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Characterisation of Atmospheric Aerosol by SEM-EDX and Ion-Chromatography Techniques for Eastern Indo-Gangetic Plain Location, Varanasi, India

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Abstract

Atmospheric aerosol consists of both natural and anthropogenic origin. Studies have shown that continuous exposure to these particles is associated with a high percentage of death from respiratory and cardiovascular disease. In the present study, we have first time used both SEM-EDX analysis as well as chemical analysis to understand the differences in morphology and elemental composition of aerosols sample from a suburban clean and green area of Banaras Hindu University campus and some much polluted urban areas of the Varanasi city situated in the eastern Indo-Gangetic plain. The analysis was done by using scanning electron microscope (SEM) coupled with energy dispersive X-ray microanalyzer (EDX) and ion-chromatography (IC). Analyses show that C, Ca, Na, S, Si, Al have dominated the samples. The concentration for urban areas of city were more than the pollution of suburban area and followed the trend as $Na^+ > SO_4^{2-} > Ca^{2+} > Cl^- > Mg^{2+} > NO_3^- > K^+ > HCO_3^+ > F^-$, where as for suburban area showed the trend as $Na^+ > SO_4^{2-} > NO_3^- > Ca^{2+} > Cl^- > Mg^{2+} > K^+ > HCO_3^+ > F^-$. This shows that more polluted urban areas were dominated by soil-dust generated due to heavy traffic movement and construction/industries. To establish differences among sites more measurements are necessary in different meteorological conditions.

Keywords: Atmospheric Aerosols; Aerosol Chemistry; Air Pollution; SEM-EDX analysis; Ion Chromatography.

1. Introduction:

Atmospheric aerosol consists of both natural and anthropogenic particles. It is now well established that the element from geological sources are generally found in coarse-mode whereas elements emitted from anthropogenic activities are fine particles (Seinfeld, 1986). Studies have shown that continuous exposure to these particles is associated with a high percentage of death from respiratory and cardiovascular disease (Schwartz, 1996; Pope and Dockery, 2006). Particles of diameter 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$) have been found to be associated with cardio-respiratory problem and mortality (Schwartz, 1994; Ostro et al., 1999). 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.

Several investigations have been made on the characteristics of aerosols and associated elemental concentration in urban areas (Espinosa et al., 2001; Wang et al., 2006; Srivastava and Jain, 2007; Campos-Ramos et al., 2009). 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 (Haapala, 1998; Conner and Williams, 2004; Shi et al., 2005; Niemi et al., 2005; Srivastava et al., 2009; Pachauri et al., 2013). The elemental composition of aerosol particles is more useful with a view to establish their origin and their potential effects on human health. Till now, the studies on elemental composition of aerosols using SEM-EDX analysis are limited (Pina et al., 2000, 2002; Shi et al., 2003; Mathis et al. 2004; Suzuki, 2006; Campos-Ramos et al., 2009; Geng et al., 2011).

However, in the context of urban experiments in India, the studies on characteristic of aerosols and associated metal concentrations are rather limited. Khemani et al. (1982) studied the size distribution and chemical composition of aerosols over Deccan Plateau in India. The chemical compositions of aerosols were also determined by Mishra (1988). The trace metal chemistry of different size fraction of aerosols in Northwest India was studied by Yadav and Rajamani (2006). Srivastava and Jain (2007) used only SEM for the morphological analysis of pollutants inside an indoor environment of Delhi. In our knowledge, till now no comparative study in India for elemental composition of aerosols using SEM-EDX has been done except Srivastava et al. (2009) who used SEM-EDX analysis to understand the differences in morphology, elemental composition and particle density of aerosols in different size ranges to investigate the potential sources as well as transport of pollutants from/at a much polluted and a very clean area of Delhi.

Thus there is a lack of systematic study of elemental composition as well as ionic composition of aerosols in Indian region simultaneously using SEM-EDX as well as ion chromatograph specially in Indo-Gangetic Basin. To complete this gap the present study has been initiated first time at Varanasi city which is situated at eastern part of Indo-Gangetic Basin. In the present study, we have first time used both SEM-EDX analysis along with chemical analysis to understand the differences in morphology and elemental composition of aerosols sample from a relatively clean suburban area of Banaras Hindu University campus and much polluted urban areas in the centre of Varanasi city.

2. Materials and methods:

2.1. Area description:

Sampling was carried out in Varanasi (latitude 25.2^0 N and longitude 82.9^0 E) located in the eastern part of Indo-Gangetic Basin (IGB). 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, Vindyana – 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 (Singh et al., 2004; Srivastava et al., 2011; Kumar et al., 2012, Tiwari and Singh, 2013, Tiwari et al., 2013). 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 September-October, 2010 was 34.5^0 C and 25.2^0 C whereas 34.3^0 C and 24.3^0 C for April 2011 respectively. To collect the samples for the present study we have chosen different sites: one a relatively clean suburban area of Banaras Hindu University (BHU) campus and the others at much polluted urban areas of Lahurabir, Samneghat and Shivpur situated in the main Varanasi city. Figure 1 shows the map of site location showing the detailed descriptions of the sites.

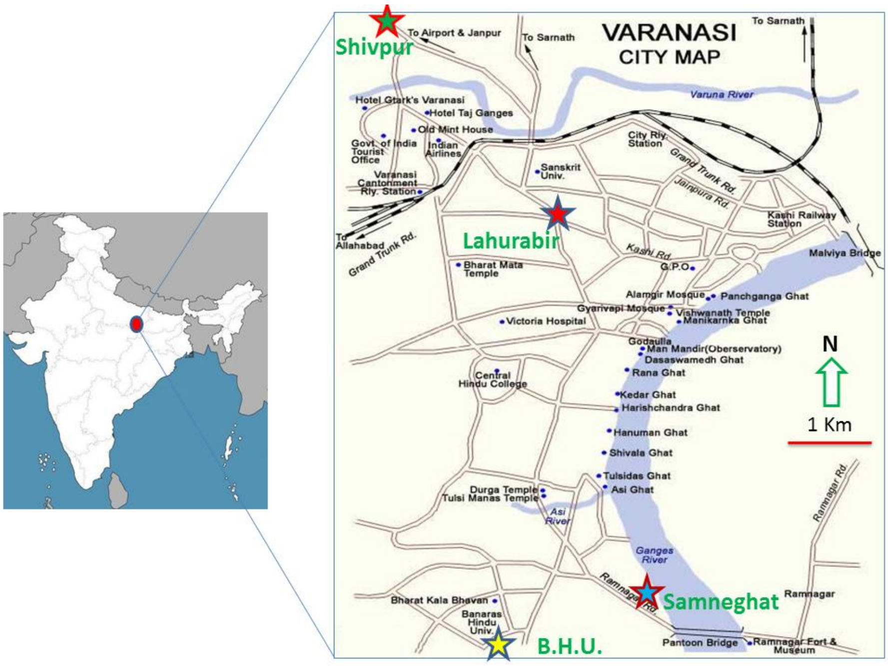

Figure 1: Map of Varanasi city showing the different urban and suburban sampling site locations used in the present study.

2.2. Ambient sampling:

To determine the morphology, elemental composition and source concentration of aerosols, sampling was performed at a relatively clean suburban area of Banaras Hindu University campus and at three urban area in Varanasi city (at Lahurabir; Samneghat, and at Shivpur) in the post- monsoon season of 2010 and pre-monsoon season of 2011. The details about the sampling dates and concentrations of aerosols at different urban and suburban locations of Varanasi are shown in Table 1. A high volume sampler of Staplex Model TFIA was used at an average flow rate of 0.6 cubic meters per minute (Khemani, 1985). To collect sufficient amount of aerosols the sampling was done for 6-10 h at the sites. The sample was collected on Whatman GF/C glass microfiber filter papers of the size 110 mm. The filter papers, used for aerosol sampling, were subjected to 24 h desiccation before and after the sampling, in order to remove the moisture content of the filter papers. The desiccated filter papers were weighted using electronic microbalance (Model GR202, A&D Company Ltd, Japan) with 0.01 mg resolution. The particle concentrations were determined gravimetrically by the difference in their weights before and after the sampling. The densities of particles are found higher at urban area than at suburban area. It is observed from Table 1 that aerosols concentrations in urban area in Varanasi city are more than two-fold higher than at suburban area.

Table 1: Concentrations of aerosols at Urban and Suburban different sampling locations of Varanasi.

Sample No.	Date	Time	Location	Concentration (µg/m^3)
1.	30/09/2010	09:00 AM – 4:30 PM	Suburban	131.46
2.	01/10/2010	06:00 PM – 07:00 AM	Suburban	131.41
3.	04/10/2010	11:00 PM – 07:00 AM	Urban	306.25
4.	05/10/2010	02:00 PM – 08:00 PM	Urban	182.87
5.	06/10/2010	01:10 PM – 07:30 PM	Urban	297.22
6.	01/04/2011	10:00 PM – 06:00 AM	Suburban	195.68
7.	26/04/2011	10:00 AM – 06:00 PM	Suburban	157.15
8.	26/04/2011	10:00 PM – 06:00 AM	Suburban	133.00
9.	29/04/2011	08:35 AM – 04:35 PM	Suburban	238.84
10.	29/04/2011	10:00 PM – 06:00 AM	Suburban	252.97

2.3. SEM-EDX measurement:

The sample was (dry filter papers) randomly cut in size of about 1 mm^2 out of the main filter (Xie et al. 2005). 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 'Merlin' type manufacturer by Carl Zeiss Microscopy, Germany. The EDX is a Genesis type with Si-Li-Detector manufactured by EDAX, Germany.

2.4. Chemical analysis using ion chromatograph:

Chemical analysis of the sample was done at Indian Institute of Tropical Meteorology, Delhi-Centre, New Delhi. In this process, 1/4th of filters were dissolved with ultrapure water (50 ml) via ultrasonication processing for 50 min. After filtering the solution through a pre-washed Whatman filter No. 41, the final product was collected into pre-cleaned polypropylene bottles. All these samples were preserved at 4°C until they have been quantitatively determined for the anions (F^-, Cl^-, NO_3^- and SO_4^{2-}) and cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) by Ion Exchange Chromatograph (IEC) (DIONEX-2000, USA). The analytical column IonPac—AS15 with micro-membrane suppressor ASRS ultra II 2 mm, 38 mM Potassium Hydroxide /1.7 mM sodium bicarbonate and the IonPac—CS17 column with micro-membrane suppressor CSRS ultra II 2 mm, 6 mM methyl sulfonic acid as eluents and triple distilled water as regenerator were used for anions and cations, respectively. The cation and anion standards were procured from Dionex for calibration. 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.

2.5 Back-trajectory analysis

The National Oceanic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT_4) (http://www.arl.noaa.gov) model is a system with simple graphical user interface for computing trajectories and air concentrations (Draxler and Hess, 1998). For calculating air mass trajectories during the different days of sampling period, gridded meteorological data at a fixed time interval are used. Air mass back-trajectory analysis is used to find out the sources and pathways of the different types of aerosols at sampling sites.

3. Results and discussion:

In the present study, we used simultaneously both SEM-EDX analysis as well as ion chromatography to understand the differences in morphology, elemental composition and ionic composition of aerosols sample from a relatively clean suburban area of Banaras Hindu University campus and much polluted urban area in the centre of Varanasi city.

3.1. SEM-EDX analysis:

To understand the morphology of aerosol particles and to have the better idea of pollutants at different locations of Varanasi city, electron micrographs of aerosols with EDX-spectra were analysed. Figure 2 shows the typical examples of different scanning electron micrographs of aerosols at urban area in Varanasi city. Figures 2b and 2d are the zoomed version of the marked area of scanning electron micrographs of aerosols of corresponding 2a and 2c respectively. Figure 3 shows the typical examples of different scanning electron micrographs of aerosols at a relatively clean suburban location of BHU, Varanasi. The micrograph of particles are taken in bulk as well as zoomed in view of particles also. Figure 3e and 3f shows micrographs of bigger single particle. From Figures 2 and 3 it can be inferred that at urban and suburban areas of Varanasi, there are difference between particle morphology. At suburban area the particles are flaky in shape as it is highly vegetated, whereas, at urban area, the particles are mostly rounded in shape.

Table 2: Percentage contribution of each elemental composition obtained from EDX spectra of aerosols at Urban and suburban different sampling locations of Varanasi city.

Elements	**Sample 1 Suburban**	**Sample 2 Suburban**	**Sample 3 Urban**	**Sample 4 Urban**	**Sample 5 Urban**	**Sample 6 Suburban**	**Sample 7 Suburban**	**Sample 8 Suburban**	**Sample 9 Suburban**	**Sample 10 Suburban**
C	28.21	7.52	51.44	43.54	20.80	29.96	32.48	36.54	35.99	42.06
O	29.15	41.04	24.48	20.71	48.81	30.63	29.86	28.91	27.31	26.73
F	0.15	0.46	0.33	0.63	0.73	0.16	0.17	0.16	0.15	0.18
Na	4.77	0.35	1.86	1.25	0.71	0.46	0.59	0.39	0.50	0.51
Mg	0.28	0.95	0.57	1.10	0.78	0.51	0.31	0.24	0.39	0.54
Al	2.68	12.61	2.36	3.79	1.64	2.35	1.51	0.87	2.03	1.63
Si	21.61	26.69	8.79	9.45	23.26	32.05	32.04	30.97	28.13	25.39
P	0.00	0.10	0.08	0.03	0.30	0.06	0.05	0.07	0.08	0.04
S	0.43	0.60	2.06	0.94	0.18	0.22	0.20	0.22	0.46	0.12
Cl	0.25	0.46	0.28	0.27	0.43	0.00	0.00	0.00	0.00	0.00
K	2.48	1.54	1.46	2.83	0.66	0.40	0.87	0.63	2.31	0.46
Ca	1.47	2.09	2.94	1.55	0.41	1.26	0.91	0.36	0.99	1.20
Ba	4.33	2.93	1.21	2.00	0.29	0.00	0.00	0.00	0.19	0.00
Fe	0.31	2.08	1.21	11.12	0.69	1.85	1.24	0.86	1.88	1.37
Zn	3.89	0.59	0.94	0.80	0.31	0.25	0.30	0.29	0.34	0.40

In order to understand the elemental composition, sources and transport of pollutants and to have better idea of pollutants in Varanasi city, scanning electron micrographs of aerosols and their EDX-analysis were analysed simultaneously for all collected samples of aerosols. The typical scanning electron micrographs with their corresponding EDX-spectra for urban area are shown in Figures 4 and for suburban area in Figure 5. At the bottom of each micrograph is provided the EDX-spectra of the marked area. EDX spectra have further been analyzed for concentration of different metals at both the sites (Table 2). The chemical bulk composition of aerosol samples is highly variable, depending upon various factors affecting air mass trajectories (Kumar et al., 2013; Tiwari and Singh, 2013). SEM analysis was narrowed down to a specific area and then to particular large particles. The elemental composition of single particles and agglomerates with SEM-EDX from sample collected at all urban and suburban sites are shown in Table 2.

Carbon content was high at all the locations of urban as well as suburban areas of Varanasi city. Relatively high carbon content at urban area of Varanasi city was observed compared to that of suburban area. Urban specific samples was found to contain high carbonaceous materials which might be expected due to the high traffic level at the site chosen emitting spent and/or semi-burnt automobile fuels being exhausted by automobile vehicles. The particular aerosol particles chosen at sample 3 (urban) seems to be carbon loaded soot particle or so with >51% carbon content. The sample 2 collected at suburban area has particularly low carbon content i.e. <10 %.

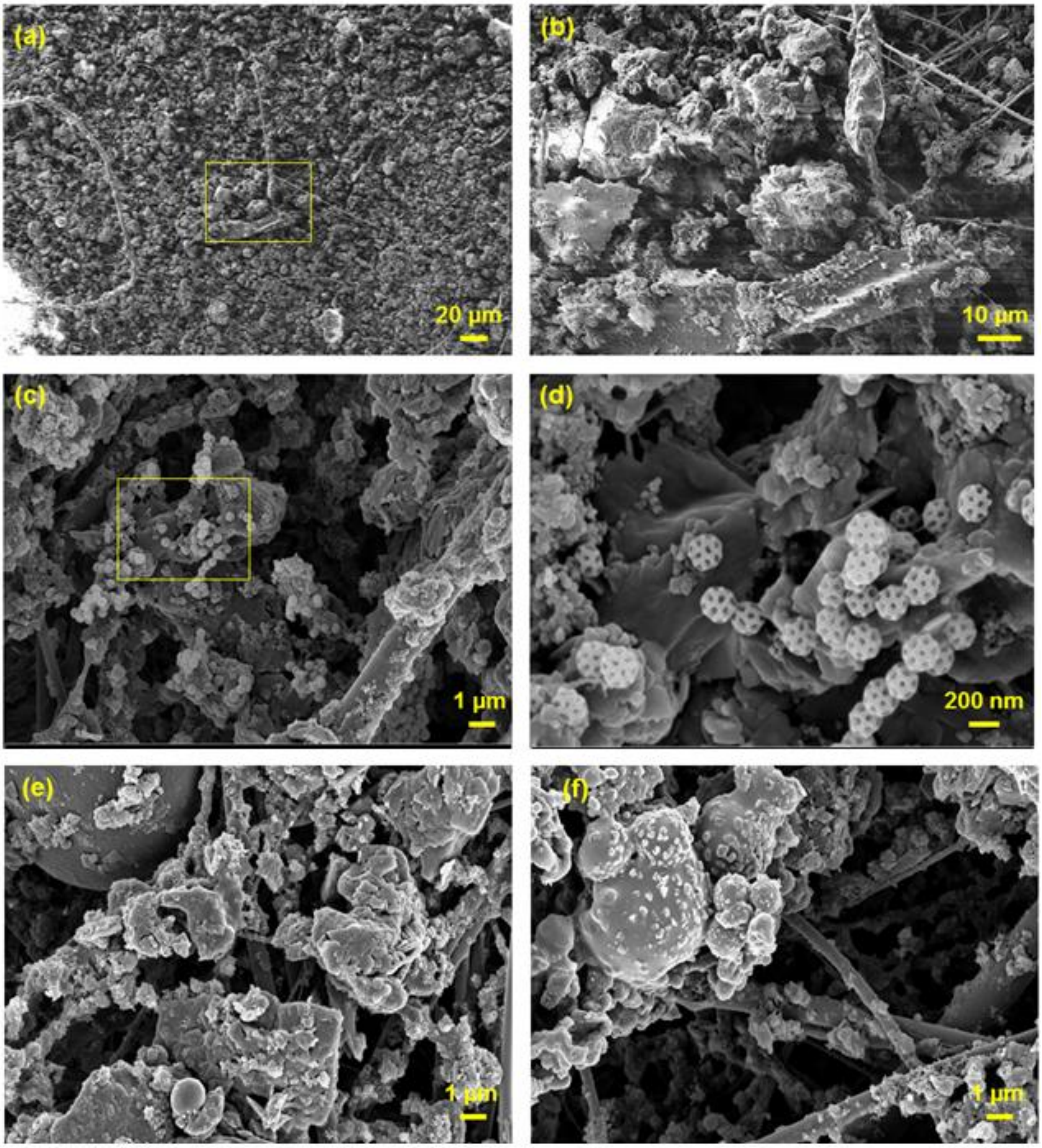

Figure 2: Typical examples of different scanning electron micrographs of aerosols at urban area, situated in the heart of Varanasi city.

If we go by sulphate content, as S is a major culprit for acid rain as SO_2, SO_3 are easily converted to H_2SO_4, a high S content has been observed in sample 3 of urban area. Manmade sources of SO_x have been reported to be localized in some urban areas. Such sources could be fuel combustion (coal), industries and transportation (De, 2006). Recently, Harris et al. (2013) reported that sulphate production plays a key role in aerosol radiative forcing of climate. The study shows in the majority of cases so-called transition metal ions such as iron, manganese or titanium act as the catalyst for the oxidation of sulphur dioxide by oxygen (Harris et al., 2013).

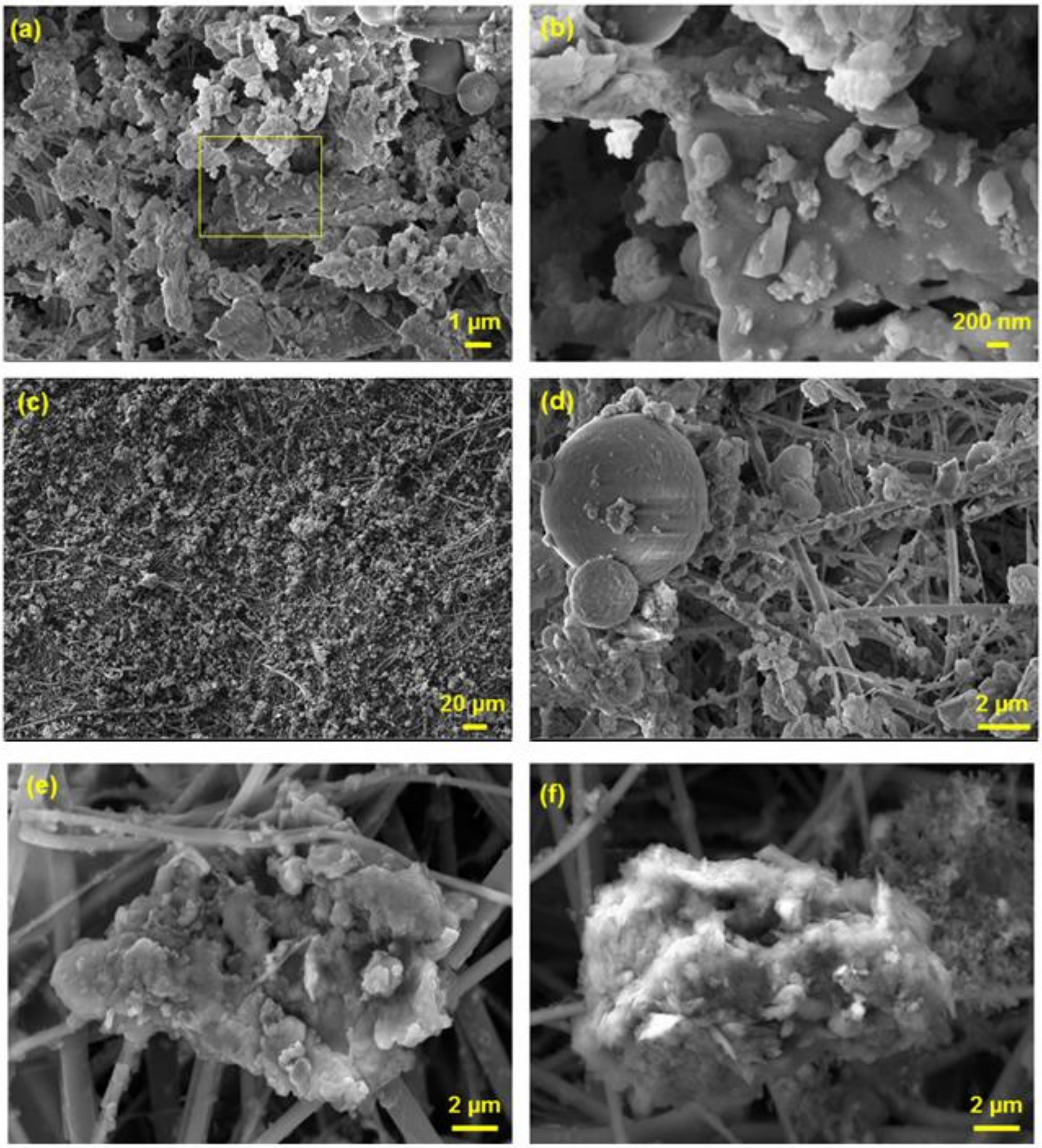

Figure 3: Typical examples of different scanning electron micrographs of aerosols at suburban area of Varanasi city.

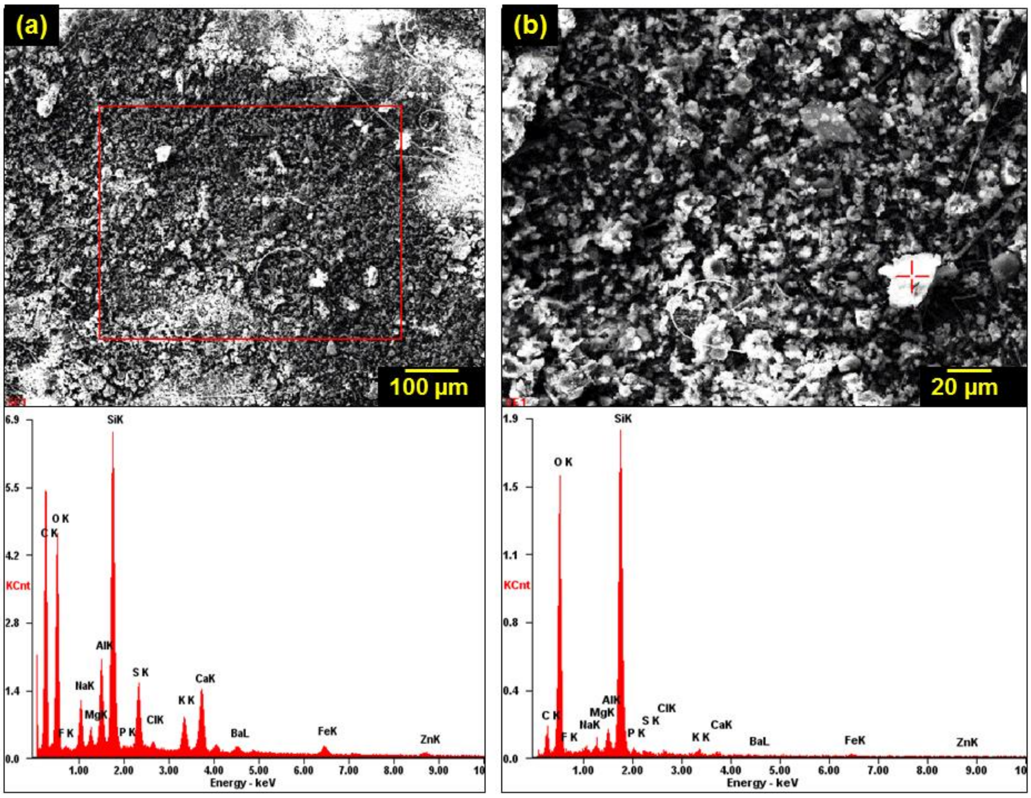

Figure 4: (a) Scanning Electron micrograph and bulk EDX-spectrum of aerosols at urban area of Varanasi city. (b) Scanning Electron micrograph and EDX-spectrum of bigger size aerosols at urban area of Varanasi city.

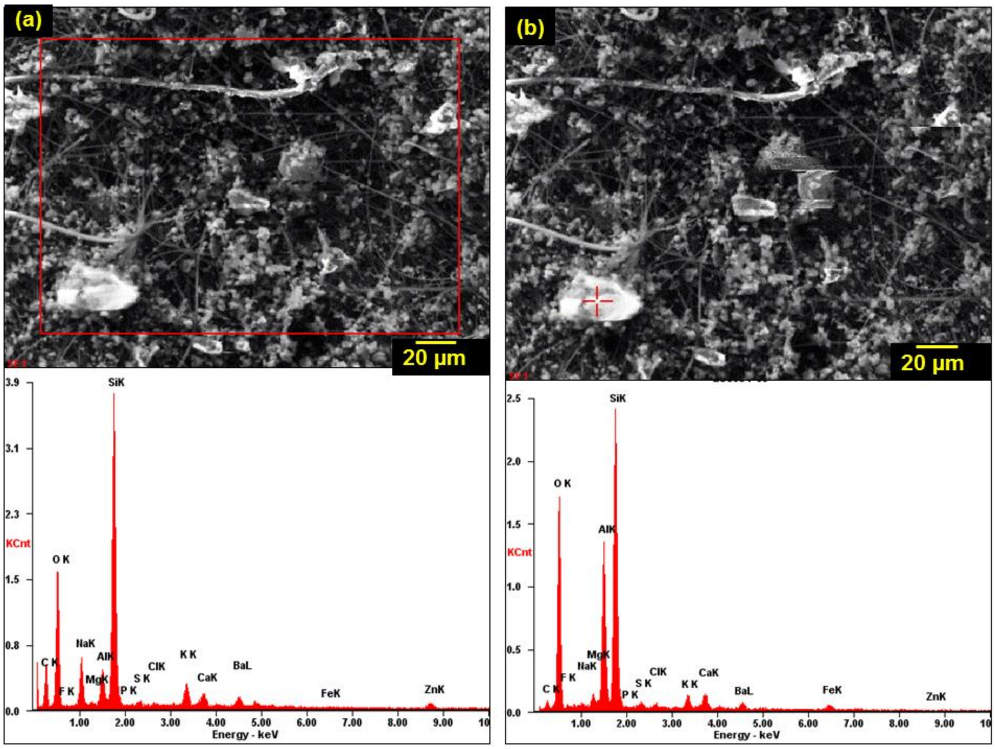

Figure 5: (a) Scanning Electron micrograph and bulk EDX-spectrum of aerosols at suburban area of Varanasi city. (b) Scanning Electron micrograph and EDX-spectrum of bigger size aerosols at suburban area of Varanasi city.

Samples of urban area were found to be rich in Si, Al, and Ca. This composition predicts that the aerosol particles are rich in silica, alumina, and $CaSO_4$. A high vehicular traffic, shops of variety of other items with other anthropogenic activities lead Si, Al, S, and C rich aerosol particles in ambient air. Such compositions might prove to be detrimental to health especially respiratory tract. The specific aerosol particles of sample 4 at urban area has high Fe content with large Si and C, indicating some ferrous oxide with absorbed C soot and silicon particles of smaller size.

A high Si content is observed in almost all samples, particularly in suburban area. Silicon (Si) can be transported through the atmosphere associated with airborne particles. Fly ash produced by industrial burning can contain Si, and those particles are abundant in heavily industrialized areas. Copious amounts of Si are transported with airborne soil particles (Tegen and Kohfeld, 2006). Soil-derived mineral dust contributes significantly to the global aerosol load; estimates of global dust emissions range from 1 000 to 3 000 Mt/yr. (Houghton et al. 2001). Dust aerosol consists of micrometer-size windblown soil particles that can be carried over thousands of kilometres through the atmosphere, and dust plumes are predominant features in satellite retrievals of global aerosol patterns (Husar et al. 1997). The transport of soil-derived dust in the atmosphere is an effective means of redistributing Si in the environment. In the neighbourhood of Varanasi, around 150 km distant, a line-up of power generation units produces fly ash which is transported to other industrial regions for various purposes. This is also clear from the back trajectory analysis shown in Figure 6. These could be a probable source of silicon rich aerosol particles observed at Varanasi.

In order to shed light on the long-range transport of atmospheric pollutants in the Northeast Asian Regions, Saitoh et al. (2008) studied a multi-probe, chemical characterization and composition profile of airborne particulate matter (PM) on Mt. Moriyoshi, located on the Sea of Japan side of northern Honshu, Japan. By the SEM-EDX analysis they observed many cubic particles throughout the winter and summer periods. These cubic and small spherical particles were found to be the silicon-rich type. Srivastava et al. (2009) used the SEM-EDX analysis to understand the differences in morphology, elemental composition and particle density of aerosols in different five size ranges to further investigate the potential sources as well as transport of pollutants collected at a polluted area (ITO) and a clean area (JNU) of Delhi. They observed that at polluted area most of the particles irrespective of size are of anthropogenic origin, whereas at clean area, in coarse size fractions particles are of natural origin, while in fine size range the presence of anthropogenic particles suggests the transport of particles from one area to the other.

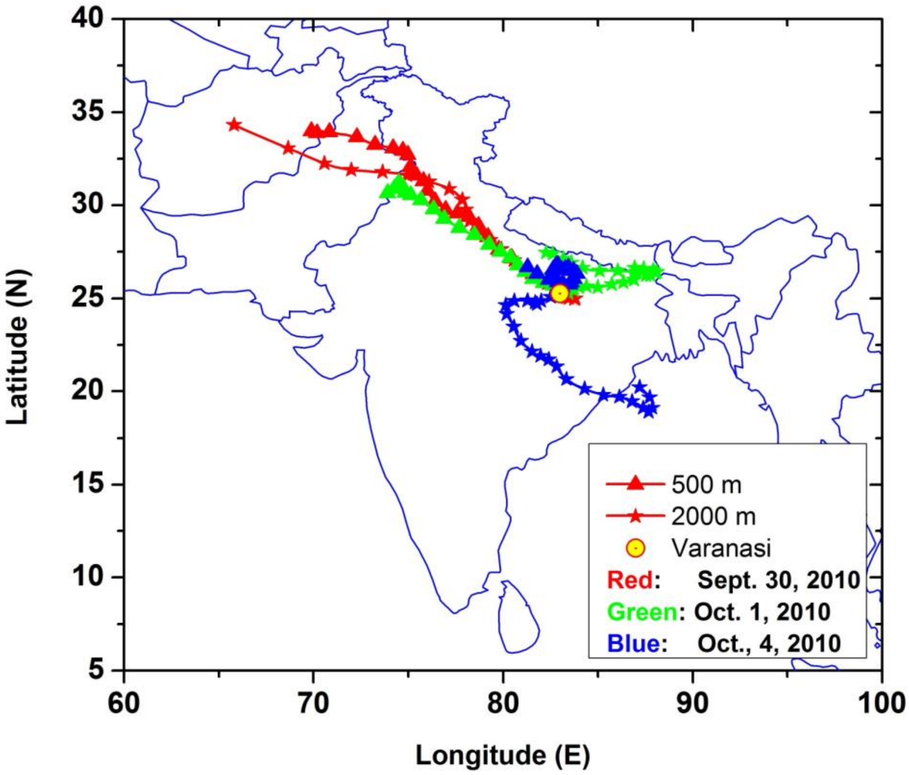

Figure 6: Five days air mass back trajectories derived from HYSPLIT model on sampling days of September 30, 2010; October 1, 2010 and October 4, 2010 for Varanasi.

3.2. Chemical analysis using ion chromatograph:

The samples were also analysed by ion-exchange chromatograph (IEC) and three typical sample data are shown in Table 3. Ion exchange chromatograph measures the ionic contents of the samples. Quantitatively, cationic content was found to be more than anionic content. The ionic contents of the aerosols at urban area followed the trend as $Na^+ > SO_4^{2-} > Ca^{2+} > Cl^- > Mg^{2+} > NO_3^- > K^+ > HCO_3^+ > F^-$, where as for suburban area showed the trend as $Na^+ > SO_4^{2-} > NO_3^- > Ca^{2+} > Cl^- > Mg^{2+} > K^+ > HCO_3^+ > F^-$. The common cationic species in all samples were H^+, Na^+, K^+, Ca^{2+} and Mg^{2+} while Cl^-, SO_4^-, NO_3^- were the common anion with lesser amount of F^-. The data from IEC cannot be compared with SEM-EDX data as IEC gives only the ionic content and was not able to measure the other species of chemical compounds which were charge neutral. Separately both data are worthy by consideration as ionic as well neutral chemical have significant impact on environmental segments with different mechanisms. Similar water-soluble ionic species at New Delhi during the year 2007 was reported by Tiwari et al. (2009). They observed that the ionic abundance, on an average, showed the general trend as $SO_4^{2-} > Cl^- > Na^+ > NO_3^- > K^+ > Ca^{2+} > Mg^{2+}$ in $PM_{2.5}$ and $SO_4^{2-} > Cl^- > NO_3^- > Ca^{2+} > Na^+ > K^+ > Mg^{2+} > F^-$ in PM_{10}. They further showed that among all chemical species, SO_4^{2-} has the highest concentration in both the aerosol samples, whereas concentration of Fluoride (F^-) ion was lowest.

Using SEM-EDX analysis as well as ion chromatography analysis Nemi et al. (2005) studied the sources, compositions and size distribution of aerosol particles during long-rang transport episodes occurred in Finland during August-September, 2002. They showed that the proportions of S-rich particles increased during the episodes, and contained elevated fractions of K, indicting emissions from biomass burning. They also showed that among all chemical species, SO_4^{2-} has the highest concentration.

Table 3: Ionic contents (μg/m^3) of the aerosols samples at Urban and Suburban different sampling locations of Varanasi city.

Elements	**Sample 1 Suburban**	**Sample 2 Suburban**	**Sample 3 Urban**
F^-	0.085	0.101	0.123
Cl^-	0.511	1.554	1.737
SO_4^-	2.748	3.465	3.163
NO_3^-	1.941	2.155	1.073
H^+	0.005	0.008	0.004
Na^+	14.462	16.635	16.372
K^+	0.660	1.119	0.636
Ca^{2+}	1.063	2.596	2.753
Mg^{2+}	0.688	1.098	1.498
HCO_3^+	0.421	0.271	0.594
Anions	5.878	7.548	6.713
Cations	16.879	21.450	21.264

Air mass back-trajectory analysis

In order to identify the aerosols sources and their different transport pathways at sampling sites five days air mass back trajectories were computed using Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model of the National Oceanic and Atmospheric Administration (NOAA) (Draxler and Hess, 1998). The air mass back trajectories provides a three dimensional information (latitude, longitude and altitude) about the aerosol pathways followed by the air mass as a function of time. Figure 6 represents the five days air mass back trajectories for three different days of sampling period on September 30, 2010; October 1, 2010 and October 4, 2010 at Varanasi for two different altitude 500 m and 2000 m.

Figure 6 clearly reflects that on different sampling days, air masses have different pathways of transportation from the different sources regions which suggest the different types of aerosols at sampling sites (e.g. dust form desert and anthropogenic aerosols from biomass/urban-industrial sources). Recently, Tiwari et al., (2013), also reported that different types of aerosol loading over entire IGB during per-monsoon 2011. It is also observed that during October 4, 2010 at lower height range of 500m the pollutants are largely influenced by locally generated aerosols whereas at upper height range of 2000m these are transported through central part of India where a line-up of power generation units produces fly ash transporting Si rich aerosols up to Varanasi.

4. Conclusions:

Aerosols samples from a relatively clean suburban area of Banaras Hindu University campus and a much polluted urban areas of Varanasi city situated in the eastern Indo-Gangetic plain were analyzed using simultaneously both SEM-EDX analysis as well as ion chromatograph at Varanasi. Based on this study, following main conclusions were drawn:

There are differences between particle morphology at the urban areas and suburban area. At suburban area, the particles are flaky as BHU is highly vegetated, whereas, at urban areas, the particles are mostly rounded. The aerosol concentrations are found higher at urban areas than at suburban areas. The concentration for polluted urban area of city was about two-fold the pollution of green area. The concentrations of C, Ca, Na, S, Si, Al have dominated the sample at both the areas. The probable source of silicon rich aerosol particles are the transportation of fly ash produced by a line-up of various thermal power generation units situated in the neighbourhood of Varanasi, around 150 km distant. The ionic contents of the aerosols at urban area followed the trend as $Na^+ > SO_4^{2-} > Ca^{2+} > Cl^- > Mg^{2+} > NO_3^- > K^+ > HCO_3^+ > F^-$, where as for suburban area showed the trend as $Na^+ > SO_4^{2-} > NO_3^- > Ca^{2+} > Cl^- > Mg^{2+} > K^+ > HCO_3^+ > F^-$. This shows that the relatively more polluted urban area was dominated by soil-dust generated due to heavy traffic movement and construction industries. The air mass back trajectory analysis shows that there are different pathways for the transport of air masses from different source regions during different days, which suggest the existence of different types of aerosols over Varanasi sites (e.g. dust from desert and anthropogenic aerosols from biomass/urban-industrial sources). To understand a better chemical composition and their morphology a complete analysis of the aerosols using both these techniques is needed for the routine basis for different months along the year.

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