



The association between PM_{2.5} exposure and daily outpatient visits for allergic rhinitis: evidence from a seriously air-polluted environment

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Abstract

Limited evidence was seen as the association between fine particulate matter (PM_{2.5}) and physician visits for allergic rhinitis (AR), especially in countries with extreme air pollution exposure. This paper addressed the issues about the association between PM_{2.5} and daily outpatient visits for AR among individuals residing in Beijing, China. Data on daily outpatient visits for AR obtained from Beijing Medical Claim Data for Employees and daily PM_{2.5} concentrations available from US embassy reports were linked by date from January 1, 2010, to June 30, 2012. A time-series analysis was conducted with a generalized additive Poisson model to assess the association between PM_{2.5} and AR, adjusting for daily average temperature, relative humidity, day of the week, calendar time, and public holiday. Totally, 229,685 outpatient visits for AR were included in the analysis. The daily mean (SD) concentration of PM_{2.5} was 99.5 (75.3) µg/m³ during the study period. We found that a 10-µg/m³ increase in PM_{2.5} content was associated with a 0.47% (95% CI: 0.39% to 0.55%) increase in the number of outpatient visits on the same day. Furthermore, results from subgroup analyses suggested that the association was consistently significant among the groups of different ages (< 65 years and ≥ 65 years) and gender. However, this study failed to find a statistically significant association in the autumn season but found significant positive associations during the spring and summer seasons (*P* for interaction < 0.001). This study indicated a possible association between PM_{2.5} and AR outpatients, which may benefit further researches in studying PM_{2.5} and its influence on diseases in a real and seriously air-polluted context.

Keywords Particulate matter 2.5 · Allergic rhinitis · Air pollution · Outpatients · Time-series

Introduction

As a global allergic disease, allergic rhinitis (AR) causes serious morbidity and disability worldwide (Brozek et al. 2017; Zhang and Zhang 2019). Symptoms of AR including rhinorrhea, sneezing, nasal congestion, and nasal itching could result in reduced quality of life (Brozek et al. 2017). In addition, AR is associated with a great loss of productivity and considerable economic burdens (Dykewicz and Hamilos

2010; Seidman et al. 2015; Yoo et al. 2016). The prevalence of AR has increased in recent years worldwide, with a variation of 10–40% across different countries (Sakashita et al. 2010; Katelaris et al. 2012; Teng et al. 2017). Approximately, the prevalence of AR was 8.7% in Asia and 14% in China (Teng et al. 2017).

Epidemiologic studies have reported positive associations between ambient levels of air pollution and increased mortality and hospital visits for cardiovascular and respiratory diseases (Di et al. 2017; Pun et al. 2017; Tian et al. 2017; Tian et al. 2018). Among the individual air pollutants, the particulate with an aerodynamic diameter of 2.5 µm or less (PM_{2.5}) was considered to be strongly associated with adverse health effects on respiratory system due to deep deposition into the lungs and large concentration of toxic substances per unit mass (Pope and Dockery 2006; Sarnat et al. 2016). Previous studies showed that long-term exposure of high PM_{2.5} content could possibly lead to an increased risk of AR (Parker et al.

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2009; Zhang et al. 2009; Nishijima et al. 2018). However, little is known about the short-term effect of ambient $PM_{2.5}$ on AR. Furthermore, outpatient data was considered as a possible outcome metric to represent the short-term effect of air pollution on health, which has been practiced extensively by literature review. (Wang and Chau 2013; Liu et al. 2017). Despite an important contributor to general practice office visits, outpatient visit data on AR was limited in many countries due to a lack of available information from the general practitioner-based referral system (Cayirli et al. 2010). In addition, although AR affects mostly adults (Min 2010), most of the previous studies merely evaluated the effect of $PM_{2.5}$ on AR among children (Zou et al. 2018; Chen et al. 2019). Therefore, further investigation on the association between $PM_{2.5}$ and outpatient visits for AR among adults is expected to suffice the evidence.

With the rapid urbanization and economic growth, China has been smothered by the severe and deteriorating air pollution. As the capital city of China, Beijing is confronted with a serious air pollution problem. Moreover, accumulating evidence has demonstrated $PM_{2.5}$ was associated with various adverse health impacts in Beijing (Li et al. 2018a, b; Guan et al. 2019). Thus, we conducted the current study to examine the association between $PM_{2.5}$ and daily outpatient visits for AR among adult individuals residing in Beijing, China, over the period of January 1, 2010, to June 30, 2012, using a time-series design.

Materials and methods

Study area

Beijing is located in northeastern China; the city covers 14 districts and 2 counties, with a total area of about 16,410.54 km². The population size in Beijing is more than 20 million, and 51.6% of them are males. In addition, Beijing has a sub-humid warm temperate continental monsoon climate, with a hot and humid summer and a cold and dry winter. In recent years, Beijing has experienced extremely serious and persistent haze pollution, especially in autumn and winter (Chen et al. 2018). Moreover, according to Köppen-Geiger climate classification, Beijing belongs to the climate type Dwa (Yang and Matzarakis 2016).

Hospitalization data

Data on daily outpatient visits for AR was obtained from Beijing Medical Claim Data for Employees (BMCDE). The BMCDE database recorded medical claim data for all working or retired employees covered by basic medical insurance in Beijing. The information including basic demographics (sex and age), dates of hospital visits, medication use, and

discharge diagnosis in Chinese and corresponding International Classification of Diseases, 10th Revision (ICD-10) codes was recorded in BMCDE. Daily outpatient visits for AR were identified using the ICD-10 code of J30.401 from January 1, 2010, to June 30, 2012, and were checked using the corresponding Chinese diagnoses.

Environmental data

The data of daily $PM_{2.5}$ content from January 1, 2010, to June 30, 2012, was available from US embassy reports, which were based on an air quality monitoring station on the rooftop of the embassy building located in Chaoyang District, Beijing, and could represent the citywide $PM_{2.5}$ content (Wang et al. 2013; Tian et al. 2017). It has been reported that all areas with population density > 5000 people/km², 97.8% of the tertiary hospitals, and 79.3% of the secondary hospitals in Beijing are located within a 40-km radius of the monitoring station (Xie et al. 2015). In addition, 79.2% of the total residents in Beijing lived within a 40-km radius of the monitoring station. Previous studies have shown that for individuals residing < 40 km from the monitoring station, the monitoring data could estimate personal exposure with the minimum error (Wilson and Suh 1997; Li et al. 2018a, b). Meteorological data of daily 24-h average temperature (°C) and relative humidity (%) were obtained from the Chinese Meteorological Bureau.

Statistical analysis

Daily average $PM_{2.5}$ content, daily outpatient visits for AR, and meteorological data were linked by date from January 1, 2010, to June 30, 2012. We conducted a time-series analysis using a generalized additive Poisson model to assess the association between $PM_{2.5}$ and AR, adjusting for daily average temperature, relative humidity, day of the week, calendar time, and public holiday.

$$\text{Log}[E(Y_t)] = \alpha + \beta PM_{2.5} + \text{day of the week} + \text{public holiday} + ps(\text{calendar time}, 10) + ps(\text{temperature}, 3) + ps(\text{relative humidity}, 3)$$

In the model above, t represents the day of the observation; $E(Y_t)$ denotes the expected number of outpatient visits for AR on day t ; α is the model intercept; $PM_{2.5}$ is the mean $PM_{2.5}$ concentration on day t ; β represents regression coefficient (log-relative risk of AR in relation to a unit increase in $PM_{2.5}$); $ps()$ denotes penalized spline function.

Public holiday and the day of the week were adjusted as categorical variables to control for the differences in outpatient visits rates for each day in the model. We used the penalized spline (ps) function of calendar time with 10 degrees of freedom (df) to adjust for seasonality and long-term trends. In addition, we adopted the ps functions of daily average temperature ($df = 3$) and relative humidity ($df = 3$) to control for

the potential nonlinear confounding effects of weather conditions (Dominici et al. 2006; Kan et al. 2007; Xie et al. 2015).

Besides, to assess the temporal association between $PM_{2.5}$ and outpatient visits for AR, we fitted the models with single-day lag structures from the current day (lag0) up to two lag days (lag02) as well as multiple-day lags (lag0–1 and lag0–2). In single-day lag models, a lag of 0 days (lag0) means the current-day $PM_{2.5}$, and a lag of 1 day (lag01) corresponds to the previous-day pollution. In multi-day lag models, lag0–2 refers to a 3-day moving average of $PM_{2.5}$ content of the current and previous 2 days. In addition, we conducted subgroup analyses to evaluate whether the association differed by sex, age (≥ 65 years and < 65 years), or season (spring, summer, autumn, and winter). Spring season was defined as March to May, summer season as June to August, autumn season as September to November, and winter season as December to February in the next year. Moreover, warm season was defined as April to September, and cold season was defined as the rest of the months in a year. The *Z* test was adopted to test the differences between the different subgroups, where *Z* was calculated by the estimates of the two groups and compared to the standard normal distribution (Altman and Bland 2003). Sensitivity analyses were also performed in terms of the df in the smooth function of time trend (8–12), daily mean temperature (2–6), and daily relative humidity (2–6).

All statistical analyses were conducted using R software (V3.5.1) with the “mgcv” and “nlme” packages. All statistical tests were two-sided, and $P < 0.05$ was considered as statistically significant.

Results

The basic characteristics of the outpatient visits for AR in Beijing, China, from January 1, 2010, to June 30, 2012, were shown in Table 1. There were 229,685 outpatient visits for

Table 1 Basic characteristics of the outpatient visits for allergic rhinitis between January 1, 2010, and June 30, 2012, in Beijing, China

Characteristics	All year	Cold season	Warm season
Total outpatient visits	229,685	80,341	149,344
Sex, <i>n</i> (%)			
Male	92,942 (40.50)	47,896 (59.62)	60,497 (40.51)
Female	136,743 (59.50)	32,445 (40.38)	88,847 (59.49)
Age (years), <i>n</i> (%)			
< 35	47,071 (20.49)	14,703 (18.30)	32,368 (21.67)
35–44	41,523 (18.08)	13,094 (16.30)	28,429 (19.04)
45–54	53,983 (23.50)	18,810 (23.41)	35,173 (23.55)
55–64	46,825 (20.39)	17,865 (22.24)	28,960 (19.39)
65–74	25,363 (11.04)	9931 (12.36)	15,432 (10.33)
≥ 75	14,920 (6.50)	5938 (7.39)	8982 (6.02)

AR, with mean (standard deviation, SD) age of 50.1 ± 15.1 years. In addition, 82.5% of the patients were aged < 65 years. The percentage of males was 40.5%. Moreover, 65.0% of the visits occurred during the warm season.

Table 2 summarized the data for the daily number of outpatient visits for AR, $PM_{2.5}$ concentration, and meteorological variables. The daily mean outpatient visits for AR were 252 during the study period. Furthermore, the average daily mean (SD) concentration of $PM_{2.5}$ was $99.5 (75.3) \mu\text{g}/\text{m}^3$, with a variation from 7.2 to $492.8 \mu\text{g}/\text{m}^3$. The average daily mean (SD) concentration of $PM_{2.5}$ was $103.4 (89.8) \mu\text{g}/\text{m}^3$ during the cold season and $93.8 (57.3) \mu\text{g}/\text{m}^3$ during the warm season. The average daily mean temperature and relative humidity were 12.6°C and 48.6%, respectively.

The association between $PM_{2.5}$ and outpatient visits for AR was presented in Table 3. After adjusting for temperature, relative humidity, public holiday, day of the week, and time trend, we found a significant temporal association between $PM_{2.5}$ and outpatient visits for AR on the same day, where a $10\text{-}\mu\text{g}/\text{m}^3$ increase in $PM_{2.5}$ content was associated with a 0.47% (95% CI: 0.39% to 0.55%) increase in the number of outpatient visits for AR. However, there was a significant association between $PM_{2.5}$ and the decrease in AR outpatient visits on lag 1 day (-0.41% , 95% CI: -0.48% to -0.34%) and lag 2 days (-0.45% , 95% CI: -0.51% to -0.39%). In addition, a negative association was observed with 3-day (lag0–2, -0.45% , 95% CI: -0.55% to -0.35%) cumulative measures of $PM_{2.5}$.

In the subgroup analysis by sex, we detected significant associations between $PM_{2.5}$ and outpatient hospital visits for AR among both men (0.47%, 95% CI: 0.34% to 0.59%) and women (0.47%, 95% CI: 0.37% to 0.58%). In addition, a $10\text{-}\mu\text{g}/\text{m}^3$ increase in $PM_{2.5}$ concentrations on the same day corresponded to a 0.40% (95% CI: 0.31% to 0.49%) increase in AR outpatients among the participants aged < 65 years and 0.76% (95% CI: 0.57% to 0.96%) among those aged ≥ 65 years. Furthermore, we failed to observe a significant increase in AR outpatients in autumn season ($P = 0.106$) but found significant increase in AR outpatients in spring season (0.40%, 95% CI: 0.22% to 0.57%) and summer season (2.23%, 95% CI: 1.97% to 2.49%) (Table 4).

We conducted sensitivity analyses by different df for calendar time, temperature, and relative humidity, and the results were shown in Table 5. We found the risk estimates were stable when changing df for calendar time, temperature, and relative humidity.

Discussion

Our study has suggested a significant association between $PM_{2.5}$ and AR morbidity between January 1, 2010, and June 30, 2012, in Beijing, China. An increase in daily $PM_{2.5}$

Table 2 Summary of the daily number of outpatient visits for allergic rhinitis and environmental variables

Variables	Mean	SD	Maximum	Median	Minimum	IQR
Number of outpatient visits	251.8	336.8	1866	76	0	430
PM _{2.5} (μg/m ³)	99.5	75.3	492.8	82.8	7.2	90.8
Cold season	103.4	89.8	492.8	72.5	9.9	107.5
Warm season	93.8	57.3	301.8	90.1	7.2	81.4
Temperature (°C)	12.6	11.6	34.5	14.1	−12.5	22.3
Relative humidity (%)	48.6	20.3	92	48	9	36

SD standard deviation, IQR interquartile range

concentrations by 10 μg/m³ would cause 0.47% (95% CI: 0.39% to 0.55%) higher number of AR outpatients on the same day after adjusting for temperature, relative humidity, public holiday, day of the week, and time trend. Our findings have sufficed the evidence for exploring the association between PM_{2.5} and AR in a real-world context with severe air pollution and may further suggest public health implications.

Several epidemiological studies have been conducted to explore the association between PM_{2.5} and physical visits for AR in western countries (Hajat et al. 2001; Villeneuve et al. 2006). However, limited evidence was seen in this topic in China, possibly due to a lack of PM_{2.5} monitoring data and morbidity data of AR. For example, a time-series analysis was conducted to estimate the effect of PM₁₀, sulfur dioxide, and nitrogen dioxide except for PM_{2.5} on daily outpatient visits for AR in Beijing, China (Zhang et al. 2011). A recent study conducted in Changchun, China, investigating the association between air pollutants and AR from 2013 to 2015 found that each 1-SD increase of PM_{2.5} corresponded to 10.2% AR morbidity (Teng et al. 2017). The results also suggested that the highest risk of AR from PM_{2.5} occurred on the same day, which was similar to our findings. While we detected a significant negative association between AR outpatients and PM_{2.5} at lag 1 day and lag 2 days. Possible explanations for the discrepancy of lag effects included different types of hospital utilization, pollution composition, environmental factors, population characteristics, and allergen exposure among cities. Thus, the findings should be interpreted with caution, and the association between PM_{2.5} and AR outpatients is to be detailed in further studies.

In the subgroup analyses, the associations were consistently significant in men and women. In addition, we found younger AR patients were less vulnerable to PM_{2.5} when compared with older patients, where a 10-μg/m³ increase in PM_{2.5} was associated with a 0.76% increase in outpatient visits for AR on the same day among patients aged ≥ 65 years (*P* for interaction < 0.001). The finding was different from a study conducted in Toronto that effect of PM_{2.5} on AR among those aged ≥ 65 years was tiny due to limited outdoor activities (Villeneuve et al. 2006). For Beijing, air quality in the warm season, especially from June to August, is relatively better. However, the air quality is comparatively poor during the cold

season due to biomass burning sources in Beijing (Zhang et al. 2011). Our study also showed that PM_{2.5} concentrations during the cold season were higher than that during the warm months. In the subgroup analysis by specific four seasons, we found a significant increase in AR outpatients in the spring and summer season. Potential explanations for the result may include that air pollen could increase the outpatient visits for AR, and the concentration of air pollen peaks during the warm season (Zhang et al. 2012). However, our study failed to take air pollen into consideration due to the lack of this data. Thus, future studies are warranted to evaluate the effect of PM_{2.5} on AR considering the role of more exposure as air pollen.

The possible mechanism of the association between PM_{2.5} and AR has been demonstrated by several experimental studies, yet the findings remain controversial to date. Allergens are one of the most important factors contributing to the risk of AR (Greiner et al. 2011). Allergen-induced inflammatory response includes IgE-mediated mast cell activation (early phase response) and a late phase response involving the recruitment of eosinophils, basophils, and T lymphocytes (Li et al. 2019). Animal studies have shown high PM_{2.5} concentrations could cause imbalance of T helper cells and promote Th2- and Th17-mediated immune responses in AR mice (Li et al. 2018a, b). In addition, the effect of PM_{2.5} on AR might be mediated through epigenetic regulations (Li et al. 2018a, b). Due to the complex etiology of AR, the pathophysiology of the effect of PM_{2.5} on AR needs to be explored further.

The study had a great statistical power to detect small increases in AR caused by PM_{2.5} due to a large number of

Table 3 The association between a 10-mg/m³ increase of PM_{2.5} and percentage change with 95% confidence interval in outpatient visits for allergic rhinitis for different lag periods

Lag days	Percentage change (%)	95% CI	<i>P</i>
Lag 0	0.47	0.39 to 0.55	< 0.001
Lag 1	−0.41	−0.48 to −0.34	< 0.001
Lag 2	−0.45	−0.51 to −0.39	< 0.001
Lag 0–1	−0.08	−0.18 to 0.01	0.091
Lag 0–2	−0.45	−0.55 to −0.35	< 0.001

CI confidence interval

Table 4 The association between a 10-mg/m³ increase of PM_{2.5} and percentage change with 95% confidence interval in outpatient visits for allergic rhinitis on the same day by sex, age, and season

Variables	Percentage change (%)	95% CI	<i>P</i>	<i>P</i> for interaction
Sex				
Male	0.47	0.34 to 0.59	< 0.001	< 0.001
Female	0.47	0.37 to 0.58	< 0.001	
Age				
< 65	0.40	0.31 to 0.49	< 0.001	< 0.001
≥ 65	0.76	0.57 to 0.96	< 0.001	
Season				
Spring	0.40	0.22 to 0.57	< 0.001	< 0.001
Summer	2.23	1.97 to 2.49	< 0.001	
Autumn	0.16	− 0.03 to 0.35	0.106	
Winter	− 0.71	− 0.95 to − 0.47	< 0.001	

CI confidence interval

outpatient visits studied. Since the study was based on medical health records, AR diagnosis did not rely on self-reported symptoms but made by trained health professionals, which may reduce the information bias in the study. Besides, Beijing is a heavily polluted city, which enables an evaluation of the exposure-response association between a wide range of PM_{2.5} concentrations and outpatients visits for AR comprehensively.

Nevertheless, the study has some limitations to be addressed. First, the air pollution data was obtained from one single monitoring station, which may cause exposure

Table 5 The association between a 10-mg/m³ increase of PM_{2.5} and percentage change with 95% confidence interval in outpatient visits for allergic rhinitis on the same day by different degree of freedom (df) for calendar time, temperature, and relative humidity

Variables	Percentage change (%)	95% CI	<i>P</i>
Calendar time			
8	0.38	0.30 to 0.46	< 0.001
9	0.33	0.25 to 0.41	< 0.001
10	0.47	0.39 to 0.55	< 0.001
11	0.22	0.14 to 0.30	< 0.001
12	0.15	0.06 to 0.23	0.001
Temperature			
2	0.47	0.39 to 0.55	< 0.001
3	0.47	0.39 to 0.55	< 0.001
4	0.78	0.70 to 0.86	< 0.001
5	0.59	0.51 to 0.68	< 0.001
6	0.65	0.57 to 0.74	< 0.001
Relative humidity			
2	0.47	0.39 to 0.55	< 0.001
3	0.47	0.39 to 0.55	< 0.001
4	0.45	0.37 to 0.53	< 0.001
5	0.47	0.38 to 0.55	< 0.001
6	0.47	0.39 to 0.55	< 0.001

CI confidence interval

measurement errors. Second, we have no access to individual characteristics including socioeconomic status and preexisting diseases in the medical database. Chronic diseases including chronic obstructive pulmonary disease and myocardial infarction may modify the association between PM_{2.5} and AR. Therefore, additional studies with more detailed information on the characteristics of the participants are anticipated to confirm these results. Moreover, monitoring data on other air pollutants, such as sulfur dioxide, nitrogen dioxide, carbon monoxide, and ozone, were unavailable in the analysis. Thus, we failed to examine the independent effect of PM_{2.5} considering the correlations between different air pollutants. Further studies are warranted to assess the independent effect of PM_{2.5} on AR.

In conclusion, this study used a population-based medical database to examine the association between PM_{2.5} and daily AR-attributed outpatient visits. We detected significant associations between short-term exposure to PM_{2.5} and AR outpatients on the same day. The findings demonstrate more attention to be drawn on the adverse health impact of air pollution in clinical practice as well as imposing effective measures to reduce possible environmental pollution in Beijing, China.

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Compliance with ethical standards

Ethical statement Since the data used in the present study was collected for administrative purpose without any personal identifiers, it is considered exempt from institutional review board approval.

References

Altman DG, Bland JM (2003) Interaction revisited: the difference between two estimates. *BMJ* 326:219

- Brozek JL, Bousquet J, Agache I et al (2017) Allergic Rhinitis and its Impact on Asthma (ARIA) guidelines-2016 revision. *J Allergy Clin Immunol* 140:950–958
- Cayirli T, EJP V, Management O (2010) Outpatient scheduling in health care: a review of literature. 12:519–549
- Chen X, Li X, Yuan X et al (2018) Effects of human activities and climate change on the reduction of visibility in Beijing over the past 36years. *Environ Int* 116:92–100
- Chen Z, Cui L, Cui X et al (2019) The association between high ambient air pollution exposure and respiratory health of young children: a cross sectional study in Jinan, China. *Sci Total Environ* 656:740–749
- Di Q, Dominici F, Schwartz JD (2017) Air pollution and mortality in the Medicare population. *N Engl J Med* 377:1498–1499
- Dominici F, Peng RD, Bell ML et al (2006) Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA* 295:1127–1134
- Dyckewicz MS, Hamilos DL (2010) Rhinitis and sinusitis. *J Allergy Clin Immunol* 125:S103–S115
- Greiner AN, Hellings PW, Rotiroti G, Scadding GK (2011) Allergic rhinitis. *Lancet* 378:2112–2122
- Guan T, Xue T, Gao S et al (2019) Acute and chronic effects of ambient fine particulate matter on preterm births in Beijing, China: a time-series model. *Sci Total Environ* 650:1671–1677
- Hajat S, Haines A, Atkinson RW et al (2001) Association between air pollution and daily consultations with general practitioners for allergic rhinitis in London, United Kingdom. *Am J Epidemiol* 153:704–714
- Kan H, London SJ, Chen G et al (2007) Differentiating the effects of fine and coarse particles on daily mortality in Shanghai, China. *Environ Int* 33:376–384
- Katalaris CH, Lee BW, Potter PC et al (2012) Prevalence and diversity of allergic rhinitis in regions of the world beyond Europe and North America. *Clin Exp Allergy* 42:186–207
- Li Y, Mu Z, Wang H, Liu J, Jiang F (2018a) The role of particulate matters on methylation of IFN-gamma and IL-4 promoter genes in pediatric allergic rhinitis. *Oncotarget* 9:17406–17419
- Li M, Wu Y, Tian YH, et al. (2018b) Association between PM2.5 and daily hospital admissions for heart failure: a time-series analysis in Beijing. *Int J Environ Res Public Health* 15
- Li Y, Zhou J, Rui X, Zhou L, Mo X (2019) PM2.5 exposure exacerbates allergic rhinitis in mice by increasing DNA methylation in the IFN-gamma gene promoter in CD4+T cells via the ERK-DNMT pathway. *Toxicol Lett* 301:98–107
- Liu Y, Xie S, Yu Q et al (2017) Short-term effects of ambient air pollution on pediatric outpatient visits for respiratory diseases in Yichang city, China. *Environ Pollut* 227:116–124
- Min YG (2010) The pathophysiology, diagnosis and treatment of allergic rhinitis. *Allergy, Asthma Immunol Res* 2:65–76
- Nishijima H, Suzuki S, Kondo K, Yamasoba T, Yanagimoto S (2018) Environmental factors associated with allergic rhinitis symptoms in Japanese university students: a cross-sectional study. *Auris Nasus Larynx* 45:1006–1013
- Parker JD, Akinbami LJ, Woodruff TJ (2009) Air pollution and childhood respiratory allergies in the United States. *Environ Health Perspect* 117:140–147
- Pope CA III, Dockery DW (2006) Health effects of fine particulate air pollution: lines that connect. *J Air Waste Manage Assoc* 56:709–742
- Pun VC, Kazemiparkouhi F, Manjourides J, Suh HH (2017) Long-term PM2.5 exposure and respiratory, cancer, and cardiovascular mortality in older US adults. *Am J Epidemiol* 186:961–969
- Sakashita M, Hirota T, Harada M et al (2010) Prevalence of allergic rhinitis and sensitization to common aeroallergens in a Japanese population. *Int Arch Allergy Immunol* 151:255–261
- Sarnat SE, Chang HH, Weber RJ (2016) Ambient PM2.5 and health: does PM2.5 oxidative potential play a role? *Am J Respir Crit Care Med* 194:530–531
- Seidman MD, Gurgel RK, Lin SY et al (2015) Clinical practice guideline: allergic rhinitis. *Otolaryngol Head Neck Surg* 152:S1–S43
- Teng B, Zhang X, Yi C, et al. (2017) The association between ambient air pollution and allergic rhinitis: further epidemiological evidence from Changchun, Northeastern China. *Int J Environ Res Public Health* 14
- Tian Y, Xiang X, Juan J et al (2017) Fine particulate air pollution and hospital visits for asthma in Beijing, China. *Environ Pollut* 230:227–233
- Tian Y, Liu H, Zhao Z et al (2018) Association between ambient air pollution and daily hospital admissions for ischemic stroke: a nationwide time-series analysis. *PLoS Med* 15:e1002668
- Villeneuve PJ, Doiron MS, Stieb D et al (2006) Is outdoor air pollution associated with physician visits for allergic rhinitis among the elderly in Toronto, Canada? *Allergy* 61:750–758
- Wang KY, Chau TT (2013) An association between air pollution and daily outpatient visits for respiratory disease in a heavy industry area. *PLoS One* 8:e75220
- Wang JF, Hu MG, Xu CD, Christakos G, Zhao Y (2013) Estimation of citywide air pollution in Beijing. *PLoS One* 8:e53400
- Wilson WE, Suh HH (1997) Fine particles and coarse particles: concentration relationships relevant to epidemiologic studies. *J Air Waste Manage Assoc* 47:1238–1249
- Xie W, Li G, Zhao D et al (2015) Relationship between fine particulate air pollution and ischaemic heart disease morbidity and mortality. *Heart* 101:257–263
- Yang SQ, Matzarakis A (2016) Implementation of human thermal comfort information in Koppen-Geiger climate classification-the example of China. *Int J Biometeorol* 60:1801–1805
- Yoo KH, Ahn HR, Park JK et al (2016) Burden of respiratory disease in Korea: an observational study on allergic rhinitis, asthma, COPD, and rhinosinusitis. *Allergy, Asthma Immunol Res* 8:527–534
- Zhang Y, Zhang L (2019) Increasing prevalence of allergic rhinitis in China. *Allergy, Asthma Immunol Res* 11:156–169
- Zhang L, Han D, Huang D et al (2009) Prevalence of self-reported allergic rhinitis in eleven major cities in China. *Int Arch Allergy Immunol* 149:47–57
- Zhang F, Wang W, Lv J, Krafft T, Xu J (2011) Time-series studies on air pollution and daily outpatient visits for allergic rhinitis in Beijing, China. *Sci Total Environ* 409:2486–2492
- Zhang F, Krafft T, Zhang D, Xu J, Wang W (2012) The association between daily outpatient visits for allergic rhinitis and pollen levels in Beijing. *Sci Total Environ* 417–418:39–44
- Zou QY, Shen Y, Ke X, Hong SL, Kang HY (2018) Exposure to air pollution and risk of prevalence of childhood allergic rhinitis: a meta-analysis. *Int J Pediatr Otorhinolaryngol* 112:82–90