Science of the Total Environment 508 (2015) 178–187

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Multi-site time series analysis of acute effects of multiple air pollutants on respiratory mortality: A population-based study in Beijing, China

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HIGHLIGHTS

- Spatiotemporal variation in relationship between air pollutants and mortality.
- Exposure to air pollutants was based on the measurements from multiple sites.
- Principal component analysis was used to adjust for the collinearity.
- All the urban and rural districts in Beijing were included.
- The statistically significant effect was only found in one rural district.

ARTICLE INFO

Article history:
Received 4 August 2014
Received in revised form 26 October 2014
Accepted 21 November 2014
Available online 2 December 2014

Editor: Xuexi Tie

Keywords:
Air pollutants
Respiratory mortality
Time series analysis
Generalized additive model
Principal component analysis

ABSTRACT

In large cities in China, the traffic-related air pollution has become the focus of attention, and its adverse effects on health have raised public concerns. We conducted a study to quantify the association between exposure to three major traffic-related pollutants — particulate matter < 10 μm in aerodynamic diameter (PM_{10}), carbon monoxide (CO) and nitrogen dioxide (NO_2) and the risk of respiratory mortality in Beijing, China at a daily spatiotemporal resolution. We used the generalized additive models (GAM) with natural splines and principal component regression method to associate air pollutants with daily respiratory mortality, covariates and confounders. The GAM analysis adjusting for the collinearity among pollutants indicated that PM_{10}, CO and NO_2 had significant effects on daily respiratory mortality in Beijing. An interquartile range increase in 2-day moving averages concentrations of day 0 and day 1 of PM_{10}, CO and NO_2 corresponded to 0.99 [95% confidence interval (CI): 0.30, 1.67], 0.89 (95% CI: 0.27, 1.51) and 0.95 (95% CI: 0.29, 1.61) percent increase in daily respiratory mortality, respectively. The effects were varied across the districts. The strongest effects were found in two rural districts and one suburban district but significant in only one district. In conclusion, high level of several traffic-related air pollutants is associated with an increased risk of respiratory mortality in Beijing over a short-time period. The high risk found in rural areas suggests a potential susceptible sub-population with undiagnosed respiratory diseases in these areas. Although the rural areas have relatively lower air pollution levels, they deserve more attention to respiratory disease prevention and air pollution reduction.

1. Introduction

Numerous epidemiological studies have shown association of acute and chronic exposure to air pollutants with adverse health outcomes in human, and a meta-analysis reported that the pooled estimate of effect size was greater for respiratory mortality compared with all-cause mortality for PM_{10}, CO and NO_2 (Dominici et al., 2006; Stieb et al., 2003). Compared with the large volume and varieties of studies carried out in the developed countries, exposure assessment studies in developing countries are relatively scarce (Han and Naeher, 2006). With the fast development of the economy, China has experienced rapid growth in the population of motor vehicles. Over the past two and a half decades, the annual rate of growth in China's vehicle stock has been over 10%, and this trend will continue (Huo et al., 2007). Transport sector's crude oil consumption in China reached 98 million tons in 2005, 21 times of that in 1980 (Yan and Crookes, 2009). Now, pollution in many cities is changing from stationary source emissions to mobile source emissions. In Beijing, Shanghai, and Guangzhou, where vehicles

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http://dx.doi.org/10.1016/j.scitotenv.2014.11.070

grow most rapidly, vehicle emissions have become the dominant pollution source, and their pollution characteristics and control progress are typical of other cities as well. At present, the total emissions of carbon dioxide (CO_2) in China ranks second in the world. The emissions of other greenhouse gases such as nitric oxide (NO) are also very high (Jiang and Feng, 2006). As a result, the traffic related environmental problems have become increasingly serious and adversely impact public health.

Beijing, the capital city of China, has experienced serious air pollution over decades. It highlights the worry about the public health catastrophe accompanying the city's rapid development (Parry, 2013). Several studies have examined the health consequences of air pollution in Beijing (Huang et al., 2012; Liu et al., 2013; Wang et al., 2013; Zhang et al., 2012). One study indicated that the economic cost associated with human health during the 2008 Olympic Games came down by 38% and 16%, respectively, compared with the pre- and the post-Olympic Games periods (Hou et al., 2010). But these studies were limited in Beijing urban area, and either was conducted before or during the period of Beijing's Olympics, used the averaged pollution data only or data from single monitoring station. However, the exposure level actually varies greatly across the communities and the districts. Therefore, city-wide ambient average concentration might not account for within-city spatial gradients in pollutants' concentrations or changes in spatial gradients over time (Yanosk et al., 2008). As yet, no study based its health risk assessment on the pollution characteristics through the whole territory of Beijing from multiple monitoring stations after 2008 Olympic Games. Furthermore, besides dependencies among responses on successive days (autocorrelation) and among responses of the same subject on different days (heterogeneity), the issue of collinearity among pollutants was not addressed in previous studies.

In the present study, we obtained air pollution data from 12 ambient air quality monitoring stations in Beijing, road information data from Beijing Traffic Management Bureau, and meteorological data from the China Meteorological Administration. We aimed to quantify the association between exposure to multiple traffic-related air pollutants and risk of respiratory mortality at a daily temporal and district's spatial resolution.

2. Data collection and methods

2.1. Study area and period

Beijing is located in the Northern China Plain and is the nation's political, economic, cultural and educational center as well as China's most important center for international trade and communications. It is one of the most populous cities in the world and has a population of 21.15 million in 2013 (Beijing Municipal Bureau of Statistics, 2013). This study included all 16 administrative districts in Beijing: 6 urban districts, Dongcheng, Xicheng, Chaoyang, Fengtai, Shijingshan, Haidian; 8 suburban districts, Mentougou, Fangshan, Tongzhou, Shunyi, Changping, Daxing, Huairou, Pinggu; and 2 rural counties, Yanqing, Miyun (Fig. 1). The study period was from January 1, 2009 to December 31, 2010.

2.2. Data collection

Daily respiratory mortality data for years 2009 through 2010 were obtained from the Causes of Death Registry (CDR) of Chinese Centers for Disease Control and Prevention. The deaths in CDR were coded in by the International Classification of Diseases, version 10 (ICD-10) after December 31, 2002. In this study, ICD-10 codes J00–J98 were used to identify the deaths for respiratory diseases. Daily air pollution data for particulate matter <10 μm in aerodynamic diameter (PM_{10}), carbon monoxide (CO) and nitrogen dioxide (NO_2) were collected from twelve fixed-site air quality monitoring (AQM) stations in Beijing (Fig. 1), which are included in the Chinese National Quality Control for Air Monitoring Network. The daily concentration for each pollutant was the average of the hourly data. The data of Beijing's road length, road density and distance to the nearest main road was obtained from Beijing Traffic Management Bureau (Fig. 2a, b). Currently, Beijing's road network is formed in a layout combining square grids with loops and rays, which has 140,000 various roads and 5.2 million vehicles (Zhang et al., 2010a; Beijing Traffic Management Bureau, 2013). To allow adjustment for the effect of weather conditions on pollution, we obtained data of meteorological condition from the China Meteorological Administration including daily mean temperature, relative humidity, wind speed and barometric pressure in 24 h. The meteorological data measured at a single fixed station, the Beijing Weather Observatory locating close to the 5th southeast Ring road, was used to represent the meteorological conditions in all the studied districts.

2.3. Exposure evaluation

To characterize the ambient air pollution and estimate the pollution level in Beijing, the data from 12 AQM stations were collected. One background station (Dingling station in Changping District) was excluded from the analyses. For the daily concentrations of the air pollutants, the criteria for calculating daily average concentrations were that at least 75% of the hourly measurements in each day were available and abnormal values were excluded. In our study, all the stations had more than 75% of the 24 1-hour values being recorded in all the days of 2-year period, thus there is no missing data on the daily pollutant concentration data. For districts with two AQM stations, the average of two stations' daily values was used. For districts without AQM stations, the pollutant concentrations were estimated according to the following steps: (1) dividing one year into warm months (April to September) and cold months (October to March); (2) using logarithmic CO, NO_2 and PM_{10} concentrations as the dependent variables separately, and temperature, logarithmic humidity, logarithmic wind speed and road length as the independent variables to fit generalized linear model (GLM) for each of the two time periods based on the data from the districts with at least one AQM station; and (3) predicting daily logarithmic CO, NO_2 and PM_{10} levels based on the GLM for districts without AQM station for each of the two time periods, respectively. The predicted exposures were then corroborated with the data from other references. The annual average values of predicted pollutant concentrations were similar to those published in Beijing Environmental Assessment Annual Report (Beijing Municipal Environmental Protection Bureau, 2012).

2.4. Statistics analyses

For descriptive purpose, the polar graph was used to illuminate the seasonal trend of daily deaths and pollutant concentrations. The daily deaths, air pollution and weather condition were linked by date and therefore were analyzed with a time-series design. We used a generalized additive model (GAM) with natural splines (NS) to associate air pollutants with daily respiratory mortality, covariates and confounders (Zeger et al., 2006; Dominici et al., 2002). The following time series function with the Poisson link, under a GAM framework, was used to account for non-linear relationship between respiratory mortality and pollution levels (Peng et al., 2006):

$$\log[E(Yt)] = \alpha 0 + \sum_{i=1}^{q} \beta i(Xi) + \sum_{j=1}^{p} fj(Zj, df) + Wt(week).$$

Here $E(Yt)$ represented the expected number of deaths at day t, β represented the log-relative rate of mortality associated with a unit increase in air pollutants, Xi was the pollutants concentrations at day t, Zj was the confounding variables (i.e., time, mean daily temperature, daily relative humidity and barometric pressure), fj was the smooth functions, and $Wt(week)$ was the dummy variables for day of the