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Seasonal trends, chemical speciation and source apportionment of fine PM in Tehran

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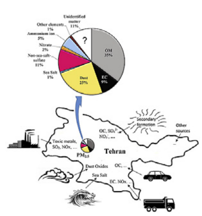
HIGHLIGHTS

- Identified and quantified $PM_{2.5}$ components and their seasonal variations in Tehran.
- Major $PM_{2.5}$ mass components found to be organic matter, dust and sulfate.
- Factors dominated by dust oxides and toxic metals explained ~70% of $PM_{2.5}$ variances.
- Dust contribution to $PM_{2.5}$ reached up to 56% in summer, while min = 7% in winter.
- Contrary to dust oxides trend, toxic metals increased significantly in cold season.

GRAPHICAL ABSTRACT



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ABSTRACT

Frequent air pollution episodes have been reported for Tehran, Iran, mainly because of critically high levels of fine particulate matter ($PM_{2.5}$). The composition and sources of these particles are poorly known, so this study aims to identify the major components and heavy metals in $PM_{2.5}$ along with their seasonal trends and associated sources. 24-hour $PM_{2.5}$ samples were collected at a main residential station every 6 days for a full year from February 2014 to February 2015. The samples were analyzed for ions, organic carbon (including water-soluble and insoluble portions), elemental carbon (EC), and all detectable elements. The dominant mass components, which were determined by means of chemical mass closure, were organic matter (35%), dust (25%), non-sea salt sulfate (11%), EC (9%), ammonium (5%), and nitrate (2%). Organic matter and EC together comprised 44% of fine PM on average (increased to >70% in the colder season), which reflects the significance of anthropogenic urban sources (i.e. vehicles). The contributions of different components varied considerably throughout the year, particularly the dust component that varied from 7% in the cold season to 56% in the hot and dry season. Principal component analyses were applied, resulting in 5 major source factors that explained 85% of the variance in fine PM. Factor 1, representing soil dust, explained 53%; Factor 2 denotes heavy metals mainly found in industrial sources and accounted for 18%; and rest of factors, mainly representing combustion sources, explained 14% of the variation. The levels of major heavy metals were further evaluated, and their trends showed considerable increases during cold seasons. The results of this study provide useful insight to fine PM in Tehran, which could help in identifying their health effects and sources, and also adopting effective control strategies.

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1. Introduction

Airborne fine particulate matter, or particles with aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$), cause profound adverse health effects, such as cardiovascular and respiratory disease, and environmental impacts, such as reducing visibility and affecting climate and ecosystems (Dye et al., 2001; Ghio and Devlin, 2001; McClellan, 2002; Pope and Dockery, 2006; Schwartz, 1994; Wu et al., 2004). Particles from different sources vary widely in their chemical compositions and impose different levels of toxicity, adverse health effects, and environmental impacts (Delfino et al., 2008, 2010; Peters et al., 2004). Several particulate components, such as highly heavy metals (e.g. zinc, copper, chromium, and vanadium), can contribute to oxidative DNA damage that consequently causes carcinogenic outcomes (Dreher et al., 1997; International Agency for Research on Cancer, 2009; Somers, 2011). Carbonaceous contents of particles consisting of elemental carbon (EC) and organic carbon (OC) make important, but deficiently understood, contributions to PM by instigating major adverse health outcomes, including cardiovascular impacts (Chow and Watson, 2002; Ostro et al., 2008; Urch et al., 2004). On the other hand, the fraction originating from soil is thought to be relatively harmless; however, re-suspended soil may be contaminated with other toxic components. A number of studies have been conducted to investigate the content of aerosols in different environments and determine the significance of each component regarding health and environmental impacts (Delfino et al., 2008, 2010; Li et al., 2003; Oberdörster, 2000; Peters et al., 2004). Moreover, different approaches, such as receptor modeling (e.g. chemical mass balance [CMB] and principal component analysis [PCA]), have been widely used in several previous studies to link chemical composition to source contributions (Bae et al., 2006; Givehchi et al., 2013; Jaeckels et al., 2007; Schauer and Cass, 2000; Schauer et al., 1996; Shahsavani et al., 2012; Sheesley et al., 2005, 2007). However, due to the complexity and variability of airborne PM properties, associating their chemical composition to health effects and sources in different environments is a challenging endeavor, and more studies are still required. Such information is extremely helpful to plan effective counter measurements and strategies to control particulate pollution, which generally require implementing long-term and budget-intensive projects. Despite the evident importance of characterizing PM components, information about chemical composition and sources is quite sparse for polluted urban environments of developing countries (Givehchi et al., 2013).

Iran's capital, Tehran, is home to over 8 million residents (Iran Census, 2011) who frequently face episodes of critically high pollutant levels (Arhami et al., 2014). Currently, fine particulate matter is the main cause of critical air pollution episodes in Tehran, as it has exceeded Iranian national ambient air quality standards (which are based on WHO guidelines) more than one-third of the days during recent years (WHO, 2006). The large number of vehicles are the main pollutant sources in Tehran (Shahbazi et al., 2016). The majority of vehicles are light duty gasoline vehicles, including a portion of highly polluting and old vehicles. The fleet also includes diesel vehicles such as minibuses, buses, and trucks which are generally more polluting compared to gasoline vehicles (Shahbazi et al., 2016). Tehran's light duty vehicles fleet with average age of about 6 years has experienced significant growth (Askariyeh and Arhami, 2013). Pollutants are also emitted from nearby industries, as almost half the country's industrial activity is placed in the vicinity of the city (Askariyeh and Arhami, 2013; Yazdi et al., 2015). In addition to urban and industrial sources, Tehran is subject to dust-originated PM from local deserts and regional dust storms (Ashrafi et al., 2014; Shahsavani et al., 2012), as it is located in the Middle East which is part of the world's dust belt (Ghotbi et al., 2016; Kamali et al., 2015; Sotoudeheian and Arhami, 2014). The tall mountain chains surrounding the city and frequent temperature inversions trap stagnant polluted air in the city; these topographical conditions together with abundant PM sources aggravate pollution episodes (Arhami et al., 2014; Kamali et al., 2015). Despite the significance of the problem, sufficient information on fine PM chemical composition, its sources, and relative contributions is not yet available.

The main focus of this study is to characterize chemical components of $PM_{2.5}$ and assess the major source categories in Tehran. To do this, daily $PM_{2.5}$ samples were collected at a main residential station in Tehran every 6 days throughout an entire year from February 2014 to February 2015. The samples were analyzed for ions (including water-soluble ions), organic (including water-soluble and insoluble portions) and elemental carbon, and all detectable elements. Major mass components of fine PM, such as organic and dust-originated components, were identified by chemical mass closure. The crustal-originated and heavy metals and their links to sources were assessed. Finally, principal component analyses (PCA) were applied using several components to quantify source contributions to $PM_{2.5}$. The insights regarding fine PM in Tehran provided by the results of this study, could be useful in identifying their health effects and planning effective control strategies.

2. Methodology

2.1. Sampling campaign

24-h $PM_{2.5}$ samples were collected at a main residential station in Tehran every 6 days for a full year from February 2014 to February 2015. The sampling station was set up on the roof of an air quality station at the Sharif University of Technology campus in a central-west part of Tehran (35.7° N and 51.4° E). This air quality station, which is a part of Tehran's air quality station network operated by Air Quality Company, recorded measurements for the following hourly criteria pollutants during the study period: PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, and O_3. The selected sampling site is a regulatory site that is used and referenced by the government of Tehran to assess air pollution in the greater Tehran metropolitan areas. This site is located in a residential area nearby a major street (Azadi) and several local streets in western/central part of the city. This area is a typical residential area in Tehran, being affected by a mixture of common urban sources, such as vehicles, road dust re-suspension, residential building, local commercial/industrial emissions, and construction activities. Thus, the selected site is a good representative of a general residential location in urban areas of Tehran.

Two sets of samples were collected concurrently on quartz fiber (47 mm diameter, Whatman Inc.) and Teflon filters (47 mm diameter, PTFE Teflon, Pall Life Science) using two low-volume ambient air samplers (PQ200 by BGI, Inc., USA). The samplers were operated at flow rate of 16.7 lpm and equipped with a volumetric sample flowrate control; the mean flow rate throughout the sampling period was used to calculate the volume of the sampled air. Quartz filters were baked before sampling at 550 °C for at least 12 h and stored before and after sampling in pre-baked foil. Field blanks were collected for every 10–15 sets of samples. All collected samples were placed and sealed in polystyrene Petri dishes and stored frozen before analysis in order to prevent evaporation of volatile components.

The results are based on the data obtained from analyzing samples collected at the sampling station. Hence, the results reflect the composition, properties and sources of fine PM at this station. Since this site is located in a typical residential urban area so it is