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RESEARCH ARTICLE

Associations between air pollution and outpatient visits for allergic rhinitis in Xinxiang, China

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Abstract

Several epidemiological studies have investigated the adverse health effects of air pollution, but studies reporting its effects on allergic rhinitis (AR) are limited, especially in developing countries having the most severe pollution. Limited studies have been conducted in China, but their results were inconsistent. So, we conducted a time-series study to evaluate the acute effect of six air pollutants (fine particulate matter [$PM_{2.5}$], particulate matter with diameter less than 10 μm [PM_{10}], sulfur dioxide [SO_2], nitrogen dioxide [NO_2], ozone [O_3], and carbon monoxide [CO]) on hospital outpatient visits for AR in Xinxiang, China from January 1, 2015, to December 31, 2018. An over-dispersed Poisson generalized additive model adjusting for weather conditions, long-term trends, and day of the week was used. In total, 14,965 AR outpatient records were collected during the study period. Results found that each 10 $\mu g/m^3$ increase in $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO corresponded to 0.70% (95% confidence interval 0.00–1.41%), 0.79% (0.35–1.23%), 3.43% (1.47–5.39%), 4.54% (3.01–6.08%), 0.97% (− 0.11–2.05%), and 0.07% (0.02–0.12%) increments in AR outpatients on the current day, respectively. In the stratification analyses, statistically stronger associations were observed with $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO for AR outpatients < 15 years of age than in those 15–65 and ≥ 65 years of age, whereas the opposite result was found with O_3. Associations between PM_{10}, SO_2, NO_2, O_3, and AR outpatients were higher in the warm season than those in the cool season. This study suggests that exposure to $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO was associated with increased AR risk and children younger than 15 years might be more vulnerable.

Keywords Air pollution · Allergic rhinitis · Outpatient · Time-series study

Abbreviations

AR	Allergic rhinitis
$PM_{2.5}$	Fine particulate matter
PM_{10}	Particulate matter with diameter less than 10 μm
SO_2	Sulfur dioxide
NO_2	Nitrogen dioxide
O_3	Ozone
CO	Carbon monoxide
GAM	Generalized additive model
df	Degrees of freedom
IgE	Immunoglobulin E

Introduction

Air pollution has become a highly important health risk factor. As the largest developing country worldwide, China faces the most severe air pollution problems, especially in city clusters, including the Jing-Jin-Ji, Yangtze River Delta, and Pearl River Delta areas (Meng et al. 2012; van Donkelaar et al. 2010). The

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gross domestic product increased from 10,028 billion in 2000 to 90,031 billion in 2018, and the number of automobiles raised from 1.6 million in 2000 to 327 million in 2018 (Statistics 2000–2018). Rapid economic growth over the last decade has led to a continuous increase in energy consumption, which is the largest contributor to ambient air pollution (Maji et al. 2019). Furthermore, the sharp increase in vehicles also discharges great amounts of air pollutants (Dong et al. 2013; Jaakkola et al. 2006; Lehmann et al. 2001). Accumulating evidence has proposed that air pollution exposure increases the risk of morbidity and mortality, particularly in respiratory and cardiovascular diseases (BF and YL 2010; He et al. 2011; Li et al. 2015; Mihălțan et al. 2016; Shang et al. 2013).

AR is a very common disease that affects people of all ages, with about 30–40% of the population affected globally (Zou et al. 2018). Usually, AR is not a serious illness, but it has a considerable effect on quality of life and can have significant consequences if left untreated (Greiner et al. 2011; Nathan 2007). Sometimes, it can cause major illness and disability (Bousquet et al. 2008; Brozek et al. 2010). Previous evidence showed that air pollution may play important roles in the etiology of AR (Penard-Morand et al. 2005). Individuals with AR have nasal hyperreactivity, rendering them more responsive to air pollutant irritants (Dunlop et al. 2016). Compared to other respiratory diseases such as pneumonia and asthma, relatively few studies have analyzed the adverse effect of air pollution on AR (Chen et al. 2016; Deng et al. 2016; Hu et al. 2017), especially in developing countries. Huang et al. found that high concentrations of fine particulate matter ($PM_{2.5}$) and particulate matter with diameter less than 10 μm (PM_{10}) corresponded to aggravated subjective symptoms in children with AR (Huang et al. 2017). One study conducted in Beijing, China, observed strong associations between sulfur dioxide (SO_2), nitrogen dioxide (NO_2), PM_{10}, and AR outpatients (Zhang et al. 2011). A study in Taiwan found that PM_{10}, NO_2, ozone (O_3), and carbon monoxide (CO) were associated with AR morbidity (Chen et al. 2016). Other studies found that $PM_{2.5}$ and PM_{10} were positively associated with AR outpatients in Changchun and Nanjing, respectively (Chu et al. 2019; Teng et al. 2017). Chen et al. also found a positive relationship between $PM_{2.5}$ and AR in six cities (Changsha, Chongqing, Nanjing, Shanghai, Taiyuan, and Urumqi) (Chen et al. 2018). However, contradictory results have been found for PM_{10} and O_3 in Taiwanese schoolchildren (Hwang et al. 2006).

With air pollution levels from industrial and motor vehicle emissions rising rapidly in quickly industrializing and urbanizing countries, respiratory disease prevalence has also been increasing (Zhang et al. 2015). Xinxiang, one of the oldest cities in China, is experiencing the worst air pollution problems. Annual concentrations of $PM_{2.5}$, PM_{10}, and NO_2 in 2015 were approximately 2.7, 2.3, and 1.3 times higher than the Chinese National Ambient Air Quality Standard ($PM_{2.5}$, 35 μg/m^3; PM_{10}, 70 μg/m^3; NO_2, 40 μg/m^3), respectively. However, few studies have examined the adverse health effects of air pollution in Xinxiang. Thus, we designed this study to investigate the acute effects of six ambient air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO) on hospital outpatient visits for AR.

Methods

Xinxiang, located in the center of the North China Plain, is about 340 km south of Beijing and 60 km north of Zhengzhou (Fig. 1). Xinxiang has over 1400 years of history and comprises four urban districts, with a total area of 8249 km^2 and a population of 5.77 million at the end of 2017. The study area was limited to the four traditional urban districts (422 km^2). Xinxiang has a warm temperate continental climate. The warm season is defined from April to September, while the cool season lasts from October to March.

Health data

There are six hospitals in Xinxiang, of which the PLA 371 Hospital is a military hospital and the Xinxiang Third People's Hospital lacks an electronic health information system. Therefore, AR outpatient records were collected from the other four hospitals: Xinxiang First People's Hospital, Xinxiang Second People's Hospital, Xinxiang Central Hospital, and the Third Affiliated Hospital of Xinxiang Medical University from January 1, 2015, to December 31, 2018. These four hospitals are distributed in four municipal administrative districts of Xinxiang (Fig. 1) and cover all residents of Xinxiang. Computerized records were retrieved from the health information system of each hospital. Several covariates such as birth date, outpatient date, age, gender, address, department of visit, doctor, and diseases were extracted for each record. Disease names were diagnosed by clinical doctors, and all hospitals have the same diagnosis guideline. The International Classification of Diseases (ICD, 10th revision) codes were re-matched, and data cleaning and quality control procedures were conducted as previously described (Song et al. 2018). The number of daily hospital visits was summarized according to ICD10 codes (J30 for AR), and the data were also classified by season, sex, and age (< 15, 15–64, and ≥ 65 years).

The Institutional Review Board of Xinxiang Medical University approved the study protocol (NO. 2018-1207-0203).

Air pollution and meteorological data

In this study, daily concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO in Xinxiang were collected from the website of

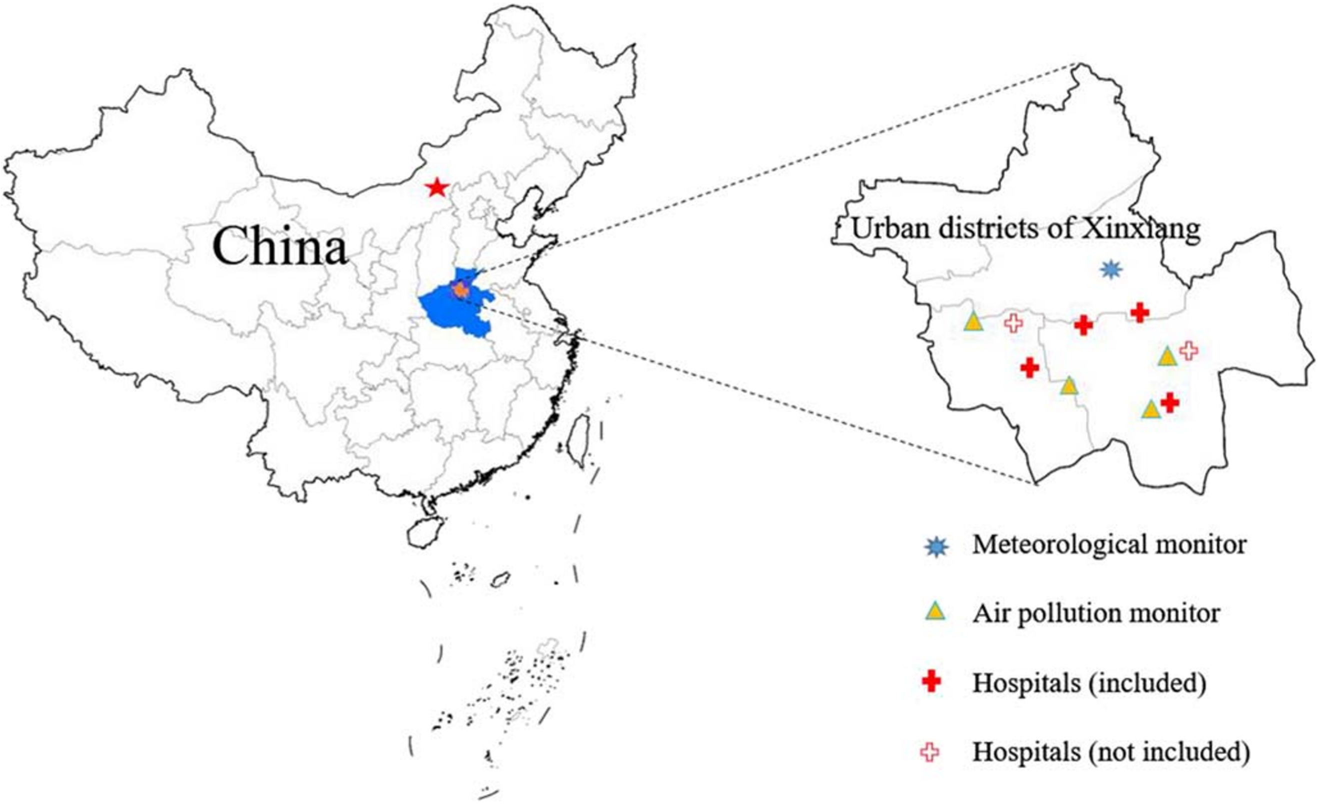


Fig. 1 The site of Xinxiang and geographical distributions of hospitals and monitors

China's National Urban Air Quality Real-time Publishing Platform (http//106.37.208.235.20035/). The daily average concentrations of these six ambient air pollutants were based on four fixed-site monitors operated under the Xinxiang Ministry of Ecology and Environment, which are distributed in urban districts (Fig. 1). Daily concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO were calculated as the 24-h mean value, and the concentration of O_3 was calculated as the maximal 8-h average. To calculate the mean concentrations of each pollutant, more than 75% of the hourly values must have been available on that day, otherwise, data for that day were excluded (Huang et al. 2017).

In addition, we collected two meteorological parameters in Xinxiang, the daily mean relative humidity and mean temperature, from China's Meteorological Data Sharing Service System (http://data.cma.cn/). The geographic description of the meteorological monitor is also indicated in Fig. 1.

Statistical analyses

To better scrutinize our research, an over-dispersed generalized additive model (GAM) was used to examine the relationships between air pollutants and AR outpatients. Several time-varying confounders were adjusted based on previous studies (Liang et al. 2018; Qiu et al. 2012; Tian et al. 2016): (1) a natural smooth function of the calendar day with 7 degrees of freedom (df) per year was incorporated into the core model to exclude unmeasured long-term and seasonal trends longer than 2 months (7 df/year was selected as it could produce the smallest Akaike Information Criterion value); (2) a natural smooth function of daily mean temperature (6 df) and mean relative humidity (3 df) were structured to control their nonlinear confounding effects (Li et al. 2015); (3) a binary variable of public holidays and indicator variable of the day of the week were also calculated.

The exposure-response (E-R) curves of air pollutant effects on AR outpatients were plotted using a natural spline function with 3 df (Chen et al. 2018).

To explore the temporal pattern of six air pollutants on AR outpatients, several lag structures including single-day lags (lag 0 to lag 7) and moving average lag days (lag 0–1, 0–2, 0–3, 0–4, 0–5, 0–6, 0–7) were analyzed. Furthermore, two sensitivity analyses of two-pollutant models and df transformation studies (wherein the df value of time was transformed from 4 to 10 per year) were conducted to examine the robustness of our models.

Finally, three more stratification analyses were constructed to explore the potential modifying effect of gender, age, and season. The statistical significance between each stratification was calculated by 95% confidence intervals (CI) as before, in brief: $(\widehat{Q}_1-\widehat{Q}_2\ )\pm1.96\sqrt{\left(\widehat{SE1}\right)^2+\left(\widehat{SE2}\right)^2}$,where $\widehat{Q}_1$ and

Table 1 The summary of descriptive statistics during the study period (January 1, 2015, to December 31, 2018)

	Mean	SD	Min	P25	Median	P75	Max
Air pollutant concentration (μg/m^3)							
$PM_{2.5}$	75.7	57.5	10.0	39.5	58.0	92.0	686.0
PM_{10}	132.1	81.0	15.0	77.0	113.0	164.0	893.0
NO_2	48.4	21.4	10.0	32.0	45.0	61.0	165.0
SO_2	33.2	25.4	2.0	16.0	26.0	42.0	230.0
$O_{3\text{-}8h}$	59.4	37.3	2.0	29.0	55.0	84.0	182.0
CO	1377	872.0	240	840	1130	1560	7850
Meteorological measures							
Temperature (°C)	16.0	10.2	− 6.1	6.9	17.2	25.3	34.6
Humidity (%)	60.0	16.9	13.0	48.0	61.0	73.0	98.0
No. of daily outpatients for allergic rhinitis (J30)	11	8	0	5	8	13	71
Gender (N)							
Male	6	5	0	2	4	7	38
Female	5	5	0	2	4	7	33
Age (N)							
<15	2	2	0	0	1	2	12
15–64	9	7	0	4	7	10	59
≥65	1	1	0	0	0	1	4
Season (N)							
Warm (Apr to Sep)	13	9	0	7	11	17	71
Cool (Oct to Mar)	7	5	0	4	6	10	32

$\widehat{Q}_2$ are the estimates and SÊ1 and SÊ2 are their standard errors (Lin et al. 2016).

All statistical analyses were conducted in the R software (Version 3.3.3) using the *mgcv* package. Results with $P < 0.05$ were considered statistically significant. The effects are described as the percent changes and 95% CI in AR outpatients per 10 μg/m^3 increase in air pollutants.

Results

Table 1 summarizes the descriptive statistics of daily AR outpatients, daily concentrations of six ambient air pollutants (PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, and CO), and daily meteorological conditions (mean relative humidity and temperature) from January 1, 2015, to December 31, 2018. In total, 14,965 AR outpatient records were collected from four hospitals, among which, there were 7912 male and 7050 female outpatients (3 more records with missing message). Additionally, of all AR outpatients, 2159 were < 15; 11,945 were 15–64; and 861 were ≥ 65 years of age. The annual mean concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO were 75.7, 132, 33.2, 48.4, 59.4, and 1377 μg/m^3, respectively. These values for $PM_{2.5}$, PM_{10}, SO_2, and NO_2 were about 1.1, 3.8, 0.6, and 1.2 times higher than the Chinese National Ambient Air Quality Standards ($PM_{2.5}$, 35 μg/m^3; PM_{10}, 70 μg/m^3; SO_2, 60 μg/m^3; NO_2, 40 μg/m^3), and only 15 and 34 days of O_3 and CO concentrations exceeded the daily limit (O_3, 160 μg/m^3; CO, 4000 μg/m^3). The daily mean relative humidity was 60%, and the mean temperature was 16 °C in Xinxiang during our study period. Except for O_3, the other five pollutants were strongly correlated with each other, with Spearman's coefficients ranging from 0.44 to 0.90, and negatively correlated with daily mean temperature and mean relative humidity.

As shown in Fig. 2, the estimated effects of single-pollutant models are presented using different lag structures. Significant results were identified between air pollutants, except for O_3, and outpatient visits for AR. Specifically, lag0 and lag01–lag07 for PM_{10}; lag0, lag1, and lag01–lag06 for SO_2; lag0, lag1, and lag01–lag07 for NO_2; and lag0 for CO were statistically significant. The estimate between $PM_{2.5}$ and AR outpatients on lag0 was marginal. Based on the model fit statistics, the current day (lag0) for $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO, and lag1 for O_3 were selected as the best lag structures as they could produce the smallest generalized cross-validation value. This means that each 10 μg/m^3 increase in concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO corresponded to a 0.70% (95% CI 0.00–1.41%), 0.79% (0.35–1.23%), 3.43% (1.47–5.39%), 4.54% (3.01–6.08%), and 0.07% (0.02–0.12%) increase in daily hospital outpatients for AR on the current day, respectively. Meanwhile, the associations

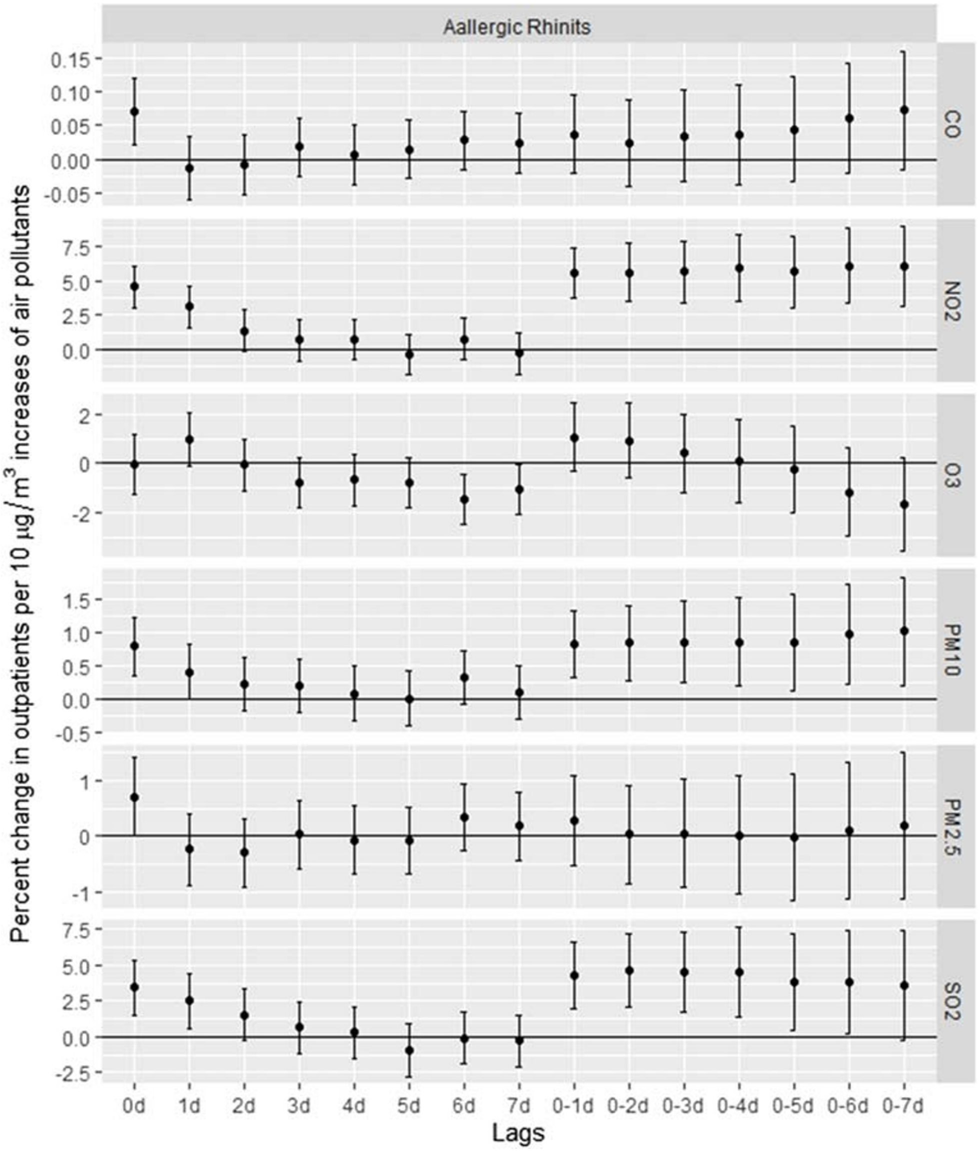


Fig. 2 Percent change (95% CI) of hospital outpatients for allergic rhinitis per 10 μg/m^3 increase in concentrations of six pollutants using different lag structures

between O_3 and AR outpatients were positive but not statistically significant with an estimate of 0.97% (95% CI − 0.11–2.05%).

The E-R curves for the relationships between six ambient air pollutants and daily AR outpatients are shown in Fig. 3. In general, the six curves were obviously positive. The E-R curves of O_3 and CO were nearly S-shaped, rising sharply for concentrations ≥ 50 and ≥ 250 μg/m^3 and flattening for concentrations ≥ 110 and ≥ 4000 μg/m^3, respectively. The E-R curves of NO_2, $PM_{2.5}$, and PM_{10} showed a steep slope at concentrations < 1000, < 300, and < 350 μg/m^3 and then drop down. The E-R curves of SO_2 showed a flat slope at low concentrations and then a slight increase at concentrations ≥ 150 μg/m^3.

Stratified analysis results are shown in Table 2. The estimated effects of $PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3 on AR outpatients were a little higher in males than in females, although no significant differences were found. Significant differences were observed with age stratification, and the effects were strongest in patients < 15 years of age (except for O_3). For the season modification, the effects of $PM_{2.5}$ and CO were stronger in the cool season than in the warm season, but this difference was not significant; however, the effects of PM_{10}, SO_2, NO_2, and O_3 were stronger in the warm season than in the cool season, and statistical significance was determined for SO_2 and O_3.

Co-pollutants with a correlation coefficient < 0.7 were added to two-pollutant models. The associations of PM_{10}, NO_2, and O_3 with AR outpatients remained robust after adjusting for co-pollutants (Table 3). However, when adjusting for SO_2, a non-significant association was identified for $PM_{2.5}$. For O_3, all estimates were significant in the two-pollutant models. Meanwhile, the estimated effects of CO were insignificant when adjusting for PM_{10}, NO_2, and SO_2.

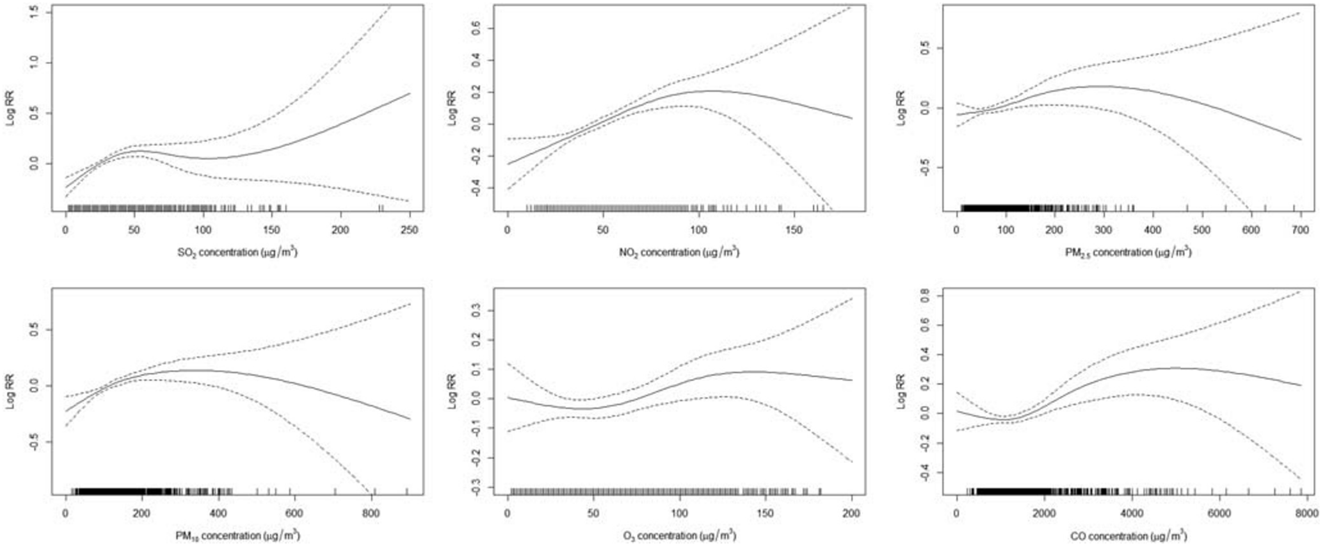


Fig. 3 The exposure-response relationship curves for concentrations of SO_2, NO_2, $PM_{2.5}$, PM_{10}, O_3, and CO with allergic rhinitis outpatients

Altogether, these results indicate that PM_{10}, NO_2, and SO_2 might play a more independent role in AR outpatient risk. Another sensitivity analysis showed similar results when the df for time were transformed from 4 to 10 (Fig. 4), suggesting that our results were likely not attributed to chance.

Discussion

We conducted a time-series study to investigate the acute association between six air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, CO) and hospital outpatient visits for AR. Significant associations were observed between $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and AR outpatients. The associations were strongest in patients < 15 years of age and weakened as age increased. The acute effects of SO_2 and O_3 on AR outpatients were stronger in the warm season than in the cool season.

Compared to other respiratory diseases, few studies have focused on the association between ambient air pollution and AR risk. In this study, we found significant associations between PM_{10}, SO_2, NO_2, CO, and AR outpatient visits. These findings are consistent with previous studies (Jo et al. 2017; Teng et al. 2017). One study conducted in Hobart, Australia, found that AR symptoms are associated with PM (IRR 1.06, 95% CI 1.04–1.08) (Jones et al. 2020). Min et al. observed a marginal association between $PM_{2.5}$ and AR in children in Seoul, Korea (Min et al. 2020). Analyzed from 646,975 children records in Shanghai, Hu et al. showed that most of the pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3) were significantly associated with AR (Hu et al. 2020). Using generalized additive Poisson model, Wang et al. also found significant association between $PM_{2.5}$ and AR outpatient (Wang et al. 2020). A case-crossover study conducted in Taipei found positive associations between PM_{10}, NO_2, CO, O_3, and AR morbidity on all days, the associations between SO_2 and AR was significant in warm days (> 23 °C) but insignificant in cool days (< 23 °C) (Chen et al. 2016). A nationwide study covering 11 major Chinese cities showed that SO_2 was significantly associated with adult AR prevalence (Zhang et al. 2009). One recently published research proved that $PM_{2.5}$ and PM_{10} would induce increased serum-specific IgE of house dust mites (allergen of AR) (Ye et al. 2019). However, a 17 years follow-up study in Toronto did not find significant association between $PM_{2.5}$, NO_2, and O_3 and AR (To et al. 2020). A recently published meta-analysis study also found no associations between PM_{10}, O_3, and childhood AR prevalence in Asia (Zou et al. 2018). Variations in study design, geographic distribution, study populations, and ethnicity may partially explain the inconsistencies between these results.

The exact mechanisms that underlie the associations between air pollutants and AR are not well established. Several pathways have been proposed, mainly inflammation exacerbation, oxidative stress promotion, signal transduction interference, enzyme inhibition, immunosuppression, and epigenetic dysregulation (Bayram 2017; Bloemsma et al. 2016; Chen et al. 2018; Heinrich and Schikowski 2018). For example, air pollutants such as PM, SO_2, NO_2, and O_3 may damage the nasal mucosa and impair mucociliary clearance, thereby facilitating the introduction of inhaled pollutants to immune system cells (Dunlop et al. 2016). PM may enhance allergic inflammation and induce the development of allergic immune responses; NO_2 is known for its adjuvant effect on airway hypersensitivity; and O_3 could induce an influx of neutrophils and eosinophils in the nasal mucosa and further stimulate immunoglobulin E (IgE) synthesis (Chen et al. 2016). Furthermore, inhalable PM could carry high quantities of

Table 2 Percent change (95% CI) in hospital outpatients for allergic rhinitis per 10 μg/m^3 increase in concentrations of six pollutants stratified by gender, age, and season in Xinxiang, China, 2015–2018

Pollutant	Gender		Age			Season	
	Male	Female	< 15	15 ~ 64	≥65	Warm	Cool
$PM_{2.5}$	0.85(−0.02–1.72)	0.54(−0.38–1.46)	_2.89(1.22–4.57)_*#	0.43(−0.33–1.18)*	− 0.03(− 2.14–2.09) #	0.03(−1.56–1.63)	0.20(− 0.55–0.96)
PM_{10}	_0.87(0.33–1.41)_	_0.72(0.14–0.89)_	_2.38(1.33–3.44)_* #	_0.59(0.12–1.06)_*	0.29(− 1.03–1.62) #	0.69(−0.14–1.53)	0.19(− 0.33–0.71)
SO_2	_3.94(1.52–6.36)_	_2.87(0.29–5.45)_	_7.62(2.82–12.41)_*	_3.16(1.08–5.24)_	− 0.90(− 7.03–5.24)*	_6.13(2.67–9.59)_*	1.38(− 0.94–3.69)*
NO_2	_5.21(3.31–7.11)_	_3.82(1.78–5.85)_	_9.23(5.66–12.81)_* #	_3.96(2.31–5.61)_*	1.01(− 3.93–5.96) #	_4.00(1.46–6.54)_	_3.45(1.46–5.44)_
O_3	1.25(−0.07–2.57)	0.64(−0.80–0.99)	− 0.22(− 2.53–2.09)	_1.44(0.28–2.60)_*	− 2.46(− 6.07–1.14)*	_2.65(1.35–3.95)_*	−1.58(−4.00–0.83)*
CO	_0.07(0.01–0.13)_	_0.07(0.01–0.13)_	_0.17(0.05–0.29)_*	_0.06(0.01–0.12)_	− 0.03(− 0.19–0.12)*	0.03(−0.07–0.13)	_0.06(0.01–0.12)_

The statistically significant estimates are highlighted in italics

*,# Statistically significant for between-group difference

Table 3 Percent change (95% CI) in hospital outpatients for allergic rhinitis in two-pollutant models

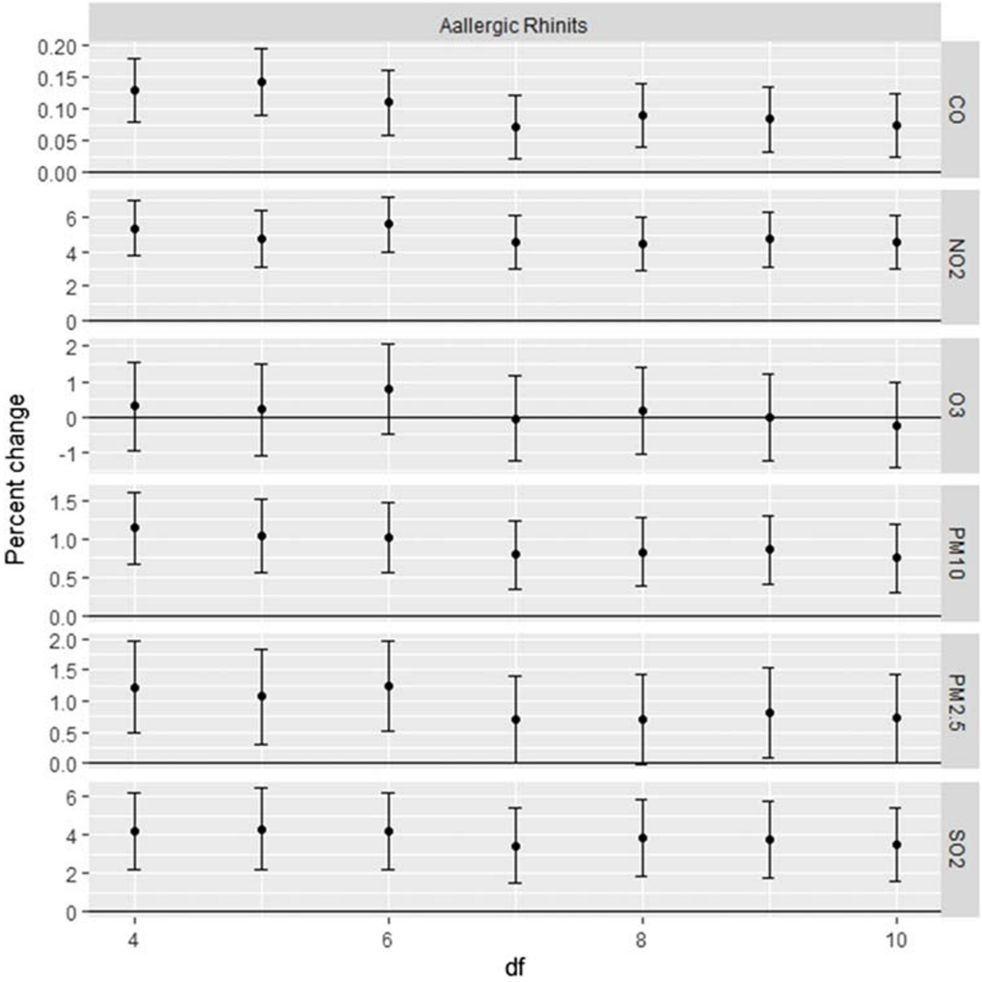
Two-pollutant models		Estimates (%)
$PM_{2.5}$	–	0.70(0.00–1.41)
	+ SO_2	0.26(− 0.51–1.04)
	+ O_3	0.70(0.00–1.41)
PM_{10}	–	0.79(0.35–1.23)*
	+ O_3	0.79(0.35–1.23)*
	+ CO	0.65(0.10–1.21)*
SO_2	–	3.43(1.47–5.39)*
	+$PM_{2.5}$	3.15(1.02–5.28)*
	+ NO_2	0.20(− 2.19–2.59)
	+ O_3	3.45(1.48–5.42)*
	+ CO	2.73(0.42–5.03)*
NO_2	–	4.54(3.01–6.08)*
	+ SO_2	4.45(2.57–6.34)*
	+ O_3	4.74(3.17–6.32)*
	+ CO	5.33(3.31–7.35)*
O_3	–	0.97(− 0.11–2.05)
	+$PM_{2.5}$	1.20(0.10–2.30)*
	+PM_{10}	1.23(0.13–2.33)*
	+ NO_2	1.24(0.14–2.34)*
	+ SO_2	1.29(0.19–2.40)*
	+ CO	1.35(0.24–2.45)*
CO	–	0.07(0.02–0.12)*
	+PM_{10}	0.03(− 0.04–0.09)
	+ NO_2	− 0.04(− 0.10–0.03)
	+ SO_2	0.03(− 0.02–0.09)
	+ O_3	0.07(0.02–0.12)*

*$p < 0.05$

toxic pollutants, such as organic compounds and transition metals, which have the ability to generate pro-inflammatory responses by activating reactive oxygen species (Brook et al. 2004), thus potentially contributing to IgE overproduction and increased permeability of nasal mucosa in susceptible individuals (Diaz-Sanchez et al. 1999; Diaz-Sanchez et al. 1996). It has also been reported that $PM_{2.5}$ may modify viability, apoptosis, cytokine release, and proliferation as well as apoptosis-regulating proteins of alveolar epithelial cells (Bayram 2017). There are no apparent plausible mechanisms by which CO influences the airway and enhances AR prevalence (Chen et al. 2016). Future studies are needed to investigate the mechanisms of CO-triggered AR.

Previous studies have demonstrated that the season might play an important role in the relationships between air pollutants and adverse health effects (Chou et al. 2017; Chu et al. 2019; Gu et al. 2017). Significantly stronger effects of SO_2 and O_3 on AR outpatients were found in the warm season in our study, which was consistent with previous studies (Chu et al. 2019; Zhang et al. 2013).

Fig. 4 Percent change (95% CI) of hospital outpatients for allergic rhinitis per 10 μg/m^3 increase in concentrations of six pollutants using different degrees of freedom per year



Generally, the highest association effects were found in outpatients under 15 years old, followed by those between 15 and 64 and ≥ 65 years of age. Previous studies speculated that children were most sensitive to air pollutants (Esposito et al. 2014; Zou et al. 2018). First, the respiratory system development is not complete at children. During the childhood, respiratory system is especially susceptible to toxicants (Goldizen et al. 2016; McBride 2015). Second, children have smaller airways than adults do, irritation caused by air pollution that would produce only a slight response in adult can result in potentially significant obstruction in a child (McBride 2015; Etzel 2007). Third, children have a higher rate of breathing, increasing the dose received (Goldizen et al. 2016). Fourth, children are shorter in height, thus their breath nearer the ground, and exposing them to higher concentrations of air pollutants (Goldizen et al. 2016; Etzel 2007). Fifth, children spend more time outside engaged in physical activity than adult does. Therefore, espousing them to higher dose of air pollutants (Goldizen et al. 2016). Finally, the detoxification systems of children are underdeveloped, which might cause serious health effects of exposure to environmental toxic substances (Goldizen et al. 2016). However, Wang et al. found higher sensitivity in the eldest outpatients (≥ 65) than in those 15–64 years of age (Wang and Chau 2013). In fact, several other studies observed no associations between PM and AR among children (Chu et al. 2019; Lin et al. 2016). These inconsistent results may be partially explained by economic statistics and the course of AR. Many AR episodes do not result in a hospital visit (Chen et al. 2016). In developing countries, especially in North China where the economy is poor, elderly patients did not visit the hospital until the symptoms were serious.

When patients were stratified by sex, we found higher associations in males, although the differences between sexes were insignificant. We speculate that this result might be due to occupational factors, as men may be engaged in more outdoor work, resulting in exposure to higher concentrations of air pollution. Esposito et al. found that boys are more affected than girls (Esposito et al. 2014), whereas the Nanjing study observed the opposite result (Chu et al. 2019). The exact reason for these differences between males and females must be elucidated in future studies.

Several limitations should be considered in our study. First, as our exposure data were obtained from fixed-site monitors, exposure measurement errors are inevitable. This could result in a misclassified exposure level. Previous studies have shown that this could produce a bias toward the null and underestimate the estimated effects (Zeger et al. 2000). Second, individual lifestyles (such as smoking and air conditioning use) and other exposure factors (such as plant pollen) can influence AR incidence (Samitas et al. 2018), which might affect the magnitude of the calculated estimates. Third, family history of AR and other allergy diseases is significantly associated with AR hospital outpatients (Dunlop et al. 2016). Due to the fact that the health data were collected from hospital outpatient records, the diseases history dates mentioned above were not collected. Finally, the study data were only collected from one highly polluted city, so the generalizability of our results may be limited.

Conclusions

This time-series study suggested that air pollutants, especially NO_2, SO_2, and PM_{10}, could significantly increase AR outpatient visits in Xinxiang, China. Children < 15 years old are the most vulnerable. This analysis provides a better understanding of the health effects of air pollution in developing countries. Although the air pollution level has been sharply reduced in 2018, the implementation of policies that seek to improve air quality should remain a priority.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interests.

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