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Wintertime source-apportionment of PM_1 from Kanpur in the Indo-Gangetic plain

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ABSTRACT

In today's scenario of increasing anthropogenic emissions, arising due to development in urban and rural areas, it has been widely realized to assess the atmospheric impact of various sources. In this context, we investigated the source contribution of ambient fine-mode aerosols (PM_1; n = 51) during wintertime (mid of November 2009 to February 2010) over Kanpur site in the Indo-Gangetic Plain (IGP). PM_1 mass concentration centers at 113 µg m^{-3}. The high loading of fine-mode aerosols is attributable to source strength and shallower planetary boundary layer. In PM_1 a total of 20 chemical constituents have been measured that include trace metals (Pb, Cd, Se, V, Cr), major elements (Fe, Mg, Ca, Na and K) and water-soluble inorganic species (NH_4^+, NO_3^-, Cl^- and SO_4^{2-}). A recent version of positive matrix factorization (PMF 5.0) was utilized to quantify the contribution of fine-mode aerosols from various sources. This study reveals that nearly 80% of the fine-mode aerosols over Kanpur region are contributed by fossil-fuel sources that include point and mobile sources (vehicular and industrial emissions). However, the contribution from biomass burning emission is about 20%. One of the most interesting features of our study relates to the observation that secondary sources (contributing 40% of PM_1 loading) are predominantly formed from vehicular emission sources (fossil-fuel combustion). Thus, our study highlights the high concentration of PM_1 loading and atmospheric fog prevalent during wintertime in the IGP can have severe impact over the human health.

Keywords: Positive matrix factorization, PM_1, Secondary aerosols, Indo-Gangetic Plain.

1. INTRODUCTION

Troposphere is a highly dynamic component of the atmosphere, and responds very quickly to the processes occurring on the Earth's surface. For example, the effect of dust storms, volcanic eruption and emission of aerosols and trace gases (Nallathambi and Shanmuganantham, 2015), from biomass burning vis-à-vis fossil-fuel combustion is recorded in the atmospheric composition soon after the occurrence of these events. In contrary to their emissions, the atmospheric budget of aerosols is controlled by their removal due to wet precipitations and/or dry deposition (gravitational settling). The intermediate process between the emission of the chemical constituents and their atmospheric removal occurs during their transport. During the course of their transport, the chemical composition and atmospheric abundances of atmospheric aerosols change due to their mixing with other atmospheric constituents and/or the chemical reactive nature of some of them.

Atmospheric aerosol composition is important in governing their interaction with solar radiations and affecting the cloud properties [*Menon et al.*, 2002; *Ramanathan et al.*, 2007]. However, the aerosol composition is highly variable on a temporal (day/night and seasonal) and spatial scale due to change in its emission from natural vis-à-vis anthropogenic sources [*Decesari et al.*, 2010]. Besides the varying sources, aerosol composition can also change during its chemical processing and/or mixing (with particles from different origin) within the atmosphere. Assessing the aerosol characteristics is essential to infer about their sources, formation mechanism, and understand their role in atmospheric chemistry and radiation impacts (through direct interaction and indirectly via entrainment into clouds) on a regional-to-global scale [*Ervens et al.*, 2011].

To characterize the emission sources and their source strength a significant work has been carried out over the globe and represented in the literature [Chakraborty and Gupta, 2010]. In this study, we have utilized a recent version of positive matrix factorization (PMF 5.0) to understand the contribution of various sources to fine-mode aerosols.

2. MATERIALS AND METHODS

PM_1 sampling was carried out on the roof of a 12 m tall building (Western Lab Extension, WLE) inside the campus of Indian Institute of Technology (IIT) Kanpur (lat: 26.30 °N; long: 80.13 °E; 142 m above mean sea-level). IIT Kanpur is an academic institution with no commercial or industrial activities. The campus lies nearly 15 km upwind (North) of the Kanpur city with relatively less local emissions. Aerosol sampling (n = 51) was integrated for 8 to 10 h each day spread over mid of November 2009 to the end of February 2010. PM_1 samples (n = 51) have been collected onto pre-combusted quartz filters (47 mm diameter) between mid of November 2009 and end of February 2010. PM_1 mass loading was ascertained gravimetrically on an analytical balance. Water-soluble inorganic species (NH_4^+, NO_3^-, SO_4^{2-} and Cl^-) was measured on an Ion-chromatograph (Metrohm) following the standard sonication technique. Trace metals (As, Cd, Co, Cr, Cu, Ni, Pb, Se, V, Zn, Mn) and major elements (Na, K, Ca, Fe, Mg) have been on an ICP-OES (Thermo Scientific) post to the aerosol digestion using HNO_3 method.

3. RESULTS AND DISCUSSION

In this study, we report the chemical composition (Table 1) of water-soluble inorganic species (WSIS), trace metals and major elements (referred collectively as metals in Table 1) in PM_1 (Av: 113 µg m^{-3}). The WSIS and metals together constitute nearly 50% of the PM_1 mass concentration. The unaccounted mass is attributable to predominant contribution from carbonaceous species. The high concentration of PM_1 and associated chemical constituents arise due to source strength and shallower planetary boundary layer in the IGP during wintertime.

Table 1 Average mass concentration of ambient aerosol species at the Kanpur site

Parameters	Abundance
PM_1 (μg m^{-3})	113 ± 72
WSIS (%)	26 ± 12
Metals (%)	20 ± 14

The PMF analysis was performed at the receptor site Kanpur. Briefly, the aforementioned chemical constituents were input to the model. The model was run several times to achieve the optimal Q value for the input matrix data set. All the base runs were ascertained to be converging. We have observed a good agreement (R^2 = 0.76; Figure 1) between the measured and model predicted PM_1 mass concentration, which also ascertains our interpretation on source-apportionment from the PMF analysis to be quite reasonable.

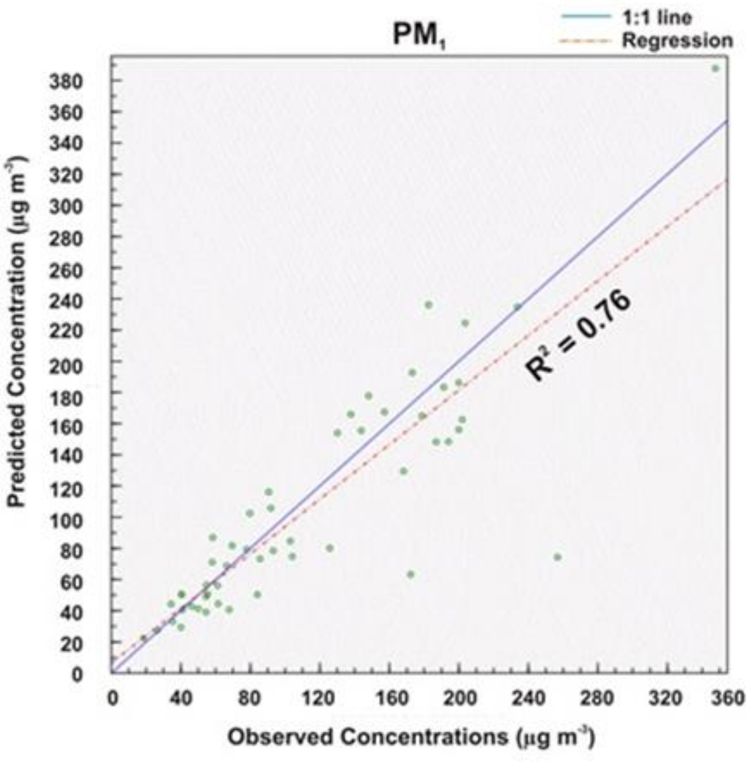

Figure 1: Linear regression analysis exhibits a strong correlation for PM_1.

The summary of the PMF analysis results are discussed as below:

Factor 1, 2 and 3: Industrial emissions and construction activities

These sources contribute ~ 30% of PM_1 over the study location during the wintertime. The source characteristics has been inferred by analyzing high content of Cd, Se, Cr, Fe, Ca and Mg in the source profile of these factors.

Factor 4, 5: Diesel emissions and Secondary aerosols

These sources contribute ~ 50% of the total PM_1. Significant amount of V, Z, Mn and Cl^- are found in this source profile of factor 4 that indicates their emissions from diesel combustion, whereas high content of ammonium, nitrate and sulfate in conjunction with Ni in factor 5 indicates vehicular emissions as the producer of precursors for secondary aerosols at Kanpur.

Factor 6: Biomass burning

This source contributes ~ 20% of the PM_1 with a high loading of K and small loading of Fe. The contribution of Fe in biomass burning assigned factor is in agreement to the previous studies reporting biomass burning emissions as one of the sources of water-soluble Fe.

The source contribution to PM1 mass over study location at Kanpur is shown in figure 2. It is obvious from the figure that factor 5 (secondary aerosols) is the dominant source of PM1 followed by factor 6 (biomass burning emissions).

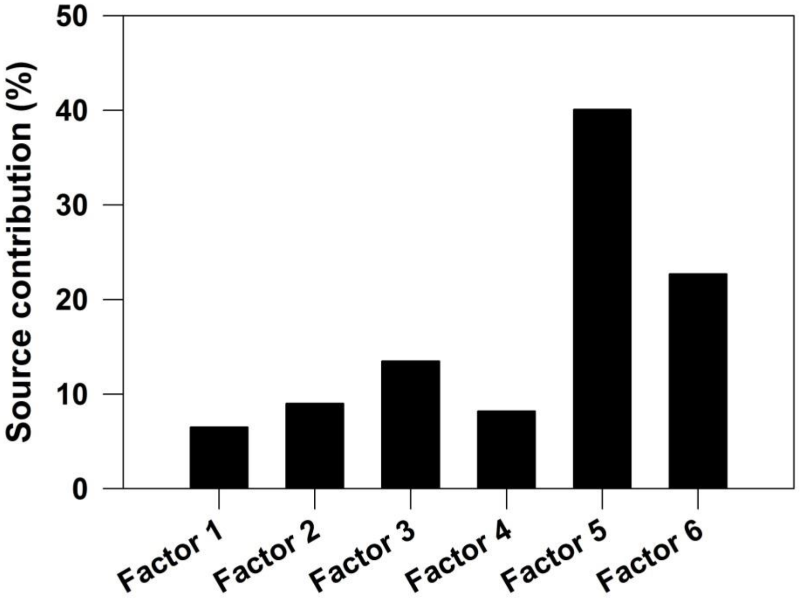

Figure 2 Percentage contribution of predominant sources of PM_1 at the study location Kanpur.

4. SUMMARY

PM_1 samples have been studied for their plausible emission sources during wintertime (2009–10) at Kanpur location in the Indo-Gangetic Plain. High PM_1 variability and associated chemical constituents is attributable to source variability and shallower boundary layer during this study. Based on trace metals, major elements and water-soluble inorganic components, a total of six source factors contributing to PM_1 mass have been resolved using the PMF analysis tool. The fossil-fuel based activities responsible for primary and secondary aerosols loading totaling to nearly 80%. However, the biomass burning emissions contribute only to about 20% in this study. This observation is in sharp contrast to those reported from upwind IGP with predominant contribution from biomass burning emissions round the year. Thus, emission source strength and variability in the IGP, and formation of secondary aerosols urges for long-term ground-based measurements of ambient atmospheric aerosols. This study has implications to the budget of trace gases on a regional scale.

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