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Review

Review of receptor-based source apportionment research of fine particulate matter and its challenges in China

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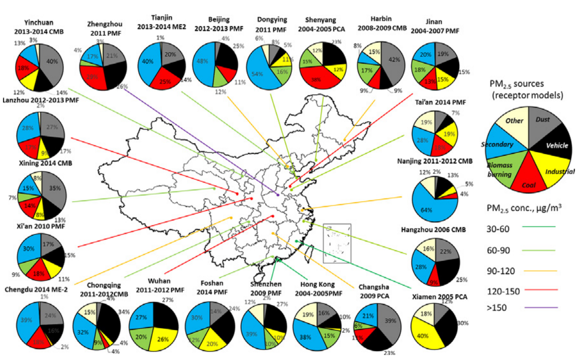
HIGHLIGHTS

- Spatial distribution of chemical speciation, sources and source profiles in China are summarized.
- In the south, contributions of secondary and traffic sources are higher while coal and dust are lower.
- Future research needs for source apportionment in China are proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

As the key for haze control, atmospheric fine particulate matter with aerodynamic diameter <2.5 μm (or $PM_{2.5}$) is of great concern lately in China. It is closely linked to fast pace of urbanization, industrialization and economic development, especially in eastern China. A good understanding of its sources is required for effective pollution abatement. Receptor models are one of the major methods for source apportionment used in China. The major objective of this study is to understand sources that contribute to fine particulate matter in China and key challenges in this area. Spatial distribution of fine particulate matter concentration, chemical composition and dominant sources in North and South China are summarized. Based on chemical speciation results from 31 cities and source apportionment results from 21 cities, it is found that secondary sources and traffic emission have higher contribution in South China while the percentage of coal combustion, dust and biomass burning to total $PM_{2.5}$ are higher in North China. Source profiles established in China from 44 cities and areas are also summarized as references for future source apportionment studies. Suggestions for future research are also provided including methods for evaluating source apportionment results, ways for integrating multiple source apportionment methods, the need for standardizing protocols and developing tools for high-time resolution source apportionment.

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Contents

1. Introduction

With fast development and expansion of industrialization, urbanization and economy, China has been experiencing severe air pollution problems in the past decades. For example, the series of episodes in January 2013 affected more than ten provinces and cities and over one million km^2 area in central and eastern China, posing great threat to climate change and human health (Yang et al., 2014). It is estimated that episodes in January 2013 can cause 690 premature deaths, 45,350 acute bronchitis and 23,720 asthma cases with 95% confidence interval in Beijing area and the economic loss is assessed to be over 250 million US$ (Gao et al., 2015b). Recent studies report that >5 million people in the world suffer from premature death due to indoor and outdoor air pollution and China and India account for half of the deaths (Brauer et al., 2016; Forouzanfar et al., 2015).

$PM_{2.5}$ is strongly correlated with low visibility and severe air pollution. As a mixture of both primary (directly from emissions) and secondary compositions (formed through processes in the atmosphere), including ions, metals, organic matter and elemental carbon and so on, $PM_{2.5}$ has complicated sources. A clear understanding of the major sources is the first step for establishing air pollution control strategies.

To understand sources, emission inventory, source-oriented methods (three-dimensional air quality models), and receptor models are three major techniques for source apportionment, of which the latter is the most widely applied in $PM_{2.5}$ source apportionment research in China (Zheng et al., 2014). Major types of receptor models include chemical mass balance (CMB), positive matrix factorization (PMF), principle component analysis (PCA), and UNMIX (a multivariate receptor model) and so on. More details of the source apportionment methods applied in China and the comparison of the performances between different source apportionment methods can be found in previous studies (Zhang et al., 2015b; Zheng et al., 2014). Numerous studies of $PM_{2.5}$ source apportionment based on receptor models have been conducted in China by different research groups in different cities (Cui et al., 2015; Fu et al., 2015; Fu et al., 2014; Gao et al., 2012; Gao et al., 2013; Gao et al., 2015a; Guo et al., 2009; Guo et al., 2013; Liu et al., 2014; Qiu et al., 2016; So et al., 2007; Sun et al., 2015; Wang et al., 2016a, b, c; Zheng et al., 2005). A comprehensive evaluation of $PM_{2.5}$ sources in China is of great help for a better knowledge of spatial diversity of fine particulate pollution in China and for policy-makers to develop effective air pollution control measurements in specific areas of China. This review aims to identify $PM_{2.5}$ sources in China by synthesizing results from published literature and to propose future research directions in $PM_{2.5}$ source apportionment in China.

2. Source apportionment results using receptor models in China

2.1. Chemical compositions of fine particulate matters in China

Studies on $PM_{2.5}$ in China started in the late 20th century and it has been increasing especially in the most recent decade. There are a few studies focusing on review of $PM_{2.5}$ characteristics in China. For example, Zhang and Friedlander summarize elemental composition of fine particulate matter in China during 1980–1993 (Zhang and Friedlander, 2000). Chan and Yao publish an overview of air pollution in China and provide a detailed comparison among Beijing, Shanghai and Pearl River Delta (Chan and Yao, 2008). Yang et al. present $PM_{2.5}$ composition in 16 locations across China during 1999–2007 (Yang et al., 2011). Based on more recent publications, this review summarizes chemical composition of $PM_{2.5}$ in China during 2005–2014, as shown in Figs. 1 and 2, to provide a more complete picture of spatial distribution of $PM_{2.5}$ speciation all over China. Only measurements covering four seasons with bulk composition are included in this summary. Fig. 1 only contains four chemical components including organic matter, elemental carbon, crustal materials, and the sum of sulfate, nitrate and ammonium (SNA) under different $PM_{2.5}$ concentration level (e.g., <30 μg/m^3, 30–60 μg/m^3, 60–90 μg/m^3, 90–120 μg/m^3, >120 μg/m^3). The data for Fig. 2 is the same as Fig. 1, but it shows more details with the information of relative contribution from sulfate, nitrate and ammonium to $PM_{2.5}$ all over China, expect for cities that only provide the sum of SNA.

From recent peer-reviewed publications, Fig. 1 summarizes chemical composition in $PM_{2.5}$ all over China during 2005–2014, with 28 urban cities and 3 background cities (Waliguan, Qinghaihu and Jianfengling). Chemical components of $PM_{2.5}$ include sulfate, nitrate, ammonium, organic matter, elemental carbon, crustal materials and others. Organic matter is converted from organic carbon by a factor of 1.6 (Chan et al., 2010). Crustal materials are calculated by [Crustal materials] $= 2.20 * [Al] + 2.49 * [Si] + 1.63 * [Ca] + 1.42 * [Fe] + 1.94 * [Ti]$ (Yao et al., 2016).

The annual averages of $PM_{2.5}$ concentrations in the above cities of China are in the range of 13–152 μg/m^3, about 12-fold difference across the nation. The color of lines in Fig. 1 indicates $PM_{2.5}$ concentration in each city or study site. As shown in Fig. 1, cities in northern and western area have higher annual $PM_{2.5}$ concentration. Relatively low concentrations usually occur in the southern coastal areas and background areas. Geographically, China can be divided into North China and South China by Qinling Mountain and Huai River, located in the area of 104°15′ E–120°21′ E and 32°18′ N–34°05′ N (http://baike.baidu.com). The average annual concentrations are 122 ± 42 μg/m^3, 75 ± 31 μg/m^3 and 23 ±

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