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Associations between daily outpatient visits for respiratory diseases and ambient fine particulate matter and ozone levels in Shanghai, China☆

Yiyi Wang [a], Yaqun Zu [a], Lin Huang [a], Hongliang Zhang [b, **], Changhui Wang [c], Jianlin Hu [a, *]

[a] Jiangsu Collaborative Innovation Center of Atmospheric Environment and Equipment Technology, Jiangsu Key Laboratory of Atmospheric Environment Monitoring and Pollution Control, Nanjing University of Information Science & Technology, 219 Ningliu Road, Nanjing, 210044, China
[b] Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, 77803, LA, USA
[c] Department of Respiratory Medicine, Shanghai Tenth People's Hospital, Tongji University, Shanghai, 200072, China

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A B S T R A C T

Air pollution in China has been very serious during the recent decades. However, few studies have investigated the effects of short-term exposure to $PM_{2.5}$ and O_3 on daily outpatient visits for respiratory diseases. We examined the effects of $PM_{2.5}$ and O_3 on the daily outpatient visits for respiratory diseases, explored the sensitivities of different population subgroups and analyzed the relative risk (RR) of $PM_{2.5}$ and O_3 in different seasons in Shanghai during 2013–2016. The generalized linear model (GLM) was applied to analyze the exposure-response relationship between air pollutants (daily average $PM_{2.5}$ and daily maximum 8-h average O_3), and daily outpatient visits due to respiratory diseases. The sensitivities of males and females at the ages of 15–60 yr-old and 60+ yr-old to the pollutants were also studied for the whole year and for the cold and warm months, respectively. Finally, the results of the single-day lagged model were compared with that of the moving average lag model. At lag 0 day, the RR of respiratory outpatients increased by 0.37% with a 10 μg/m^3 increase in $PM_{2.5}$. Exposure to $PM_{2.5}$ (RR, 1.0047, 95% CI, 1.0032–1.0062) was more sensitive for females than for males (RR, 1.0025, 95% CI, 1.0008–1.0041), and was more sensitive for the 15-60 yr-old (RR, 1.0041, 95% CI, 1.0027–1.0055) than the 60+ yr-old age group (RR, 1.0031, 95% CI, 1.0014–1.0049). O_3 was not significantly associated with respiratory outpatient visits during the warm periods, but was negatively associated during the cold periods. $PM_{2.5}$ was more significantly in the cold periods than that in the warm periods. The results indicated that control of $PM_{2.5}$, compared to O_3, in the cold periods would be more beneficial to the respiratory health in Shanghai. In addition, the single-day lagged model underestimated the relationship between $PM_{2.5}$ and O_3 and outpatient visits for respiratory diseases compared to the moving average lag model.

1. Introduction

Air pollutants, for instance particulate matter (PM) and ozone (O_3), can lead to various health problems (Costa et al., 2014; Lichtman et al., 2016; Mimura et al., 2014; Tam et al., 2015; Tsangari et al., 2016), among which respiratory diseases are very common (Lim et al., 2012; Tam et al., 2014). Studies on the association between air pollutants and respiratory health effects have been performed, but mainly focused on some developed countries (Pope, 1989; Waldbott, 1972; Wise, 2016). Many developing countries, such as India and China, are suffering from serious air pollution problems (Guo et al., 2017; Hu et al., 2014; Verma et al., 2003; Wang et al., 2014). However, few health effects studies have been conducted and most of them were based on the exposure-response correlations found in developed countries (Gurjar et al., 2010). Due to the severity of air pollution, high population density, and lack of

☆ This paper has been recommended for acceptance by Baoshan Xing.
* Corresponding author.
** Corresponding author.
E-mail addresses: hlzhang@lsu.edu (H. Zhang), jianlinhu@nuist.edu.cn (J. Hu).

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local exposure-response correlations in developing countries, the assessment has large uncertainties. Recent studies (Mehta et al., 2013; Phung et al., 2016) in Vietnam found that the increased concentration of air pollutants (PM_{10}, NO_2, SO_2) can lead to elevated risk of hospital admission among young children and adult residents. Such studies should be conducted to assess the health risks of air pollutants in other countries/regions with severe air pollution. Understanding the relationship between air pollutants and human health helps identify the pollutants and sources that have the largest negative impacts on human health, provides valuable information for clinical and public health interventions, and is the basis for developing effective policies and regulations to improve air quality and protect human health. It has been well recognized that the relationship between air pollutants and human health can vary in different regions, due to differences in the degree and nature of air pollution, as well as differences in population (Burnett et al., 2000; Hu et al., 2015; Shang et al., 2013). Therefore, directly applying the relationship established mostly in developed countries to Shanghai or other cities in China would lead to large bias and it is necessary to conduct studies with local data of air pollutants and health outcomes.

China is facing severe air pollution problems (Chan and Yao, 2008), especially in the more populous regions, for instance Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta and Sichuan Basin (Cheng et al., 2013; Tan et al., 2016; Tao et al., 2013, 2014a). The major air pollutants include $PM_{2.5}$, SO_2, NO_2, and O_3. Some studies in China (Cui et al., 2016; Kan and Chen, 2003; Tao et al., 2014b) have demonstrated that air pollutants caused respiratory and cardiovascular disease contribute to the increasing mortality and morbidity in China (Hu et al., 2017).

Shanghai is the most populous megacity with a population of 24 million in 2015 in China. It is also one of the heaviest polluted cities in China (Li et al., 2009). During the study period, there are 256 days exceeding the CAAQS Grade II standard for $PM_{2.5}$, 115 days for O_3. Several studies have investigated the relationships between air pollution and death rate and morbidity in Shanghai (Cai et al., 2014, 2015; Cao et al., 2009; Chen et al., 2010; Hua et al., 2014; Huang et al., 2009; Kan and Chen, 2003; Kan et al., 2007; Zhao et al., 2013). For example, Cai et al. (2014) found that air pollution was an important contributor to asthma development and exacerbation. Cao et al. (2009) found air pollution had a significant effect on increased risk of hospital outpatient and emergency room visits, and a 10μg/m^3 increase in concentrations of PM_{10}, NO_2, and SO_2 corresponded to 0.11%, 0.34%, and 0.55% increase of outpatient visits and 0.01%, 0.17%, and 0.08% increase of emergency room visits, respectively. Chen et al. (2010) found outdoor air pollution also had an effect on increased risk of total and cardiovascular hospital admission in Shanghai. Hua et al. (2014) found the $PM_{2.5}$ and the BC had a significant influence on childhood asthma admissions using a single-pollution model. Kan and Chen (2003) found that a 10 μg/m^3 increase over a 48-h moving average concentrations of PM_{10}, SO_2 and NO_2 corresponded to 1.003 (95%CI 1.001–1.005), 1.016 (95%CI 1.011–1.021), and 1.020 (95%CI 1.012–1.027) RR of non-accident mortality, respectively.

Previous studies have discussed the effects of air pollutants in China, mostly focusing on PM_{10}, NO_2, and SO_2. Recent studies have suggested that the major pollutants in urban cities of China are $PM_{2.5}$ and O_3. (Hu et al., 2015; Wang et al., 2014). Regulatory monitoring network of $PM_{2.5}$ and O_3, as well as other four criteria pollutants (i.e., CO, SO_2, NO_2, and PM_{10}), has been gradually built up in major cities of China since 2013. In this study, we took advantages of four-year ambient measurements of $PM_{2.5}$ and O_3 in 2013–2016, and assessed the relationships between different air pollutants and outpatient visits of respiratory diseases in Shanghai.

2. Materials and methods

2.1. Data collection

Daily data of outpatient visits for respiratory diseases were collected from Shanghai Tenth People's Hospital between March 1, 2013 and December 31, 2016. Respiratory diseases include upper respiratory and lower respiratory tract diseases. The upper respiratory tract diseases mainly include sinusitis, acute upper respiratory tract infection, and the lower respiratory tract diseases include pneumonia, asthma, bronchitis, and chronic obstructive pulmonary disease. These records contained the date of outpatient visit, age, gender, and discharge diagnosis from the 10th revision of the international classification of diseases (ICD-10). The records had 99.4% with age above 15 years, therefore, the outpatient visits were classified into two age groups: 15-60 yr-old age group and 60+ yr-old age group.

Four criteria air pollutants data in the same period were collected from the website published by the National Environmental Monitoring Center of China (http://113.108.142.147:20035/emcpublish/). SO_2, NO_2, $PM_{2.5}$, and O_3 with hourly concentrations in Shanghai were obtained. SO_2 and NO_2 were used to test the stability of the model. In a previous study, the measurement method for each pollutant, and the quality control on the data set were described (Wang et al., 2014). Hourly concentrations were then averaged to 24-h averaged concentrations for $PM_{2.5}$, SO_2, NO_2 and daily maximum 8-h mean ozone (8-h O_3).

To consider the effects of meteorological conditions, meteorological parameters were obtained from the National Climate Data Center (NCDC) (ftp://ftp.ncdc.noaa.gov/pub/data/noaa/). In this study, daily average temperature and daily average relative humidity were used.

All the data were classified into two time periods, i.e. the warm periods and the cold periods, according to the mean temperature of every month. Months with mean temperature above 20 °C (the median value of temperature in Shanghai during 2013–2016) were classified into the warm periods and months with mean temperature below 20 °C were classified into the cold periods. As a result, the warm periods were ranged from May to October, and the cold periods include the rest.

2.2. Statistical analysis

Daily outpatient visits for respiratory diseases and four criteria air pollutants concentrations (i.e., $PM_{2.5}$, O_3, NO_2 and SO_2) were recorded by date information and could be analyzed with a time-series analysis. Because counts of daily outpatient visits for respiratory diseases data roughly subordinate to the Poisson distribution and the relationship between outpatient visits for respiratory diseases and explanatory variables are mostly nonlinear (Bhaskaran et al., 2013), a generalized linear model (GLM) was used to quantify the relationships, in which the main exposure variables were the daily averages of individual air pollutants. The GLM model combines the time-series regression analysis with the family of Poisson distribution and natural splines, and estimates both the short-term and the long-term relationship between the $PM_{2.5}$, O_3 and the outpatient visits for respiratory diseases. We used a flexible spline function to control long-term trend and seasonal effects with 8 degrees of freedom (Qiu et al., 2013; Tian et al., 2014), and natural cubic spline functions with 4 degrees of freedom to adjust the influences of relative humidity (Phung et al., 2016), and with 3 degrees of freedom to adjust the effects of temperature. Sensitivity analyses were performed to examine the stability of the model by selecting different degrees of freedom, described in the Discussion section. The day of the week (DOW), flu days and public holidays