses were carried out with the help of a computer controlled field emission equipped with an EVEX- EDX detection system. In the present investigation, the SEM was used in the emission mode. The SEM was a 'Supra' type manufactured by Carl Zeiss Microscopy, Germany. The EDX is a Genesis type with Si-Li-Detector manufactured by EDAX, Germany. SEM was operated at 20 keV.

For Ion Chromatography one fourth of the filters evacuated from desiccators were cut and dissolved in deionised water and ultrasonicated for 10 minutes. Then this ultrasonicated solution was filtered using Whatman filter for further

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chemical analysis. All these samples were preserved at 4° C until they have been quantitatively determined for the anions and cations by Ion Exchange Chromatograph (IEC) (Metrohm, 930 Compact IC Flex, Switzerland). The analytical column Metrosep Supp5 and Metrosep C4 were used for anions and cations, respectively. The detection limit for ion chromatographic analysis is ~0.02 ppm. The glassware used in extraction and analysis were dipped overnight in dilute nitric acid and washed several times with double distilled water to remove any adhered impurities.

The ground based AOD measurements were carried out using hand held and portable multiband sunphotometer MICROTOPS-II (Solar Light Company, USA). It contains five different interference filters at 380, 440, 500, 640, and 870 nm wavelengths and provides columnar information of aerosols. An additional channel (940 nm) is used for perceptible water vapour contents. The sunphotometer works on the principle of extension of solar radiation intensity at a certain wavelength and calculates the corresponding optical depth by using the knowledge of the solar intensity at the top of the atmosphere. The details of MICROTOPS-II, its calibration and performance are given in Morys et al. [14]. AOD was measured on daily basis using MICROTOPS-II spectroradiometer. Satellite data was also collected from MODIS on board Terra satellite. MODIS, a major instrument on the EOS (Earth Observing System) polar orbiting Terra/Aqua satellites has high spatial resolution (250 m at nadir), wide swath (2330 km) and large spectral range (36 channels between 0.412 to 14.2 μm). The aerosol properties are retrieved in the wavelength range 0.4 - 2.1μm, and near-infrared wavelength range is used for retrieval of WV.

TABLE 1: Sampling Schedule and concentrations of PM10 and PM2.5.

SAMPLES	SAMPLING DATE	DURATION (HRS)	CONCENTRATION (μg/m ³)	
			PM2.5	PM10
PRE DIWALI	25-10-2016	24	94.595	160.380
	27-10-2016	24	146.609	199.206
	29-10-2016	24	84.125	96.745
DIWALI	30-10-2016	24	185.285	204.484
	31-10-2016	24	175.769	258.102
POST DIWALI	01-11-2016	24	131.681	167.677
	03-11-2016	24	134.697	170.388

III. RESULT AND DISCUSSIONS

We have analysed the data recorded at Varanasi from 25 October, 2016 to 03 November, 2016 during Diwali festival and found significant results. Figure 1 shows the variation of MICROTOPS-II AOD and MODIS AOD over Varanasi during the Diwali festival. AOD was observed high on Diwali and next day of Diwali as compared to days preceding Diwali. It shows increasing trend from 29th October and keep on increasing till 1st November and then starts decreasing. Enhanced AOD during this period is result of vast use of firecrackers which people start practicing few days prior to Diwali and ends 1-2 days post Diwali.

Ion Chromatography and SEM-EDX analysis for Chemical characterisation has been carried out for total 8 samples comprising four of PM2.5 and four of PM10 collected on 29th Oct, 30th Oct, 31st Oct and 1st Nov 2016 respectively. The samples were analysed by ion-exchange chromatograph (IEC) and four typical sample data during Diwali for PM2.5 and PM10 are shown in Tables 2(a) and 2(b) respectively. Ion exchange chromatograph measures the ionic contents of the samples. Figure 2 shows the results of ion chromatography during Diwali for PM2.5 and PM10 particles. From the figure we found notable increase in concentrations of Sulphate (SO₄²⁻) and Potassium (K⁺) ions and on the other hand increase in Fluoride (F⁻), Chloride (Cl⁻), Nitrate (NO₃⁻), Lithium (Li⁺), and Sodium (Na⁺) ions were also noticed. Table

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2(a) shows results for PM_{2.5} particles and it is observed the highest increase in Sulphate ion up to 18.45 ppm after Diwali event which was 10.43 ppm prior to Diwali, similarly Potassium reaches to 3.738 ppm on post Diwali days as compared to 2.36 ppm on pre Diwali days. Chloride also becomes almost double 3.271 ppm on next day of Diwali which was 1.718 ppm on pre Diwali day. From Table (b) for PM₁₀ particles it is observed that Sulphate ion attains value of 412.763 ppm on post Diwali days as compared to 157.534 ppm on pre Diwali day as being prime component of crackers used during Diwali event. Similarly Fluoride, Chloride, Nitrate, Potassium and Sodium ion reaches 160.65, 67.842, 171.135, 307.685, 110.774 ppm respectively on post Diwali days which is much higher than the safe limits for human health. The ions found in the current study are prime components of firecrackers used during Diwali festival. Singh et al. [12] reported the ionic contents of aerosols over Varanasi in which they observed maximum concentration of Sodium (Na⁺) and Sulphate (SO₄²⁻) ions in the atmosphere and presence of other cations and anions were also noticed.

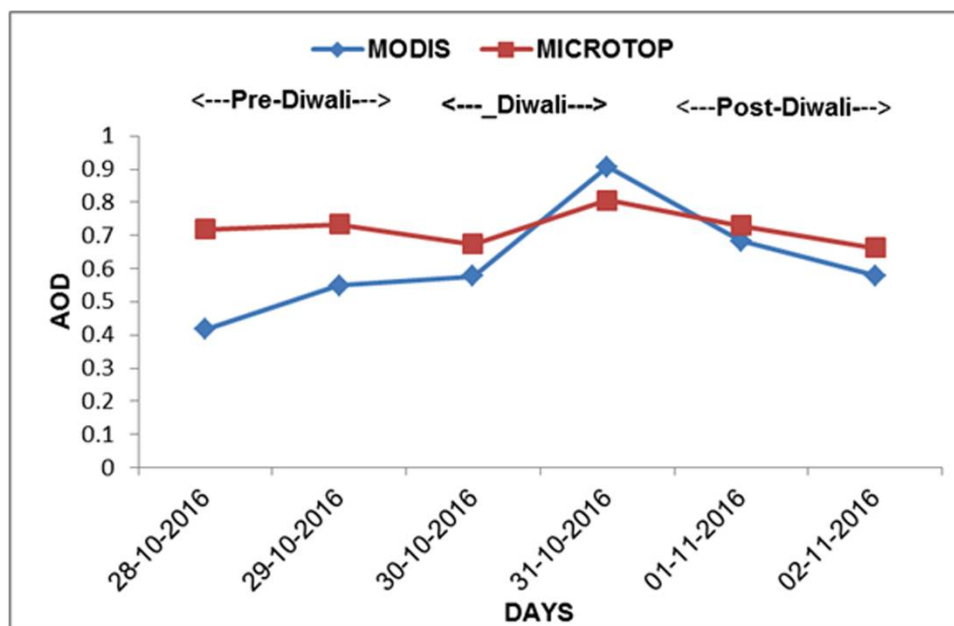


Figure 1: Variation of MICROTOPS-II AOD and MODIS AOD over Varanasi during the Diwali festival.

SEM-EDX analysis shows elemental composition of PM_{2.5} and PM₁₀ particles. In this analysis percentage contribution of different elements has been observed on pre-Diwali, Diwali and post-Diwali days which is shown in Figure 3. For PM₁₀ enhancement of Carbon (C), Silicon (Si), Aluminium (Al), Potassium (K), Sodium (Na) and Zinc (Zn) were found on Diwali and post-Diwali days as compared to pre-Diwali days as a consequence of massive bursting of fire crackers on Diwali. Similarly elevated levels of Carbon, Fluorine, Aluminium, Chlorine and Potassium was noticed for PM_{2.5} particles on Diwali and post-Diwali days. Carbon was found high for all the samples from pre to post-Diwali days which may be attributed to firecrackers and vehicular emissions. Carbon was found 33.2% prior to Diwali and gets increased up to 47.13% and then decreases to 44.91% on post Diwali days. Potassium is also observed to show increasing trend on Diwali and post-Diwali days which are used in firecrackers in order to oxidize firework mixtures. Samples collected on Diwali and post-Diwali days were also found to be rich in Silicon, Aluminium, Chlorine and Fluorine. Similar studies have been performed by Perrino et al. [15] for different periods of year including Diwali

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over New Delhi in which they have observed enhancement in Carbon, Silicon, Aluminium, Potassium and Chlorine. Enhancement in these elements in the atmosphere has adverse effects on human health.

Table 2 (a): Ion Chromatography results for PM2.5.

DATE	Fluoride × 10 (PPM)	Chloride (PPM)	Nitrate × 10 (PPM)	Sulphate × 3 (PPM)	Lithium × 100 (PPM)	Sodium (PPM)	Potassium (PPM)	Magnesium × 5 (PPM)	Calcium (PPM)
29-10-2016	3.11	1.718	8.41	10.434	7	3.193	2.36	8.07	3.051
30-10-2016	4.1	1.75	11.82	7.914	0	4.412	3.161	4.145	2.955
31-10-2016	6.83	3.271	19.27	17.004	7	9.403	3.492	7.45	4.836
01-11-2016	2.71	2.929	14.12	18.45	7.1	8.033	3.738	6.095	4.824

Table 2 (b): Ion Chromatography results for PM10.

DATE	Fluoride × 50 (PPM)	Chloride (PPM)	Nitrate (PPM)	Sulphate (PPM)	Lithium × 20 (PPM)	Sodium (PPM)	Potassium (PPM)	Magnesium × 5 (PPM)	Calcium (PPM)
29-10-2016	84.7	26.465	102.916	157.534	0	91.441	46.888	48.85	57.36
30-10-2016	78.05	99.781	132.627	154.162	57.2	98.652	77.003	55.6	44.129
31-10-2016	136.35	104.675	160.233	391.084	58.6	105.464	296.133	117.04	46.43
01-11-2016	160.65	67.842	171.135	412.763	58.2	110.774	307.685	87.23	42.262

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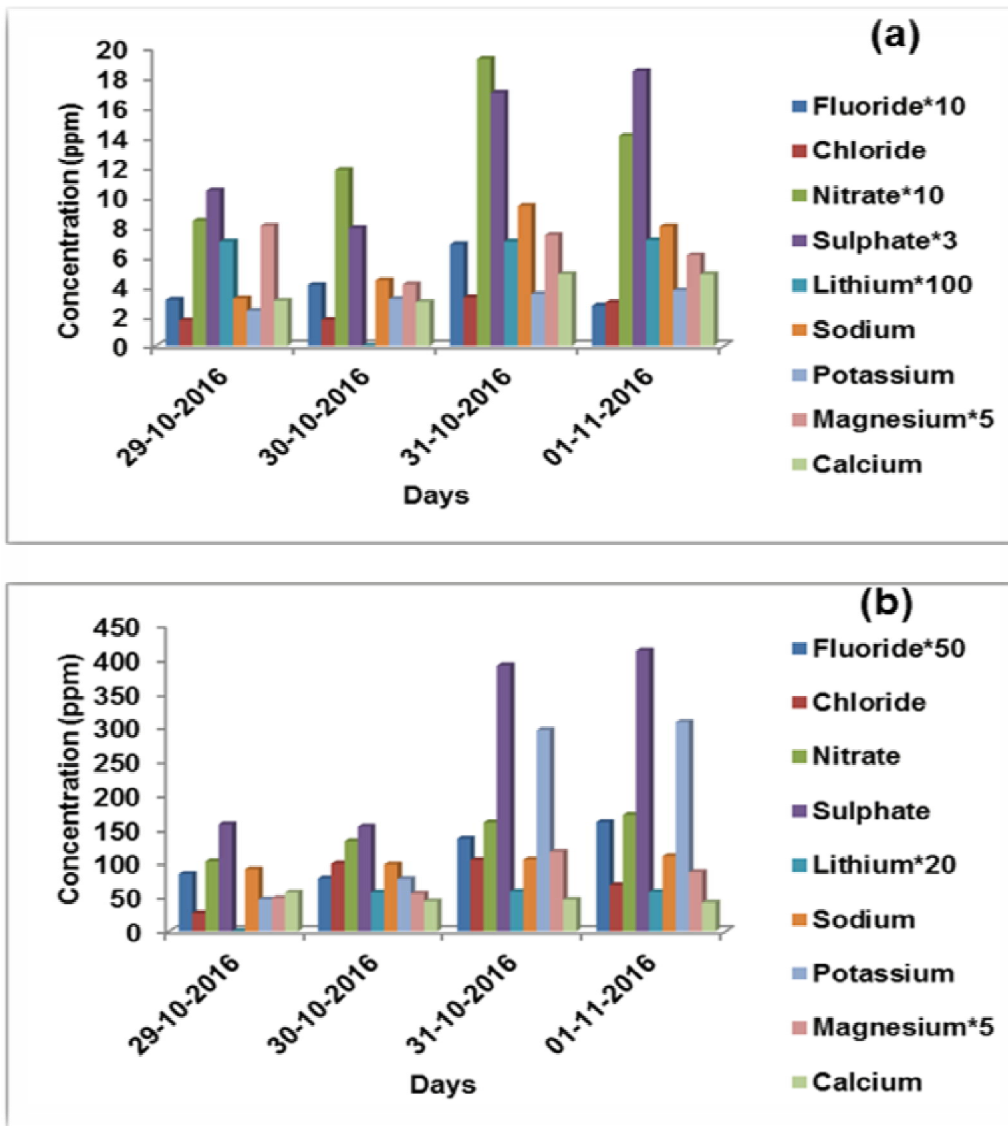


Figure 2: Concentrations of different ions (a) PM2.5 (b) PM10 during Pre-Diwali, Diwali and Post-Diwali.

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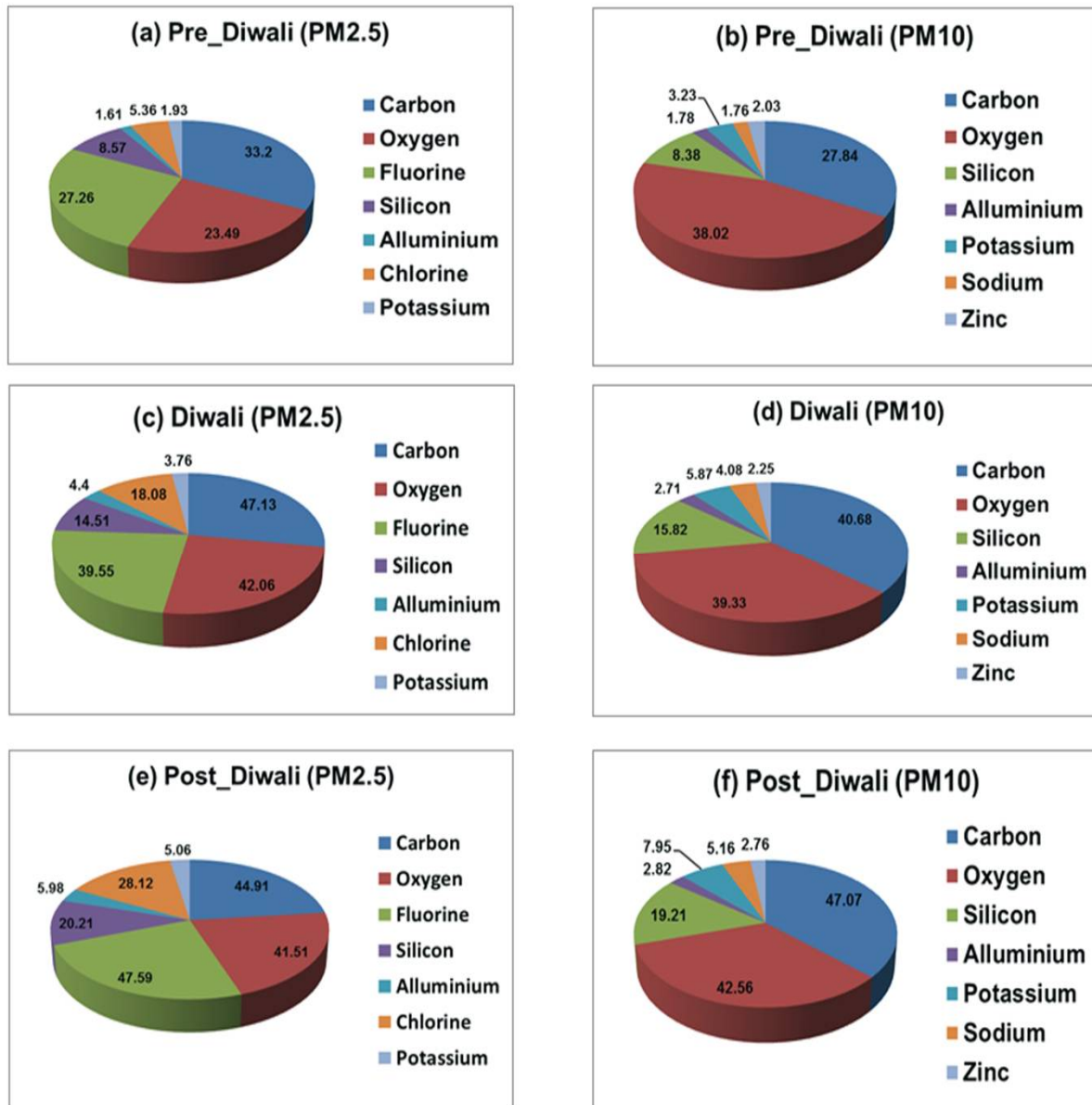


Figure 3: Elemental components by SEM-EDX analysis for (a) pre-Diwali (PM2.5), (b) pre-Diwali (PM 10), (c) Diwali (PM2.5), (d) Diwali (PM10), (e) post-Diwali (PM2.5) and (f) post-Diwali (PM10) periods.

IV. CONCLUSIONS

The Present study shows air quality degradation associated with much celebrated Diwali festival in which firecrackers are used as a part of celebration. The analysis of PM2.5 and PM10 particles reveals main sources of particulate matters in the atmosphere specially during Diwali festival. Enhanced level of ions and metals during Diwali and for next few days of the event can sour the happiness of Diwali celebration as it may impose serious health impact on people residing this holy city. Certain measures are expected from the local or regional authority in due course.

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