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Chemical composition and source apportionment of ambient $PM_{2.5}$ during the non-heating period in Taian, China

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A B S T R A C T

Ambient $PM_{2.5}$ samples were collected in the urban area of Taian in China in August–September and November, 2014. The chemical compositions and emission sources of $PM_{2.5}$ were analyzed. The results indicated that the mean concentration of $PM_{2.5}$ reached 70.8 μg/m^3 during the non-heating period, and water soluble inorganic ions (WSIIs), carbonaceous materials, including elemental carbon (EC) and organic carbon (OC); and elements contributed 43.80%, 10.34% and 17.36%, respectively, to $PM_{2.5}$. The mean concentrations of WSIIs at three sampling sites decreased in the same order: $SO_4^{2-} > NH_4^+ > NO_3^- > Cl^-$ during the non-heating period. NO_3^- and NH_4^+, SO_4^{2-} and NH_4^+, showed extremely significant positive-correlations ($r = 0.79, 0.54$; $P < 0.01$). The variability of OC was larger than the variability of EC during the non-heating period. The high concentration of secondary organic carbon (SOC) could reduce correlation-level between the OC and EC. Moreover, the percentages and concentrations of the total detected elements (TDE) increased significantly, ranging from August–September to November ($P < 0.01$). Major sources of $PM_{2.5}$ identified from positive matrix factorization (PMF) model and enrichment factors (EFs) included secondary aerosol, coal combustion, metal manufacturing, soil dust/resuspended dust/construction dust and vehicle exhaust/biomass burning, which contributed 27.47%, 17.94%, 19.06%, 9.41% and 16.65%, respectively, to $PM_{2.5}$. The backward trajectory analysis identified three transport pathways that originated from Mongolia (12% of the total trajectories), Inner Mongolia (2%), and southeast of Shandong Province (86%), and the potential source contribution function (PSCF) model identified southeast of Shandong Province was mainly a potential source-area that affected air quality in Taian.

1. Introduction

$PM_{2.5}$ (particle matter with an aerodynamic diameter of less than or equal to 2.5 μm) is a crucial air pollutant on the basis of its adverse human health effects and degradation of visibility (Pope and Dockery, 2006; Tao et al., 2013; Watson, 2002). Epidemiological studies have also demonstrated that PM (particle matter) exposure is associated with the occurrence of acute respiratory infections, lung cancer and chronic respiratory and cardiovascular diseases (Kok et al., 2006; Pope et al., 2002; Taus et al., 2008). $PM_{2.5}$ is a complex mixture from both natural and anthropogenic sources, including primary and secondary particle species, and consists mainly of WSIIs, carbonaceous species (OC and EC) and elements, such as Al, Si, Mg, Fe, Pb, Zn, etc. (Pathak et al., 2009; Tiwari et al., 2009; Zhang et al., 2013, 2014). The chemical composition of $PM_{2.5}$ is a key to fully understanding and assessing its impacts on climate, air quality and human health (Tao et al., 2013). Many studies have been conducted to characterize the chemical properties of $PM_{2.5}$ and achieve source apportionment around the world (Bahadur et al., 2009; Chen et al., 2010; Haglera et al., 2007; Kim et al., 2007; Tao et al., 2014; Yang et al., 2011).

To date, rapid economic growth and dense urbanization in China have led to heavy particulate pollution (Che et al., 2009; Tie and Cao, 2009; Yang et al., 2011). Most Chinese residents (approximate 1.02 billion, accounting for 75.20% of the total population) live in medium and small cities (refer to the city that resident population in the urban is less than 1,000,000) (http://www.csmcity.com/zt/lvzt2013/), where the atmospheric pollution is also very severe (Wu et al., 2009; Wang et al., 2014), and the character of the pollution is significantly distinct from larger or mega cities. Nevertheless, the studies related to $PM_{2.5}$ pollution mostly concentrated in large or mega cities or areas, such as Beijing–Tianjin–Hebei (Yang et al., 2011; Zhao et al., 2012), the Pearl River Delta (Cheng et al., 2008; Deng et al., 2008; Hu et al., 2008) and the Yangtze River Delta (Du et al., 2011; Fu et al., 2008). Yet $PM_{2.5}$ has seldom been sampled and chemically analyzed in medium or small cities, such as Taian, and the related published data for $PM_{2.5}$ in the urban areas of these cities are also scarce. A better understanding of $PM_{2.5}$ sources and their relative contributions is urgently needed to enact effective emission control policies and to implement multi-pollutant reduction measures (Gu et al., 2014; Tao et al., 2014).

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Taian (36.18°N; 117.11°E) is a famous tourism site in China and is situated south of Mount Tai (1545 m a.s.l.), which is known as throughout the world as a cultural and natural heritage site and has a world famous geological park. The urban area exceeds 120 km^2, with a population of approximately 0.65 million. Although the practices of fuel consumption have been changing as a result of rapid economic development, coal is still the primary fuel in Taian and is widely used for industrial processes and daily life. More coal is burned for heating between the 15th of November and the 10th of March (heating period) because of the cold winter. In spite of the heavy pollution always occurred in the heating season, the non-heating period (from 11th of March to 14th of November) accounts for most time in a year, comparing to the coal combustion as the dominated source in the heating period, the predominated sources during the non-heating period are not explicit so far. Furthermore, the proportion of secondary transformation in particle matter was also higher in the non-heating period. Therefore, comparing to the heating period, there was the value of more in-depth discussion on the non-heating period. Additionally, the number of motor vehicles in the urban area now exceeds 0.45 million, and therefore, the contribution of exhaust to $PM_{2.5}$ cannot be ignored.

As a famous tourist site, Taian is experiencing the effects of severe pollution. According to the online monitoring data supplied by Taian Environmental Monitoring Center, the annual average concentration of $PM_{2.5}$ was up to 84.6 μg/m^3 from 2013 to 2014, which significantly exceeded the MEPC (Ministry of Environmental Protection of China) 2012 guideline value (1 year) of 35 μg/m^3. Meanwhile, in 2014, the number of tourists in Taian was more than 50 million, and most of them visited the Mount Tai during the non-heating period. Therefore, the information of pollution level and emission sources during the non-heating period is critical for enacting effective measures to reduce the health impacts on tourists and local residents. However, corresponding studies of particulate source apportionment and chemical compositions are rare. Consequently, few targeted measures and emission control policies have so far been launched. The main objectives of this study are to: (1) understand the pollution level of Taian during the non-heating period; (2) characterize the mass concentration variations of $PM_{2.5}$ and its major chemical composition; (3) estimate the source categories and their contributions by using EFs analysis and PMF model; and (4) identify the transport pathway and potential sources-areas of $PM_{2.5}$ in Taian using backward trajectory analysis and PSCF analysis, respectively.

2. Materials and methods

2.1. Sampling site

Taian is a medium-sized tourism site with few heavy industrial factories and is located in Shandong Province in the northeast of China, where Mount Tai is located (Fig. 1). The urban area is more than 120 km^2, with a population of nearly 0.65 million. Taian experiences a half-moist continent monsoon climate, with an annual average temperature of 13 °C. The prevailing wind direction is NE (16%), and the annual average wind speed (WS) is 2.7 m/s. From 26 August to 8 September, and 3 to 9 November, 2014, ambient $PM_{2.5}$ samples were collected at three sites (AU, EPS and PS) in Taian, as shown in Fig. 1. Site AU (36.17°N, 117.15°E) is located in Shandong Agricultural University at the southeastern part of the city, which is near industrial plants and busy roads, and this site represents mixed industrial and heavy traffic area. Site EPS (36.18°N, 117.11°E) is located in the Electric Power School, which is adjacent to the center of the city and represents a mixed commercial-traffic area. Site PS (36.20°N, 117.09°E) is situated at Population School in the northern part of the city and is near Mount Tai, around which there are residential and tourist areas, and this site represents a residential and traffic area. The three sampling sites are set on the rooftops of buildings that are approximately 9–15 m above ground level.

2.2. Ambient sampling

Based on our previous work and other related studies (Bi et al., 2007; Tian et al., 2014; Xue et al., 2010; Zhao et al., 2013), $PM_{2.5}$ samples were collected at 09:30 am for 24 h using two medium-volume samplers (TH-150C, Wuhan Tianhong Ltd., China) and quartz fiber filters (90 mm in diameter, 2500 QAT-UP, Pall Life Sciences) for water-soluble ion and carbon analysis and polypropylene fiber filters (90 mm in diameter, Beijing Synthetic Fiber Research Institute, China)

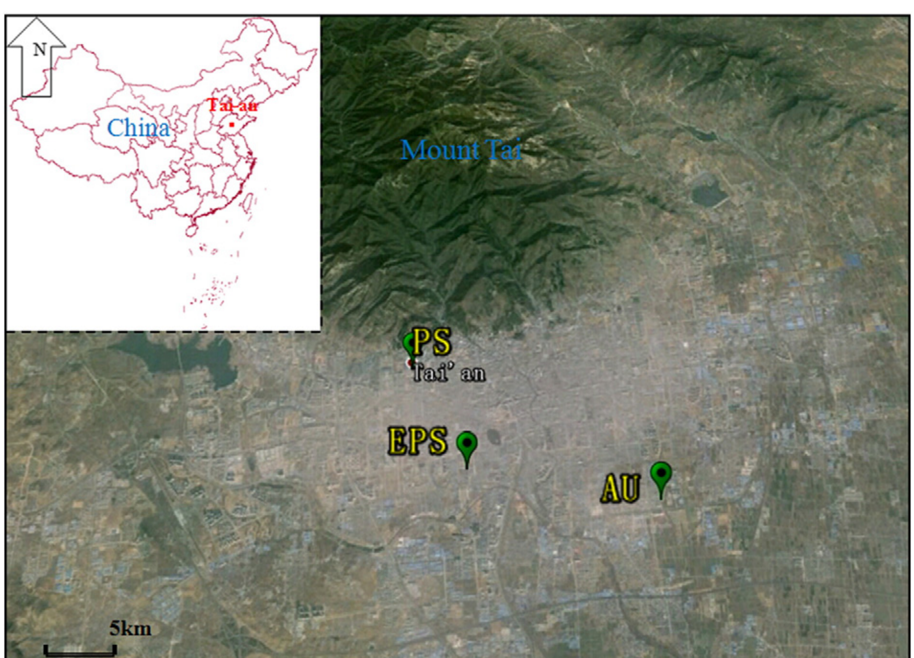

Fig. 1. Location of the sampling sites in Taian, China. Agricultural University (AU) represents a mixed industrial and heavy traffic area, Electric Power School (EPS) represents a mixed commercial and traffic area, Population School (PS) represents a residential and traffic area.