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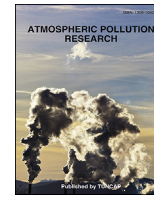

Original Article

The characteristics of environmental particulate matter in the urban area of Beijing, China, during the 2008 Olympic Games

Qingqing Qiao [a, c, *], Baochun Huang [b], John D.A. Piper [c], Andrew J. Biggin [c], Chunxia Zhang [d]

[a] *Xinjiang Research Center for Mineral Resources, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China*
[b] *Key Laboratory of Orogenic Belt and Crustal Evolution, Ministry of Education, School of Earth and Space Science, Peking University, Beijing 100871, China*
[c] *Geomagnetism Laboratory, Department of Earth, Ocean and Ecological Sciences, University of Liverpool, Liverpool L69 7ZE, UK*
[d] *Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China*

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ABSTRACT

Atmospheric particulate matter (PM) and street dust samples from the Chaoyang District of eastern Beijing were studied over a period encompassing the 2008 Beijing Olympic Games. PM_{10} concentration data are combined with trajectory clustering and potential source contribution function (PSCF) methods to identify the principal transport pathways. Sources for high-concentration aerosol events and airflow from the surrounding Hebei Province and Shandong Province to the southeast are found to exert the most significant external influence on Beijing's air quality. China undertook a number of initiatives to improve air quality for the Olympic Games and we show that PM_{10} concentrations and magnetic susceptibility were significantly lower during the Olympic period compared to the pre-Olympic period confirming that controlling local sources in Beijing and shutting factories in surrounding provinces substantially improved air quality. On short timescales PM_{10} shows an inverse correlation to relative humidity and hence precipitation which acts to improve air quality. Atmospheric PM and street dust remained high through the Olympic period probably due in part to redistribution of historical sources and implying that the aim of zero pollution is not achievable in the short term. Analysis of the heavy metal content in both PM and street dust identifies consistently high values of Zn, with Pb relatively higher in the PM; a primary source in vehicular emissions therefore seems likely.

1. Introduction

Particulate matter (PM) in the atmosphere and in ground deposits can originate from natural sources (dust blown into the air by wind, salts splashed into the air by sea spray and soot from volcanoes and forest fires) and from various anthropogenic activities of which the biggest sources are vehicle and smokestack emissions, and the creation of dust generated when vegetation has been removed for construction or grazing purposes. When averaged globally, anthropogenic PM appears to account for about 10% of the total aerosol amount (Perrino, 2010) but this figure varies greatly from place to place as do the chemical compositions and inferred sources. PM can vary in size from sub-micron aerosols to visible dust particles: the coarse particles rapidly removed from the air by sedimentation are of local impact only, whereas fine particles can have a global reach (Perrino, 2010). Urban surfaces typically receive fine PM issued from remote sources through atmospheric transport as well as a wider range of particle sizes from local human activities (Harrison et al., 1981; Thornton, 1991). Street dust can also be easily re-suspended back into the atmospheric aerosol by wind (Wise and Comrie, 2005) or vehicle movement (Almeida et al., 2006). Analysis is therefore complex but the integrated data from studies of PM in street dust nevertheless provides the essential basis for understanding atmospheric pollution and assessing effects on human health (e.g. Hien et al., 1999).

PM typically contains magnetic particles characterized by stable and intense magnetic properties (Maher et al., 1999) with this

* Corresponding author. Xinjiang Research Center for Mineral Resources, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Beijing South Road 818, Urumqi 830011, China.
E-mail address: qiaoqq@ms.xjb.ac.cn (Q. Qiao).
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magnetic fraction linked closely to heavy metals such as zinc, cadmium and chrome (Georgeaud et al., 1997) but also to mutagenic organic compounds (Morris et al., 1995), all of which are dangerous to human health. Thus magnetic properties provide valuable proxies for deducing the origin of PM and because of their control by the above factors they become a convenient signature of air pollution (Qiao et al., 2013). Routinely-measureable magnetic parameters provide information on the concentration, domain state (or indirectly the magnetic grain size), and mineralogy of magnetic particles and collectively these are related to original geological or subsequent environmental processes (Liu et al., 2012). Statistical methods such as trajectory clustering have been widely used to identify the pathways and sources of air pollution (e.g. Ashbaugh, 1983; Sirois and Bottenheim, 1995; Wang et al., 2006; Borge et al., 2007). In the present investigation we study magnetic susceptibility in atmospheric fallout samples and apply statistical clustering technique to a 5-month dataset of atmospheric trajectories to identify the particulate matter sources and long-range transport patterns that can influence air pollution.

The 29th Olympic and Para-Olympic Games were held between 2008 August 8 and September 17, in Beijing, a densely populated city with more than 16 million residents and 3 million motor vehicles. Traffic congestion and air pollution thus presented two major challenges to the organizers of the games. To improve air quality and control traffic a series of measures were implemented which included the relocation of industrial plants with large emissions outside of the city and the implementation of new standards to reduce vehicular emission and limit their use. Domestic controls included a progressive switching to clean fuels and low-sulfur coal for household use before and during the Olympic period (Li et al., 2010; Zhou et al., 2010). Whilst most of these measures were intended to have a lasting effect, the vehicular restrictions were largely temporary in nature and are therefore expected to be detectable for only a limited time period. This research evaluating the impact of these air pollution control measures is therefore classified as "before", "during" and "after" the Games. The present study has had two objectives: firstly we have aimed to determine the source regions influencing the air in Beijing in order that effective source control strategies can be put into place in the longer term; secondly, we have sought to evaluate the relationship between atmospheric PM and street dust. It is well known that the re-suspension of road dust particles from urban street surfaces is an important source of atmospheric PM pollution (Amato et al., 2009; Martuzevicius et al., 2011; Zhao et al., 2016), and the measurement of atmospheric deposits on street surfaces can be useful for studying deposition over a longer time intervals.

2. Experimental section

2.1. Sample collection

Atmospheric PM was determined by the gravimetric method at monthly intervals from June 2008 to March 2009 in the Chaoyang Distinct of eastern Beijing. The PM samples were collected in 15 × 30 cm cylindrical glass vessels containing glycol and the vessels placed on a 1.5 m sampling frame. PM samples were collected at two sampling sites: the first was a residential location at Sanlitun (SLT) near the Chaoyang Park (CY) containing the Olympic Site and the second was an industrial site, Fatou (FT) located near the Jing-Shen Highway. The Olympic Park is located at the northwestern sector of Chaoyang district (Fig. 1), and street dust samples were collected on roads with different traffic densities or pavements around the Olympic Park between November 2007 and October 2008. The sampling sites were selected from the traffic avenue and forest park inside the Olympic Park (AT) near to the north 5th ring road (Fig. 1) with samples collected using a nylon brush and non-magnetic scoop from squares 0.5–1 m^2 in area prior to transfer to clean, self-sealing polyethylene bags. To evaluate the relationship between PM and street dust over the interval of enforcement measures, the samples were selected for analysis between June 2008 and October 2008. The details of sampling sites and methods are described in Qiao et al. (2011a, b).

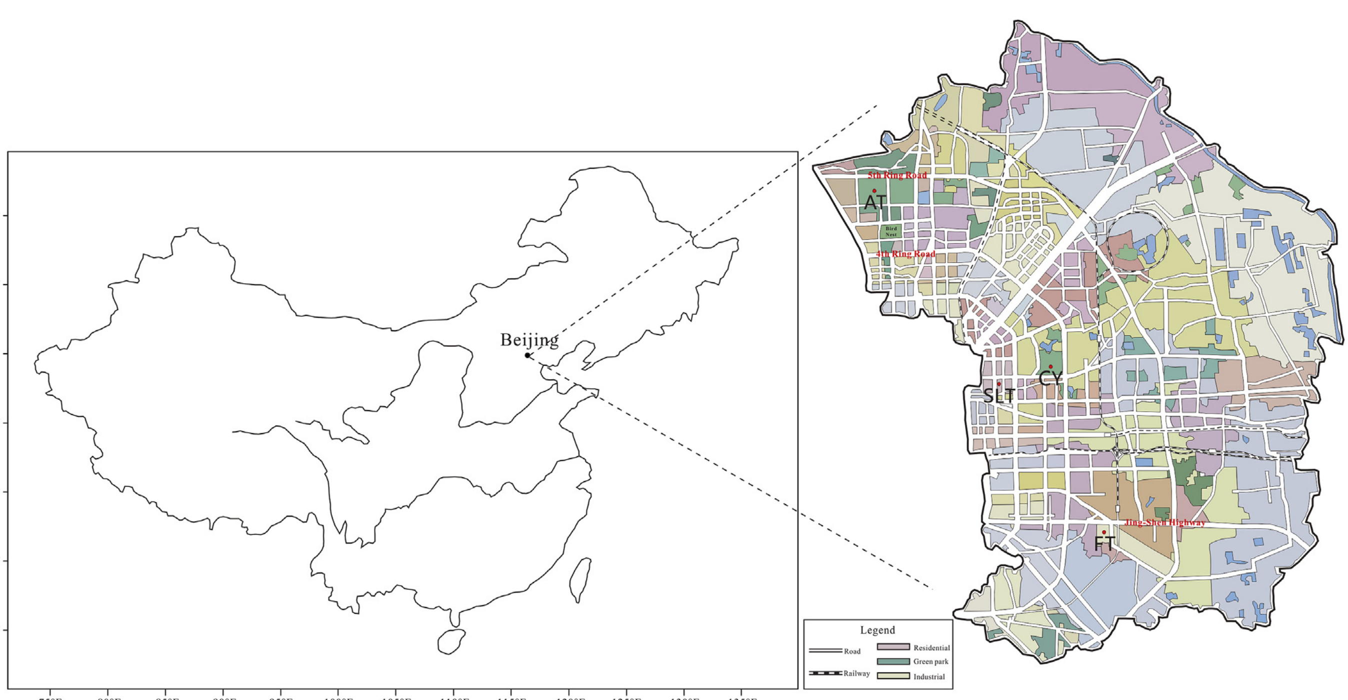

Fig. 1. Schematic map of the study area showing sampling locations of atmospheric PM and street dust.

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