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Estimation of daily $PM_{2.5}$ concentration and its relationship with meteorological conditions in Beijing

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ABSTRACT

When investigating the impact of air pollution on health, particulate matter less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$) is considered more harmful than particulates of other sizes. Therefore, studies of $PM_{2.5}$ have attracted more attention. Beijing, the capital of China, is notorious for its serious air pollution problem, an issue which has been of great concern to the residents, government, and related institutes for decades. However, in China, significantly less time has been devoted to observing $PM_{2.5}$ than for PM_{10}. Especially before 2013, the density of the $PM_{2.5}$ ground observation network was relatively low, and the distribution of observation stations was uneven. One solution is to estimate $PM_{2.5}$ concentrations from the existing data on PM_{10}. In the present study, by analyzing the relationship between the concentrations of $PM_{2.5}$ and PM_{10}, and the meteorological conditions for each season in Beijing from 2008 to 2014, a U-shaped relationship was found between the daily maximum wind speed and the daily PM concentration, including both $PM_{2.5}$ and PM_{10}. That is, the relationship between wind speed and PM concentration is not a simple positive or negative correlation in these wind directions; their relationship has a complex effect, with higher PM at low and high wind than for moderate winds. Additionally, in contrast to previous studies, we found that the $PM_{2.5}/PM_{10}$ ratio is proportional to the mean relative humidity (MRH). According to this relationship, for each season we established a multiple nonlinear regression (MNLR) model to estimate the $PM_{2.5}$ concentrations of the missing periods.

Introduction

With people becoming increasingly keen on healthy living, the levels of atmospheric particulate matter (PM) have received considerable attention. Although the detailed effects of each type of PM on health have not yet been established, epidemiological studies (Ostro et al., 2010; Zhang et al., 2002; Cairncross et al., 2007) have identified a strong exposure–response relationship between PM and both short-term (coughing, sneezing, runny nose, shortness of breath and lung irritation) and long-term health effects (lung cancer, cardiovascular and cardiopulmonary diseases).

PM_{10} is particulate matter of less than 10 μm in aerodynamic diameter. It can penetrate into the air passages of the lungs. Different from PM_{10}, $PM_{2.5}$ is less than 2.5 μm in-aerodynamic diameter. It can reach the deeper alveolar spaces and is more harmful than particulate matter of other sizes (Hossain and Easa, 2012; Fan et al., 2013; Chun et al., 2014; Park and Kim, 2014).

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Moreover, it has been reported that $PM_{2.5}$ can easily penetrate into other organs, and its removal takes longer. Thus, within the research on the health-related effects of air pollution, $PM_{2.5}$ has attracted widespread attention.

Air pollution has long been a serious problem in China, especially in eastern areas such as the Yangtze River Delta, southern areas such as the Pearl River Delta (Wang and Christopher, 2003) as well as in the Jing-Jin-Ji (Beijing, Tianjin and Hebei provinces) region (Xu et al., 2005; Ding et al., 2008; Zhang et al., 2013). Beijing, the capital of China, has a large population and high energy consumption, both of which have led to serious air pollution. The weather in Beijing is typical of a temperate monsoon climate: summers are hot and rainy, while winters are cold and dry. Particulates in Beijing are very complicated in terms of sources, pollution characteristics, and their effects on the environment and health. Among these particulates, $PM_{2.5}$ is one of the main air pollutants, and its concentration is extremely high. For example, January 2013 witnessed the most frequent and serious episodes of heavy haze to date, which caused consternation among the public (Che et al., 2014; Wang et al., 2014; Zhang et al., 2014). In 2014, Beijing residents suffered seven periods of heavy pollution that lasted more than 3 days, including a week-long period in February.

However, in China the time spent on $PM_{2.5}$ ground observation has been quite short, only about a few years, and the density of the $PM_{2.5}$ ground observation network is relatively low. Moreover, the distribution of observation stations is uneven. Particularly before 2013, information about the concentration of $PM_{2.5}$ in Beijing was not released. The limited number of observation stations meant that the $PM_{2.5}$ characteristics throughout Beijing could not be well established. One solution to this problem is to estimate the $PM_{2.5}$ concentrations using the existing PM_{10} concentration data.

In this respect, the existing research has focused on estimating the concentration of $PM_{2.5}$ based on the aerosol optical depth (AOD), NO_2, SO_2, CO or O_3 concentration (Che et al., 2015; Huo et al., 2011; Zhang et al., 2015; Wang et al., 2013). Furthermore, since $PM_{2.5}$ is a part of PM_{10} (Wang et al., 2006), many researchers of previous studies believed that the $PM_{2.5}$ concentration has a linear relationship with PM_{10} concentration, therefore they conducted a linear regression analysis to estimate $PM_{2.5}$ concentration according to the PM_{10} concentration. In the present study, we first analyzed the relationships between $PM_{2.5}$ and PM_{10}, as well as the meteorological conditions, including mean relative humidity (MRH), sunshine duration, wind speed, and wind direction. Accordingly, we found that the concentrations of $PM_{2.5}$ and PM_{10} are nonlinear with respect to MRH. Secondly, since different seasons have different weather conditions, their influences on PM concentrations are also different. Therefore, according to the above nonlinear relationship, for each season we conducted a multiple nonlinear regression (MNLR) model. Since our PM_{10} concentration data covered an entire seven-year period from 2008/01/01 to 2014/12/31, but the $PM_{2.5}$ data only covered about 4 years and 5 months (from 2010/01/01 to 2014/12/31, with the exception of 2012/05/16 to 2012/12/31), we used the model to estimate the $PM_{2.5}$ concentration data of the missing period. In addition, we analyzed the relationship between the wind speed from different directions and PM concentrations in detail.

1. Materials and methods

1.1. Study area

The study was conducted in Beijing. As shown in Fig. 1, the red area represents the urban region of Beijing and the black dot indicates the location of the observation point.

1.2. Materials

Two datasets were used in the research. The first dataset consisted of hourly observations of $PM_{2.5}$ concentrations at the United States (US) Embassy station from 2010/01/01 to 2014/12/31 (with the exception of 2012/05/16 to 2012/12/31), which were obtained from the website of the Embassy of the United States in China (http://chinese.usembassy-china.org.cn/070109air.html), and the daily mean concentrations of PM_{10} at the same station from 2008/01/01 to 2014/12/31, which were obtained from the website of the Beijing Municipal Environmental Monitoring Center (http://www.bjmemc.com.cn/).

The second dataset consisted of daily meteorological data from 2008/01/01 to 2014/12/31 in Beijing, which was obtained from the website of the China Meteorological Data Sharing Service System (http://cdc.nmic.cn/home.do). The meteorological parameters are listed in Table 1.

1.3. Methods

In this research, some common statistical methods were employed, for example Spearman correlation analyses and an MNLR model which was utilized to fit the $PM_{2.5}$ concentration

Fig. 1 – The study region and the observation point.