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The spatial-temporal characteristics and health impacts of ambient fine particulate matter in China

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A B S T R A C T

Airborne particulate matter presents a serious health threat to human beings, but in China there have until now been few epidemiological studies, especially regarding the impact of ambient fine particulate matter ($PM_{2.5}$). This study explored first the temporal and spatial characteristics of ambient airborne $PM_{2.5}$ in China, 2013. Mortality, respiratory diseases, cardiovascular diseases, and chronic bronchitis were then evaluated as four health endpoints attributed to $PM_{2.5}$. The results showed that the average annual $PM_{2.5}$ concentration was 72.71 μg/m^3; the $PM_{2.5}$ concentration was below 35 μg/m^3 for only 6% of the time, for the whole year. In terms of the $PM_{2.5}$ concentration, January (133.10 μg/m^3) and December (120.19 μg/m^3) were the most polluted months, whereas July (38.76 μg/m^3) and August (41.31 μg/m^3) were the least polluted months. The most highly polluted areas were concentrated in North China. In terms of the health endpoints attributable to $PM_{2.5}$, there were 763,595 mortality, 149,754 cardiovascular diseases, 446,035 respiratory diseases, and 2,389,035 chronic bronchitis cases. Results were very important to clarify the current $PM_{2.5}$ pollution situation and the health impact of $PM_{2.5}$ in China. And also provided a reference for the assessing damage caused by $PM_{2.5}$ pollution.

1. Introduction

Air pollution is a major problem in many big cities all over the world (Yuan et al., 2012; Wang et al., 2013a; Yang et al., 2015), especially in developing countries (Zhang et al., 2013; Chen et al., 2014). Human exposure to high levels of airborne particulate matter (PM) can reduce projected life expectancies by between 1 year (WHO, 2003) and 5.5 years (Chen et al., 2013). Fine particulate matter ($PM_{2.5}$) with a diameter less than 2.5 μm has serious adverse effects on human health (Kampa and Castanas, 2008; Dockery and Pope, 1994; Zhang et al., 2012). Because of its small particle size, $PM_{2.5}$ can reach the lungs and alveolar regions (Kampa and Castanas, 2008), and ultrafine particles (<0.1 μm) can enter the blood vessels (Nemmar et al., 2002). Previous studies showed that there are positive and statistically significant relationships between short-term exposure to $PM_{2.5}$ and cardiovascular and respiratory diseases (Ostro, 2004; Pascal et al., 2014). Moreover, research has shown that there are long-term effects of $PM_{2.5}$ pollution on mortality (Giannadaki et al., 2014; Weichenthal et al., 2014).

In many cities in China, the air quality is poor. According to 2005 data, only 1% of Chinese citizens live in cities where the annual average concentration of PM_{10} (particulate matter with diameter less than 10 μm) is less than 40 μm/m^3 (World Bank, 2007). According to Aaron et al. (2010), the annual average concentration of $PM_{2.5}$ in eastern China in 2010 was more than 80 μm/m^3. China has the largest population in the world (1.36 billion by the end of 2013). There were some studies which have examined the health effects of PM pollution in China (e.g. Chen et al., 2011; Anderson et al., 2012; Chen et al., 2012). Some of these studies have researched the health impacts of PM_{10} (Chen and Kan, 2008; Chen et al., 2011; Jahn et al., 2011). And some researches focus on the health impacts of $PM_{2.5}$ (Cheng et al., 2013; Lee et al., 2012; Turner et al., 2011). But studies based on real-time monitoring data of the whole country were few.

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So our study was important to accessing pollution situation of $PM_{2.5}$ in China and the health damage caused by $PM_{2.5}$ in China.

2. Literature review

2.1. The data sources

The data sources of some studies about the health impacts of PM, were either from satellite-based remote sensing or recalculated from the air pollution index. Aaron et al. (2010) produced a global $PM_{2.5}$ distribution based on satellite imagine. Yao and Lu (2014), estimated the spatiotemporal distribution of $PM_{2.5}$ over China by satellite remote sensing. Qu et al. (2010) and Cheng et al. (2013) recalculated the concentration of $PM_{2.5}$ from the air pollution index (API). But the studies based on real time date were few. Until 2012, 74 cities in China's national monitoring network have released $PM_{2.5}$ data in real-time, and at the beginning of 2013, the number of cities releasing $PM_{2.5}$ data reached 113, and at the end of 2013, 190 cities were releasing $PM_{2.5}$ data. We selected 463 monitoring stations to conduct our research. These stations were located in all over the country of China.

2.2. The health impact assessment

The Health impact assessment (HIA) was widely used in air pollution hazard. Huang and Zhang (2013) evaluated the health benefit from $PM_{2.5}$ pollution controlling in the region of Beijing-Tianjin-Hebei province. Dias et al. (2012) assessed the particulate matter and health risk in Portugal. Matus et al. (2012) used this model to estimate the health damages in China attributed to air pollution. We quantitatively assessed the health impact of airborne $PM_{2.5}$ by exposure–response functions, as described by Cheng et al. (2013) and the World Bank (2007).

The aims of this study were first to explore the spatial-temporal characteristics of $PM_{2.5}$ concentrations in Chinese cities, and then, in combination with population data, to estimate the health impacts of airborne $PM_{2.5}$ exposure.

3. Data and methods

3.1. Source of $PM_{2.5}$ data

We collected the 347-day dataset from January 18, 2013 to December 31, 2013 for use as experimental data, from the National Urban Air Quality Real-time Publishing Platform (http://113.108.142.147:20035/emcpublish/). These data were measured by 463 monitoring stations, which were distributed throughout the country of China. Each monitoring station automatically measured hourly $PM_{2.5}$ concentration of the air. Each city has at least four air quality monitoring stations, which are distributed from the suburbs to downtown. Big cities, like Beijing, have 12 monitoring stations. The annual average of $PM_{2.5}$ concentration of each monitoring station was calculated based on the hourly real-time data. As the original $PM_{2.5}$ concentration data were at discrete points, Ordinary Kriging method was used to interpolate the site data into surface data to characterize concentrations over the entire area of each city. Then we got the annual average concentration of $PM_{2.5}$ in each city or county-level city of China. The unit of concentration is $\mu g/m^3$.

3.2. Census data

The population data were from the Sixth National Population Census of the People's Republic of China, 2010. The population data includes the permanent resident population of the city, but does not include data on temporary residents. According to the Sixth National Population Census of the People's Republic of China, 2010, the population of China was 1.36 billion, and which located in 2690 cities or county-level cities of China in our study.

3.3. Health impact assessment

The basic assumption of Health impact assessment (HIA) method is that, if the pollutant concentration exceeds the safe threshold, we can calculate the risk by 1 $\mu g/m^3$ increment based on an epidemiological coefficient for one person. If we know the population of one city, we can estimate the health impact for the whole city.

Four health endpoints associated with $PM_{2.5}$ were examined in this study: mortality, respiratory diseases, cardiovascular diseases, and chronic bronchitis.

The relative risk (*RR*) for the health outcomes was calculated using Equation (1):

$$RR = \exp[\beta^*(C - C_0)] \quad (1)$$

Where C is the annual average $PM_{2.5}$ concentration, and C_0 is the reference $PM_{2.5}$ concentration. Here, we applied a value of 10 $\mu g/m^3$ for C_0 because according to the WHO (2005), an average annual $PM_{2.5}$ concentration less than 10 $\mu g/m^3$ is considered safe. The β is the empirical coefficient, i.e., the percentage increase in health effect per 1 $\mu m/m^3$ $PM_{2.5}$ increment. The β values for the four endpoints are listed in Table 1.

The number of cases for each health endpoint attributed to $PM_{2.5}$ (E) is calculated by multiplying the population (P) by the difference in the current incident rate (f_p) and the incidence rate in a clean environment (f_0), as shown in Equation (2).

$$E = P^*\left(f_p - f_0\right) \quad (2)$$

The current incident rate (f_p) is calculated by multiplying the incidence rate in a clean environment (f_0) by the relative risk (RR), as shown in Equation (3).

$$f_p = f_0^*RR \quad (3)$$

By substituting Equation (3) into Equation (2), we obtain E.

$$E = ((RR - 1)/RR)^*f_p^*P \quad (4)$$

The f_p values for the four endpoints are listed in Table 1.

4. Results

4.1. Annual and seasonal variation of $PM_{2.5}$

The annual average $PM_{2.5}$ concentration in all cities was 72.71 $\mu g/m^3$. The hourly variation of $PM_{2.5}$ concentrations in China (Fig. 1) showed that for only 6% of the time was the $PM_{2.5}$ concentration below 35 $\mu g/m^3$ (Interim target-1 of WHO, 2005). For more than half of the time during the whole year, the $PM_{2.5}$ concentration was between 35 $\mu g/m^3$ and 75 $\mu g/m^3$. The rest of the time (37% of the year), the airborne $PM_{2.5}$ concentrations were over 75 $\mu g/m^3$. During December, there were two episodes when the average $PM_{2.5}$ concentration of all cities reached 215 $\mu g/m^3$, which is more than five times higher than the reference value (35 $\mu g/m^3$). January (133.10 $\mu g/m^3$) and December (120.19 $\mu g/m^3$) were the months with the most pollution, while July (38.76 $\mu g/m^3$) and August (41.31 $\mu g/m^3$) had better air quality in China. The highest $PM_{2.5}$ concentrations were recorded in the winter (112.30 $\mu g/m^3$), whereas the lowest $PM_{2.5}$ concentrations were recorded in the summer (44.63 $\mu g/m^3$). In the spring and autumn, the average