Trend of PM$_{2.5}$ concentration in urban Beijing from 2000–2010

Shaojie Song, song33@mit.edu, Massachusetts Institute of Technology, Cambridge, MA, USA

Abstract

Long-term trend of PM$_{2.5}$ mass concentrations in the urban areas of Beijing during 2000–2010 is studied. Quality-controlled measurement data from scientific publications showed a significant decreasing trend of -1.5 (95% confidence interval: [-2.6, -0.3]) μg m$^{-3}$ a$^{-1}$. This corresponded to a 19% decrease of PM$_{2.5}$ in 2000–2010, smaller than those of PM$_{10}$ (27%), NO$_2$ (31%), and SO$_2$ (57%), suggesting that previous efforts of improving Beijing’s air quality are less effective for PM$_{2.5}$. The divergence between our fitted PM$_{2.5}$ concentration and recently released official data was mainly attributed to different instrument systems. It is a tremendous challenge for Beijing to achieve air quality goal in 2013-2017 (about 6 μg m$^{-3}$ decrease of PM$_{2.5}$ per year).

Keywords: PM$_{2.5}$; Particulate matter; Beijing; Air quality; TEOM

1. Introduction

Fine particulate matter (particles with diameter < 2.5 μm; PM$_{2.5}$) has strong impacts on global climate, human health, and atmospheric visibility (Jacobson, 2001; Schichtel et al., 2001; Kampa and Castanas, 2008). Therefore, many countries and regions have set limit values for its concentration in ambient air (Kulshrestha et al., 2009; Friend et al., 2011). China passed its first National Ambient Air Quality Standard (NAAQS) for PM$_{2.5}$ in 2012 and has recently begun to incorporate it into routine monitoring of air pollutants (Cao et al., 2013). Beijing is the capital of China and is also known for its poor air quality (Chan and Yao, 2008). The continuous increase in fossil fuel consumption as a result of rapid economic development and population growth may have, to a large extent, offset past efforts to mitigate air pollution in this megacity (Wu et al., 2010; Wang and Hao, 2012).
The knowledge of historical trend of PM$_{2.5}$ concentration is valuable because it can be used to evaluate the effectiveness of past control measures and provides insights into air quality management in the future as well. In this paper I attempt the first reconstruction of the trend of PM$_{2.5}$ from the available measurements of known quality in scientific publications, due to the lack of historical official data in Beijing. The first year-long monitoring of PM$_{2.5}$ in Beijing was conducted around 2000 (He et al., 2001), and the trend of PM$_{2.5}$ from 2000–2010 is studied.

2. Experimental

2.1 Measurement methods

Techniques for measuring PM concentration in ambient air include manual and automated ones (Chow, 1995). The manual method is to acquire deposits over a certain time period on filters from air drawn at a controlled flow rate. Teflon filters are widely used for the purpose of PM mass determination due to high insensitivity to humidity during the weighing procedure (Perrino et al., 2013). Quartz fiber filters are less suitable for such a purpose because they are brittle and may lose filter material during sampling and analysis (Hueglin et al., 2005). Thus this paper does not include studies using quartz fiber filters to collect PM$_{2.5}$ (Zhao et al., 2013).

The Tapered Element Oscillating Microbalance (TEOM, model 1400A, Rupprecht and Patashnick Co. Inc., USA) (Patashnick and Rupprecht, 1991) is a widely accepted method for automatically monitoring PM mass concentration at fixed urban stations. In the TEOM 1400A, particles pass through a filter connected to a vibrating hollow tapered glass tube. As particles are deposited on the filter, the vibration frequency of the tube becomes smaller. A microprocessor converts the vibration frequency into mass concentration. The sample stream is preheated to 50 °C to avoid variations in the microbalance response owing to temperature fluctuations and to eliminate the effect of water droplets (Ayers et al., 1999).
2.2 Monitoring sites

As shown in Table 1, data set used for reconstructing the trend of PM$_{2.5}$ concentration was collected at eight monitoring sites in the urban areas of Beijing. Locations of these sites are plotted in Figure 1. At THU and CGZ, low flow rate samplers (Aerosol Dynamics Inc., USA) were used to collect one week integrated PM$_{2.5}$ samples with Teflon filters. PM$_{2.5}$ mass on the Teflon filters was then obtained by gravimetric analysis after stabilizing under controlled temperature (20±5 °C) and relative humidity (40±5%) (He et al., 2012). All other sites automatically measured concentrations of PM$_{2.5}$ using the TEOM 1400A.

Table 1. Details of PM$_{2.5}$ mass concentration measurements in urban Beijing

<table>
<thead>
<tr>
<th>code</th>
<th>site location</th>
<th>time period</th>
<th>method</th>
<th>references</th>
</tr>
</thead>
<tbody>
<tr>
<td>THU</td>
<td>Tsinghua University</td>
<td>Sep 1999-Sep 2002, Mar 2005-Feb 2006, 2008</td>
<td>Teflon filter sampling</td>
<td>Yang et al. (2002); Duan et al. (2006); Yang et al. (2011); He et al. (2012)</td>
</tr>
<tr>
<td>CGZ</td>
<td>Chegongzhuang</td>
<td>Sep 1999-Sep 2002</td>
<td>Teflon filter sampling</td>
<td>Yang et al. (2002); Duan et al. (2006)</td>
</tr>
<tr>
<td>BSP</td>
<td>Baolian Sports Park</td>
<td>2005-2010</td>
<td>TEOM 1400A</td>
<td>Zhao et al. (2009); Zhao et al. (2011); Hu et al. (2013); Liu et al. (2014)</td>
</tr>
<tr>
<td>IAP</td>
<td>Institute of Atmospheric Physics, Chinese Academy of Sciences</td>
<td>2005-2010</td>
<td>TEOM 1400A</td>
<td>Liu et al. (2014)</td>
</tr>
<tr>
<td>BNU</td>
<td>Beijing Normal University</td>
<td>2009-2010</td>
<td>TEOM 1400A</td>
<td>Li et al. (2011); Yu et al. (2013)</td>
</tr>
<tr>
<td>TBG</td>
<td>Teaching Botanical Garden</td>
<td>2009-2010</td>
<td>TEOM 1400A</td>
<td>Wang et al. (2012)</td>
</tr>
<tr>
<td>EES</td>
<td>Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences</td>
<td>2008</td>
<td>TEOM 1400A</td>
<td>Wang et al. (2012)</td>
</tr>
<tr>
<td>BDA</td>
<td>Beijing Dance Academy</td>
<td>2003</td>
<td>TEOM 1400A</td>
<td>Xu et al. (2007)</td>
</tr>
</tbody>
</table>
2.3 Data quality and comparability

Discontinuous measurements (e.g. one month per season) of PM$_{2.5}$ cannot be used to derive annual average because it is strongly affected by meteorological conditions, and thus only continuous monitoring data are used to ensure good data quality. As described above, two monitoring sites (THU and CGZ) used Teflon filter sampling and the others used the TEOM 1400A. Collocated measurements with the TEOM 1400A and Teflon filter sampling showed systematically lower PM$_{2.5}$ concentrations from the TEOM 1400A by 10-50% (Allen et al., 1997; Ayers et al., 1999; Charron et al., 2004). This divergence is primarily a result of different temperatures in the TEOM 1400A and filter sampling/weighing. The loss of semi-volatile aerosol very likely occurs from the heated filter in the TEOM 1400A (Tortajada-Genaro and Borras, 2011). PM$_{2.5}$ concentrations from BSP and IAP (using the TEOM 1400A) were 32% and 37% lower than those from THU (using Teflon filter sampling) in 2005 and 2008, respectively.
In order to correct the systematic bias between the two techniques, PM$_{2.5}$ concentrations at THU and CGZ are reduced by 30% and denoted as THU$_{\text{low}}$ and CGZ$_{\text{low}}$.

3. Results and discussion

Figure 2 summarizes annual mean concentrations of PM$_{2.5}$ measured at eight monitoring sites in urban Beijing from 2000 to 2010. Note that all PM$_{2.5}$ data are normalized to levels of the TEOM 1400A and, therefore, are comparable. A least-square regression of PM$_{2.5}$ concentrations showed a significant decreasing trend of -1.5 μg m$^{-3}$ a$^{-1}$ ($n = 26$), with the 95% confidence interval of [-2.6, -0.3] μg m$^{-3}$ a$^{-1}$. Starting from about 80 μg m$^{-3}$ in 2000, the trend of -1.5 μg m$^{-3}$ a$^{-1}$ leads to a decline of 15 μg m$^{-3}$ until 2010, i.e., a decline of 19% in this ten-year period.

![Image](image_url)

**Figure 2.** Annual means of PM$_{2.5}$ concentrations measured at eight monitoring sites in urban Beijing from 2000–2010. The slope is from the least-square regression of PM$_{2.5}$ concentrations.

As indicators of urban air pollution, PM$_{10}$ (particles with diameter < 10 μm), NO$_2$, and SO$_2$ have been routinely monitored at fixed stations by Beijing Environmental Protection Bureau (BJEPB) since the 1990s (Beijing Environmental Protection Bureau, 1996-2013), and all of them showed significant decreasing trends from 2000–2010 (see Figure 3). In this ten-year period, concentrations of PM$_{10}$, NO$_2$, and SO$_2$ were reduced by 27%, 31%, and 57%, respectively. This more than 50% decline of SO$_2$ was largely attributed to energy structure adjustment and
extensive application of flue gas desulfurization (FGD) devices in power plants and industry (Hao et al., 2007). Although total energy demand was increasing, coal consumption in Beijing remained in 25–30 Tg a\(^{-1}\) during 2000–2010. Because denitrification had not become mandatory targets by 2010, as well as contribution from increasing motor vehicles, the reduction rate of NO\(_2\) was lower than that of SO\(_2\). The trend of PM\(_{10}\) (-4.4 µg m\(^{-3}\) a\(^{-1}\)) was about 3 times that of PM\(_{2.5}\) (-1.5 µg m\(^{-3}\) a\(^{-1}\)) calculated in this study. Given that PM\(_{2.5}\) accounts for > 50% in PM\(_{10}\) mass in urban Beijing’s atmosphere (Zhang et al., 2010), this result implies that emission control measures during this time period were more effective for coarse particles (PM\(_{10-2.5}\)) than for fine particles (PM\(_{2.5}\)).

**Figure 3.** Annual means of concentrations of PM\(_{10}\), NO\(_2\), and SO\(_2\) at routine monitoring stations of Beijing and their temporal trends from 2000−2010.

By 2013, BJEPB has built a citywide monitoring network including 35 stations and began to release official PM\(_{2.5}\) data. For that year, annual mean of PM\(_{2.5}\) concentrations in Beijing was 90 µg m\(^{-3}\) (Beijing Environmental Protection Bureau, 1996-2013). For comparison, PM\(_{2.5}\) concentration derived from the linear-regression of previous measurement studies was only 65 µg m\(^{-3}\) in 2010, about 30% lower than this recently released data. We attribute this discrepancy
mainly to different instrumentation systems. All TEOM instruments used by BJEPB were equipped with the filter dynamic measurement systems (FDMS) in order to compensate for the loss of semi-volatile aerosols due to high temperature (50 °C). However, the TEOM 1400A used by these studies did not install FDMS. Collocated measurements using the TEOM 1400A and TEOM-FDMS have indicated that the former instrument underestimated PM$_{2.5}$ mass concentrations by 10–50% (Favez et al., 2007; Sciare et al., 2007).

In its five-year Clean Air Action Plan (2013-2017), the Beijing Municipal Government promised to reduce PM$_{2.5}$ concentration in the urban areas by 30% or more, i.e., from about 90 to < 60 μg m$^{-3}$. This means a need to reduce PM$_{2.5}$ by a future trend of -6 μg m$^{-3}$ a$^{-1}$. Comparing it with the historical trend of -1.5 μg m$^{-3}$ a$^{-1}$, it will be a tremendous challenge to achieve this goal.

References


