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Microscopic morphology and seasonal variation of health effect arising from heavy metals in PM2.5 and PM10: One-year measurement in a densely populated area of urban Beijing

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ABSTRACT

In order to study the sustained impact of particulate matter on urban residents, 572 PM2.5 and PM10 samples in all were attained simultaneously from a densely populated area of Beijing from September 2015 to August 2016. 11 types of heavy metals were determined as to better ascertain the seasonal variation characteristics of particle composition. In the course of the year, the mean concentrations of PM2.5 and PM10 were detected to be 102.45 $\mu g\,m^{-3}$ and 144.75 $\mu g\,m^{-3}$, respectively. From general perspective, winter turned out to be the longest in haze day quantity and the highest in particle concentration, followed by spring, autumn and summer, successively. The mass concentrations of numerous PM2.5 elements fluctuated evidently in the decreasing order of Ba, Zn, Mn, Sr, Cu, Pb, Cr, V, Ni, Cd and Sb. In contrast with other seasons, winter displayed the most evident increase of metal content in particulates, especially under the condition of haze. Relationship between different size particles was also reckoned with in this study. High concentration ratio of PM2.5 and PM10 (0.76–0.84) was detected during haze period, and PM2.5 was accounted as a primary pollutant during haze-fog day in Beijing. Moreover, the carcinogenic and non-carcinogenic risk posed by detected heavy metals was investigated. Cr posed the highest carcinogenic risk, and in the meantime, as compared with other non-carcinogenic metals, value of Pb was the highest in Hazard Quotient. Risk arising from Cr and Cd in winter shall be noteworthy, and accordingly it may pose danger or potential risk to adults in haze days. Eventually, a large amount of fly ash and soot particles in winter samples were indicated from SEM-EDX analysis results, whereas those are rarely detected in summer samples.

1. Introduction

The issue of environmental contamination arising from atmospheric particles has become prominent and serious in populous cities in Asia, inclusive of Xi'an, China and Mumbai, India (Gao, Cao, and Seto, 2015a; Maji, Dikshit, and Deshpande, 2016). Rapid industrialization, large population and heavy traffic were responsible for worsening the air quality in the cities stemmed from the elevated levels of gaseous and particulate pollutants. Biomass burning, factories, utilities, refineries, power plants construction activities and fossil fuel burning were perceived as the crucial vital anthropogenic sources giving rise to particulate matter in urban air (Gumede and Savage, 2017; Xie, Dai, Dong, Hanaoka, and Masui, 2016). Furthermore, Particulate sizes < 10 mm shall outstrip coarse particles in absorbing toxic substances, and can enter the human body via deposition in the lungs through respiration, consequently resulting in various respiratory and cardiovascular diseases (Makkonen, Hellén, Anttila, and Ferm, 2010; Wiseman and Zereini, 2009).

In the past decade, China's dramatic economic rise, rapid industrial development, population growth, construction and demolition projects, and the increase in traffic flow have critical impact on the atmospheric environment, especially with respect to the contamination of atmospheric particulate matter. The study of particle concentrations, sizes and chemical composition at the receptors shall be of great necessity to elucidate the sources of the aerosols and the processes bound by their formation (Kulshrestha, Satsangi, Masih, and Taneja, 2009; Putaud et al., 2010; Wang et al., 2003; Yin and Harrison, 2008; Zhang et al., 2015). Cities in Asia have been subject to comparatively serious metal contamination from atmospheric particle according to the previous research. Many studies have reckoned with the issue of contamination

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stemmed from heavy metals, inclusive of Cu, Cr, Fe, Ni, Pb, Zn, V, As, Be, Cd, Mn etc. Most of these are short-term studies of suspended particulates or of total suspended particulates (Tripathi et al., 2004; Wu et al., 2013). Short-term differences of atmospheric metal content have been observed on a day-to-day or even an hour-to-hour basis (Gharaibeh, El-Rjoob, and Harb, 2008; Wang and Xie, 2009; Wiseman and Zereini, 2009). Therefore, the reductions of particulate and associated metal contamination to some acceptable levels are deemed as crucial environmental highlights.

A statistically significant correlation between air contamination and mortality has been observed by most researchers. The rate of hospitalization, lung function and mortality were closely associated with PM2.5 levels (Bell, Ebisu, Peng, Samet, and Dominici, 2009; Han, Kim, Cho, Kim, and Kim, 2015). The increase in lung cancer and cardiopulmonary mortality with enhanced PM2.5 concentrations had been further indicated (Huang et al., 2012). Although heavy metals merely result in a small fraction of PM2.5, heavy metals were carcinogenic and less effectively biodegradable. The heavy metals turned out to be toxic if humans are exposed to them to a high extent for a longtime period (Greene and Morris, 2006; Liu et al., 2005). There were more comprehensive studies on the airborne toxic heavy metals in Europe and North America (Díaz and Rosa Dominguez, 2009; Kim, Kim, Ahn, Ko, and Lee, 2005), whereas limited studies have been conducted in Asia, especially in the countries with rapidly developing economy, such as China and India (Massey, Kulshrestha, and Taneja, 2013; Zereini et al., 2012). Scanning Electron Microscopy with Energy-Dispersive X-ray analysis (SEM-EDX) counts as an effective method for the micro-analysis. The morphological and elemental information of individual aerosol particles can be determined accordingly. SEM-EDX has been successfully adopted to ascertain the chemical and physical characterization of individual particle (Alastuey et al., 2005; Chithra and Shiva Nagendra, 2013; Lü et al., 2012; Tolis et al., 2014).

To ascertain the current situation of PM2.5 and PM10 contaminations in densely populated area of Beijing, one-year continuous survey since September 2015 to August 2016 has been conducted. Chemical characteristics of PM2.5 and PM10 were compared between in terms of different seasons. Additionally this study statistically anatomized contamination characteristics of haze days and non-haze days of a full year. To lay a theoretical basis, the health risks posed by exposure to the metals in the levels observed to residents in Beijing were tested in this study. Eventually, morphological analysis of particle for different season was performed to ascertain the possible sources.

2. Materials and methods

2.1. Sampling locations and methods

In this study, sampling site was located in an urban area of Beijing. In order to study the continuous effects of particulate matter on citizen, we chose densely populated Haidian District as the study area. According to the government, the region has a population of over 3 million (Bureau of statistics of Haidian District, http://hdtjj.bjhd.gov.cn/tjsj/jdsj/2016n_626/czrk/4jd/). The sampling site is located in a campus (39 °99′56.15″ N, 116 °35′47.55″ E), and this site is near the north 4th-ring road (Fig. 1). Numerous residential areas, schools and stadiums are in the neighborhood of the sampling site, with large traffic flow and few factories. The main influential factor near sampling site is traffic emission.

PM2.5 and PM10 samples were simultaneously attained from September 2015 to August 2016. With the exception of adverse weather conditions, all the samples were attained under no-rainy conditions. Sampling was conducted once a day, and each sampling event continued for 23.5 h (from 8 am to 7:30 am). In this study, two instruments produced by the same manufacturer were used to collected samples. During the sampling, one medium-volume sampler along with a PM2.5 cutting equipment (manufactured by Laoying, Qingdao, China) was adopted at a flow rate of 100 L min^{-1} to attain the PM2.5 samples. In the meantime, the other one along with a PM10 cutting equipment was adopted to attain PM10, and the flow rate was set as 100 L min^{-1} too. To eliminate error, these two samplers were bought from the same factory. To ensure the same sampling environment, the distance between two instruments was set as 10 m. Each total volume could be automatically computed by the flow recorder of the machine. All the samplers were placed on the roofs of buildings which were approximately ten meters above the ground. Glass fiber filters were adopted during the sampling period (a diameter of 88 mm, Beijing Synthetic Fiber Research Institute, Beijing, China). Prior to sampling, all filters were baked at 450 °C for 2 h to remove volatile substances and other impurities. The scale adopted for weighing is accurate to one-hundred-thousandth of a gram (XP105DR, Mettler-Toledo, Switzerland). Eventually, 572 samples in all were attained at sampling site throughout the process. The quantity of samples in each season was as follows: Spring, 134 (February–April); Summer, 136 (May–July); Autumn, 134 (August–October); Winter, 168 (November–January). After sampling, all the filters were airproofed in tin foil packages which

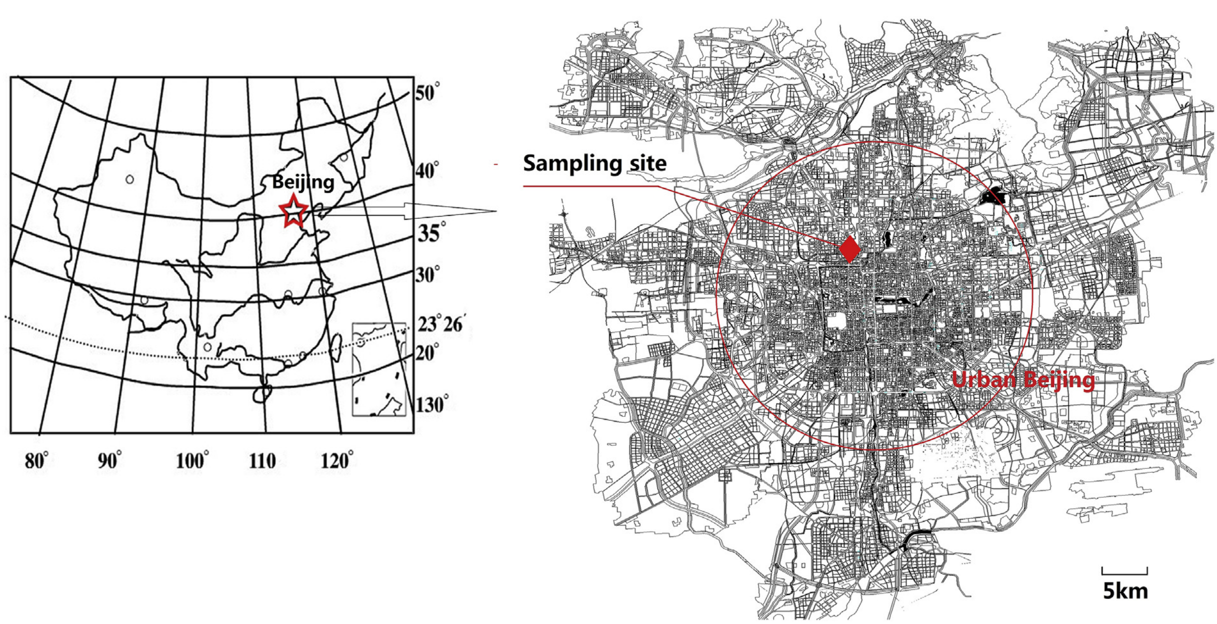

Fig. 1. Map showing location of sampling site in Beijing.