Atmospheric Research 178–179 (2016) 506–520

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Composition and source apportionment of PM_1 at urban site Kanpur in India using PMF coupled with CBPF

Pragati Rai [a], Abhishek Chakraborty [a], Anil Kumar Mandariya [a], Tarun Gupta [a,b,*]

[a] Department of Civil Engineering, Indian Institute of Technology, Kanpur, Uttar Pradesh 208016, India
[b] Centre for Environmental Science and Engineering, Indian Institute of Technology, Kanpur, Uttar Pradesh 208016, India

ARTICLE INFO

Article history:
Received 1 January 2016
Received in revised form 4 April 2016
Accepted 25 April 2016
Available online 27 April 2016

Keywords:
Source apportionment
PMF
Metals
Ions
PM_1
CBPF

ABSTRACT

This study addresses the three major questions: (1) what are the emission sources of PM_1 which are affecting the study area; (2) where do these emission sources come from; and (3) is there any temporal variation in the emission sources. To address these issues, two advanced statistical methods are described in this paper. Identification of emission sources was performed by EPA PMF (v 5.0) and to understand the temporal variability, sampling was done for three winter seasons 2008–09, 2009–10 and 2011–12 within Kanpur city. To identify the possible source directions, Conditional Bivariate Probability function (CBPF) was used. The average PM_1 concentration was higher in 2008–09 followed by 2011–12 and 2009–10 winter seasons. 2008–09 winter showed sources such as secondary sources mixed with power plant emission (42.8%), industrial emission (32.3%), coal combustion, brick kilns and vehicular emission (13.2%) and residual oil combustion and road dust (11.7%). The major contributors during winter season 2009–10 were secondary sources (33.1%), biomass burning (23.3%), heavy oil combustion (13%), vehicular emission mixed with crustal dust (11.3%), leather tanning industries (10.3%), industrial emission (4%), coal combustion and brick kilns (3.4%) and solid waste burning and incineration (1.5%) compared to secondary sources mixed with biomass burning (42.3%), industrial emission and crustal dust (35.1%) and vehicular emission and brick kilns (22.6%) during 2011–12 winter season. PMF model revealed that secondary sources were the main contributors for all the three winter seasons followed by biomass burning and power plant emission. The results of CBPF analysis agreed well with the locations of known local point sources., e.g. in the case of industrial emissions, the maximum probability was in the direction between NES direction where almost all the major industries are located in and around Kanpur while in the opposite direction the probability of biomass burning was high due to a rural area in NWS direction.

1. Introduction

Atmospheric aerosols are currently a subject of high scientific and political interest, which is due to their significant effects on climate, human health, ecosystems and agricultural yields. Apart from that, atmospheric aerosols also affect visibility and alter the Earth's radiative balance (Sharma et al., 2016). Several studies have concluded that aerosols, especially fine mode (particulate matter having aerodynamic diameter ≤ 2.5 μm) particles, can lead to respiratory and cardiovascular diseases (Dockery and Pope, 1994; Mishra et al., 1999). Therefore, identification of particulate matter (PM) sources is essential to develop air quality management strategies to control and reduce ambient PM. There are various tools available to identify and quantify the PM sources (Paatero and Tapper, 1994). Receptor modeling is one of the most sought after approach for identification of sources and their respective contribution to airborne PM across the world. Recently, Positive Matrix Factorization (PMF) has been used successfully in many studies (Lee et al., 1999; Anderson et al., 2002; Kim et al., 2003; Pekney et al., 2006; Kim and Hopke 2007; Bhanuprasad et al., 2008; Heo et al., 2009; Tao et al., 2013; Sharma et al., 2014; Banerjee et al., 2015; Sharma et al., 2016). PMF is powerful and widely used multivariate method among several source apportionment methods that can satisfactorily resolve the dominant sources without any prior knowledge of individual source profiles. PMF has the advantage of non-negative constraints and scale each data point individually over traditional factor analysis. PMF permitted to obtain better results than other receptor models due to more stringent requirements of associated uncertainties (Callén et al., 2009). Therefore, in the present study, PMF (US EPA PMF Ver. 5.0) was used to identify sources of PM_1 at Kanpur; located at the heart of the IGP. The CBPF was also used in this study to analyze pollutant source contributions in relation to winds at the site and has been applied to find source directions. The CBPF method is an extension of Conditional Probability Function (CPF) which can analyze point source impacts from varying wind directions and wind speed using source

* Corresponding author at: Department of Civil Engineering, Indian Institute of Technology, Kanpur, Uttar Pradesh 208016, India.
E-mail address: tarun@iitk.ac.in (T. Gupta).

http://dx.doi.org/10.1016/j.atmosres.2016.04.015
0169-8095/

contribution estimates from a source apportionment model coupled with wind direction values measured on site (Kim and Hopke, 2008; Bae et al., 2011). CBPF has been widely used in conjunction with PMF to identify source directions (Lee and Hopke, 2006; Qin et al., 2006; Kim and Hopke, 2008; Heo et al., 2009; Bae et al., 2011). While there is one shortcoming of CBPF, i.e., it cannot distinguish directionality between local and long range transported sources when a mixture of sources from local and long range transport impact the receptor site (Bae et al., 2011). Very few studies have been done based on CPF in India so far (Raman et al., 2011; Bapna et al., 2013) while using CBPF, there is no study available so far from India.

Kanpur lies in the central part of the Ganga basin and is severely affected by ever increasing air pollution levels (Tare et al., 2006; Kaul et al., 2012; Gupta and Mandariya, 2013; Gaur et al., 2014). Several sources like; industrial activities, vehicular emission, power plants plume, local and remotely occurring biomass burning activities (which are then transported here via winds), and crustal dust is contributing to air pollution in Kanpur (Gupta and Mandariya, 2013; Ghosh et al., 2014). Earth crust and road dust resuspension followed by vehicular emissions are the major source of air pollution in India Pant and Harrison (2012); Banerjee et al., 2015). In India, during past few decades, several aerosol chemical characterization studies have been carried out in urban sites to understand the impact on regional air quality and climate change. Most of those studies have reported much higher aerosol concentrations during winter compared to other seasons. Main reasons behind high aerosol concentrations during winter are favorable meteorological conditions for accumulation of pollutants like; low wind speed, low boundary layer heights and enhanced local burning activities for heating purposes. For example, some observations made at Delhi showed much higher mass concentrations of PM_1 in the winter season compared to other seasons (Tiwari et al., 2009, 2012, 2013). However, same studies indicated that $PM_{2.5}$ concentrations varies significantly from year to year (range for mean $PM_{2.5}$ conc. = 105–205 μg/m^3, from 2007 to 2011 winter) and even within a winter season (116–339 μg/m^3, in 2011 winter and 110–550 μg/m^3, in 2007 winter) (Tiwari et al., 2012, 2013). At a semi-urban site of Agra, the average mass concentrations of PM_{10} and $PM_{2.5}$ were 234–278 μg/m^3 and 80–90 μg/m^3, respectively (Pipal et al., 2011). Several studies have also been carried out on PM_1 chemical characterization in Kanpur itself, and all of them reported significantly higher PM_1 values in winter compared to other seasons. Like, during the winter season 2008–2009 at Kanpur, the average mass concentration of PM_1 was observed to be 199 μg/m^3 in the winter (December–January) season while 31 μg/m^3 in the monsoon season (Chakraborty and Gupta, 2010). In, 2010, a study carried out at the same location reported PM1 concentration > 400 μg/m^3 (Kaul et al., 2012) while other studies reported much lower values in other years. Results of these previous studies clearly indicate that aerosol mass concentration varies significantly from one winter to another, and there is a significant amount of intra seasonal variability present as well (Tiwari et al., 2009, 2012, 2013, Kaul et al., 2012). Major reasons behind these variations are changes in meteorological parameters; like variations in boundary layer heights, temperature, wind speed, occurrence of fog/haze events, etc. (Table 1). Local burning activities also vary with ambient temperatures, presence/absence of foggy weather, etc., thus causing changes in aerosol mass concentrations.

Although several studies have been carried out at this location, none has tried to look into the aerosol concentration and compositional trends of several years in detail. Also, the role of wind directions and which nearby areas are contributing to higher aerosol loadings at this site have not been evaluated. In this work, we have reported chemical characteristics and source apportionment of PM_1 mass concentration at an urban site of Kanpur, India for three winter seasons (2008–09, 2009–10 and 2011–12) and tried to understand variations in aerosol sources and composition with possible role of wind directions in causing such differences.

2. Experimental methods and data analysis

2.1. Sampling site

Sampling was done at Indian Institute of Technology Kanpur (IITK) (26.51° N, 80.23° E) as shown in Fig. 1, about 17 km away from Kanpur city, on the roof of a 12 m high building (Western Lab Extension) inside the campus. IITK is a residential institution of national importance, and there are no commercial and industrial activities inside the campus. While few construction activities are going on almost throughout the year as a part of capacity expansion within premises of the campus (Gupta and Mandariya, 2013). Vehicular population mainly comprises of two wheelers and cars inside the campus (Devi et al., 2009; Chakraborty and Gupta, 2010). The campus is located in upwind direction with several emission sources in its near vicinity. The dominant sources of pollution in the Kanpur city are traffic emissions, biomass fuel (domestic cooking and heating), wood and coal burning, industrial activities, brick kilns and thermal power plant plumes. There are two major national highways (Grand Trunk road) which are passing through the middle of the Kanpur city and touch IIT Kanpur main gate, mostly responsible for traffic emission, vehicular exhaust, soil, and road dust. In addition, there is a coal based thermal power plant in South–East direction of sampling site and many industries (cotton, jute, leather, iron and steel, cement, aluminum, oil refinery, metal, etc.; Fig. 1). Biomass burning is significantly higher during winter season in Kanpur compared to other seasons (Gupta and Mandariya, 2013).

Sampling was carried out for 8 h per day for winter season of December, 2008–February, 2009 and November, 2011–January, 2012 while 10 h per day for winter season of November, 2009–February, 2010 with a single stage round nozzle, vacuum grease impaction substrate based impactor type PM_1 sampler developed in our lab at IITK itself (Gupta et al., 2009). A total of 103 samples were collected with 27, 51 and 25 numbers of samples each from 2008 to 09, 2009–10 and 2011–12, respectively. The samples were analyzed using inductively coupled plasma–optical emission spectrometer (Thermo Fisher, iCAP 6300 Duo), Ion Chromatography (Metrohm Compact IC 761, Switzerland) and TOC (only for 2011–12 season, Total Carbon Analyzer, Shimadzu, Japan). For 2008–09 winter season, the analyzed species were As, Ca, Co, Cr, Cd, Mg, Fe, Ni, Pb, Cu, Zn, V, Se, F^-, Cl^-, NO_3^-, SO_4^{2-}, and PO_4^{3-} (Chakraborty and Gupta, 2010) and As, Ca, Co, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Se, Ti, V, Zn, F^-, Cl^-, NO_3^-, SO_4^{2-} and NH_4^+ during 2009–10 (Gupta and Mandariya, 2013) while Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Zn, Cl^-, NO_3^-, SO_4^{2-} and NH_4^+ (chemical analysis is same as

Table 1
Average meteorological conditions observed at sampling site.

Year	Temp. [^{0}C]	RH [%]	Wind speed [m·s^{-1}]	Mixing layer height [m]	Ventilation coefficient [m^2·s^{-1}]
2008–09	18.2 ± 0.44	78.82 ± 8.66	4.36 ± 2.76	411 ± 101.96	1791.96
2009–10	15.8 ± 5.07	84.08 ± 10.90	3.02 ± 1.63	451.43 ± 166.20	1363.32
2011–12	22.16 ± 3.54	74.84 ± 12.03	3.4 ± 2.08	326.3 ± 89.30	1109.42