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Association between fine ambient particulate matter and daily total mortality: An analysis from 160 communities of China

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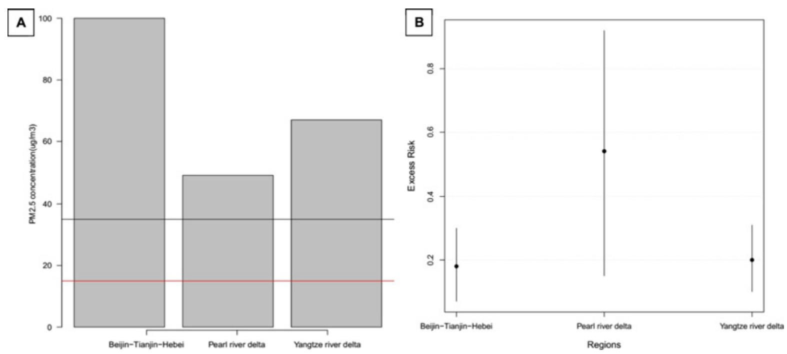
HIGHLIGHTS

- In this study, target area included 160 communities of 27 provinces, which covered 124 million inhabitants in China
- The associations were stronger in the widowed population than that in the married population.
- The associations were higher in low polluted areas than that in high polluted areas.

GRAPHICAL ABSTRACT



Three typical areas are also selected: Beijing-Tianjin-Hebei regions (Beijing, Tianjin, Hebei), Pearl River Delta (Guangdong), Yangtze River Delta (Shanghai & Zhejiang). We found that all three regions were all higher than either the national standard 2 level (black line, 35 μg/m^3) or national standard 1 level (red line,15 μg/m^3) (Fig. A). Interestingly, we found the estimates of PM in the regions with higher PM levels generally lower than that in lower PM level (Fig. B).

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ABSTRACT

Short-term exposure to outdoor fine particulate matter air pollution is associated with adverse health effects. However, existing literature have been limited in size and scope in countries with high air pollution level, especially in China. The study aims to examine the association of fine particulate matter with daily total mortality in 160 Chinese communities between 2013 and 2014. Two-stage analyses were used to assess the relationship between fine particulate matter ($PM_{2.5}$) and mortality. Firstly, Poisson regression model was used to estimate the community-specific $PM_{2.5}$-mortalty association. Secondly, a meta-analysis was used to pool the effect estimates within each region. During the study period, a total of 1.4 million deaths were recorded in 160 communities. There was a significant association between $PM_{2.5}$ and mortality. Specifically, a 10 μg/m^3 increase in 2-day moving average $PM_{2.5}$ concentration on total morality corresponded to a 0.17% (95% confidence interval (CI): 0.10, 0.23) in national level. The estimate of $PM_{2.5}$ on morality in Pearl Delta River was highest among Beijing-Tianjin-Hebei regions, Pearl River Delta, and Yangtze River Delta. Females, older population and widowed population appeared to be more vulnerable to particulate matter exposure. Conclusively, this largest epidemiologic study of fine particulate matter in China suggests that $PM_{2.5}$ is associated with increased mortality risk.

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1. Introduction

The adverse health effects of exposure to outdoor particulate matter air pollution are of concern in recent years, and epidemiological time studies have provided good evidence in this field (Lelieveld et al., 2015; Shang et al., 2013; Torjesen, 2015; Zeng et al., 2016). For example, it was reported that more than 40,000 people die from air pollution each year in Europe, accounting for 6% of all deaths (Kunzli et al., 2000). Biological mechanism evidence has been published for plausible mechanisms between particulate matter (PM) and mortality. However, studies from Asian countries with high air pollution level are still sparse and mostly concentrated on single city (Huang et al., 2012; Lin et al., 2016b; Ma et al., 2011).

With the rapid socioeconomic development in recent years, China has some of the worst air quality in the world (Xu et al., 2013). Mortalities from stroke, ischemic heart disease and lung cancer attributed to $PM_{2.5}$ increased from approximately 800,000 cases in 2004 to over 1.2 million cases in 2012. The disease burden illustrated strong spatial variations, and high attributable deaths concentrated in regions including Pearl River Delta, Yangtze River Delta and Beijing-Tianjin-Hebei region (M. Liu et al., 2016).

In China, $PM_{2.5}$ was included in the *Ambient Air Quality Standard* in 2012, and the national Air Reporting System in 2013. There were only a limited number of studies to examine the health effects of ambient $PM_{2.5}$ in China. Surface-monitoring sites in China have made it possible to assess health effects of air pollution at a large-scale level. In the case of time-series study of short-term exposure, the need to have a study population of a size for sufficient power has limited analyses to multicity. Until now, only one study was carried out in 6-icity setting in Pearl River Delta region (Lin et al., 2016a).

The present study aimed to explore the association of particulate matter with total mortality in 160 Chinese communities. We explored both $PM_{2.5}$ and PM_{10} on the air pollutant adverse effects. Considering the winter heating policy, we divided the communities into two parts (north China and south China) on provincial level. We also examined the modifying effects of gender, age, and marital status on the association between particulate matter and mortality.

2. Materials and methods

2.1. Data

In China, disease surveillance points system and the Ministry of Health's vital registration system have been used for decades to provide nationally representative data. In 2013, the National Health and Family Planning Commission combined the vital registration system and disease surveillance points system to create an integrated national mortality surveillance system. This new system increased the surveillance population from 6 to 24% of the Chinese population (12). The number of surveillance points, each of which covered a district or county, increased from 161 to 605. Considering the air pollution data availability ($PM_{2.5}$), the current study was constrained to only 160 points (Fig. 1). The 160 communities are located in 65 cities of 27 provinces. They are home to 124 million inhabitants, nearly 10% of the overall population in China. Three typical areas are also selected: Beijing-Tianjin-Hebei regions (Beijing, Tianjin, Hebei), Pearl River Delta (Guangdong), Yangtze River Delta (Shanghai & Zhejiang).

Community-specific daily total mortality data from 1 January 2013 through 31 December 2014 were obtained from Center for Health Statistics and Information, National Health and Family Planning Commission, Beijing, China. Data from the 605 surveillance points will be reported at the time of death registration to the national CDC. The standard information collected individual-level information, such as age, gender and marital status. In this study, we also divided daily deaths into several strata by gender, age groups (0–60 years, 65 years or older), marital status (married status, widowed status).

Daily meteorological data for all communities were collected from the publicly accessible China Weather Data Sharing System, including daily mean temperature and relative humidity. Meteorological data for each community was obtained from one basic-reference surface weather observation station or automatic station.

The air pollution data were collected from the national Air Reporting System from 2013. We collected 657 monitoring stations data from 65 cities from 2013 to 2014. The air pollutants included $PM_{2.5}$, PM_{10}, SO_2 and NO_2. For each community in every city, the air pollutants' data were daily average concentrations of monitors in corresponding community. If there is no specific data in one community, we used data from the nearest community in the same city.

2.2. Statistical analysis

We used a two-stage analytic approach using time series data from the 160 communities all round China. In the first stage, we applied a time-series model to each community's data to get the estimates of the community-specific PM-mortality relationship. Then, we pooled the estimated relationships in the second stage at the region and country level with a meta- analysis. This approach was clearly described in previous studies (Gasparrini and Armstrong, 2013; Gasparrini et al., 2012).

In the first stage, we used Generalized Linear Model (GLM) to obtain community-specific estimates, which is a standard method in environmental epidemiology for its good performance in demonstrating the exposure-response association between air pollution and health effect. We assumed daily death counts followed a Poisson distribution. The long-term trend and seasonality was controlled for using a natural cubic spline for time. We also introduced the air pollutants' concentration and weather conditions into the model. Based on previous literature, 3 df for daily mean temperature and relative humidity were used. Because of the lagging effects of temperature, the 14-day moving average of temperature was used. As for relative humidity, only present day relative humidity was incorporated into the model considering little evidence of its confounding in current studies.

The model is as follows:

$$Yi = \alpha + ns(\text{Time}, 7 \times \text{no of years}) + ns(\text{temperature}/\text{humidity}, 3) + \eta \text{DOW}t + \beta Zt \quad (1)$$

where Yi is the observed daily death counts at day i, and for every i, Yi obey the Possion distribution. ns is the natural cubic spline, Seven degrees of freedom (df) per year for time were used to control long-term trend and seasonality. β is the coefficient of the explanatory variable. Zt is $PM_{10}/PM_{2.5}$ concentrations at day t.

At the second stage, we used meta-analysis to pool the community-specific estimates obtained from the first-stage model. The meta-analyses were fitted using a random effects model by maximum likelihood, and was applied in each region, obtaining region-level pooled estimates. We used both I^2 statistic and Q-test to examine the heterogeneity of the estimated effects between the 160 cities. I^2 was a quantitative indicator of the proportion of the overall variation across the cities attributable to heterogeneity rather than to chance (Madaniyazi et al., 2016).

To avoid the underestimation of single-day lag models on the effect of air pollutant on health outcome, we used the 2-day moving average of current and previous day's concentration (mv01) of PM for our main analysis. To fully capture the effects of PM on mortality, we also checked the associations with different lag structures, including both single-day lag (from lag0 to lag7) and multiday lag (mv01, mv02, mv07). As for single day structure, a lag of 0 days (lag0) refers to the current-day PM concentration, and a lag of 1 day (lag1) corresponds to the previous day's concentration. In multiday lag structure, mv07 refers to an 8-day moving average of PM concentration of the current and previous 7 days. In addition, we stratified analyses by sex (men and