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Time-series studies on air pollution and daily outpatient visits for allergic rhinitis in Beijing, China

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ABSTRACT

To investigate the effects of urban air quality change on health, we carried out a time-series analysis of daily general practitioner consultations for allergic rhinitis (AR) in Beijing, China. Non-parametric generalized additive model (GAM) was used to analyze the highly non-linear or non-monotonic exposure–response relationship between three air pollutants (namely PM₁₀, SO₂ and NO₂) and daily outpatient visits for AR, after controlling for long term trends, the ‘day of the week’ effect and confounding meteorological factors. The objective of this study was to assess the possible effects of air pollutants on outpatient visits caused by AR in Beijing during the period 2009–2010. Our work indicates that strong associations exist between daily concentration of the three air pollutants and the daily number of outpatients for AR.

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1. Introduction

Allergic rhinitis (AR) has become a serious systemic allergic disease that, along with asthma, causes major illness and disability worldwide (Arnedo et al., 2009; Bousquet et al., 2008). The symptoms occur in the nose and eyes; and patients can become severely restricted in their daily activities resulting inter alia in excessive absenteeism from work place or school. The prevalence of AR disease has increased in recent decades (Hajat et al., 2001; Hwang et al., 2006; Lindgren et al., 2009) and has apparently spread across a wider age range (Grize et al., 2006; Hajat et al., 2001; Zhang et al., 2009). The self-reported prevalence of AR was 30.0% in 2978 children in Beijing in 1995–1996 (Zhao et al., 2000). There is accumulating evidence that both genetic and environmental factors play important roles in the etiology of AR (Kramer et al., 2000; Li et al., 2009). However, large increases in the prevalence of AR within a short period of time are unlikely to be explained by variations in the genetic background (Hsu et al., 2009; Hwang et al., 2006; Kim and Bernstein, 2009). Therefore, further studies on the influence of environmental factors on AR prevalence are necessary (D’Amato, 2003; Grize et al., 2006; Hajat et al., 2001; Zhang et al., 2009). It is well established that even small increases in the daily concentrations of air pollutants can cause

adverse health effects (Penard et al., 2005). Air pollutants, especially diesel exhaust particulates, are able to trigger an Immunoglobulin E (IgE)-response (Polosa, 2001). Dust storms and high particulate matter content in the air were related to the increase of the number of daily outpatients seeking treatment for respiratory and circulatory diseases (Meng et al., 2007). Recent studies have shown an association between high levels of air pollution and an increased risk of allergic sensitization and prevalence of rhinitis (Bhattacharyya, 2009; Mosges and Klimek, 2007; Zhang et al., 2009). The increase in atmospheric pollutant (NO₂, SO₂, PM₁₀, etc.) levels could be one of the possible explanations for the current increase in the prevalence of AR (Hsu et al., 2009; Hwang et al., 2006; Kim and Bernstein, 2009; Kramer et al., 2000; Medina et al., 1997), although contradictory findings have been published for the NO₂, O₃ and PM₁₀ levels based on some long term studies on children (Ramadour et al., 2000).

Most studies are related to epidemiological research on possible causalities between air pollution and allergic conditions (Lee et al., 2003; Leung et al., 1997; Luke et al., 2006; Makra et al., 2008). Studies on controlled long term trends, the ‘day of the week’ effect and confounding meteorological factors, to analyze the highly non-linear or non-monotonic exposure–response relationship between air pollutants and daily outpatients visits for AR are rare (Hajat et al., 2001, 2002). A large number of epidemiologic studies that analyzed effects from traffic related pollution on asthma and/or rhinitis have focused on children (Hsu et al., 2009; Hwang et al., 2006; Kim et al., 2009; Kramer et al., 2000; Lee et al., 2003; Penard et al., 2005; Zhao, 2008; Zhao et al., 2000). Few air pollution studies have focused on AR

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as an outcome among adults (Villeneuve et al., 2006; Zhang et al., 2009); although in adults, a higher proportion of this disease is triggered by non-allergic factors than in children. Lindgren et al. (2009) have shown that exposure to traffic related pollution is associated with a higher prevalence of AR in adults.

For Beijing with its serious air pollution problem, previous studies have demonstrated some adverse health effects of air pollutants, indicated in daily hospital admissions for stroke and cardiovascular disease in Beijing (Guo et al., 2009). But to our knowledge no earlier study has examined the relationship between daily outpatient clinic visits for AR and daily concentration of air pollutants. This is mainly due to a lack of insufficient information from general practitioners (GP) (Zhang et al., 2009). Such studies require a sufficient number of patients with a clinically confirmed AR diagnosis and a characterization of the responsible allergens (Li et al., 2009).

GAM has been used for scientific research in various fields (Ballester et al., 2010; Bayentin et al., 2010; Damalas and Megalofonou, 2010; Dominici et al., 2002; Gutierrez and Bilton, 2010; Powell et al., 2010). In the field of ecology, it was widely used to forecast the species distribution; in the field of fishing research, it was often used to analyze the distribution of fishes; in the field of public health, it was mainly used to study the distribution of infectious disease (Dominici et al., 2002; Jiang et al., 2007; Mentzakis and Delfino, 2010; Ramsay et al., 2003; Tsai et al., 2010; Wood and Augustin, 2002).

We carried out a time-series analysis of daily general practitioner consultations for AR in Beijing, China. Non-parametric generalized additive model (GAM) was used to analyze the highly non-linear or non-monotonic exposure–response relationship between air pollutants and daily outpatient visits for AR, after controlling for long term trends, the ‘day of the week’ effect and confounding meteorological factors. The object of this study was to assess the possible effects of air pollutants on (adult) outpatient visits for AR in Beijing during the period 2009–2010. The study is the first one to undertake such a comprehensive analysis for Beijing, and even the first one for China. Our results and methods should be applicable to other cities in China, and are intended to also contribute to the emerging discussion in China on global change, urbanization and health (Wang et al., 2006).

2. Materials and method

2.1. General practitioner consultation data

Daily numbers of outpatients consulting general practitioners for AR between March 19 2009 and March 18 2010 (study period) were obtained from the Department of Otolaryngology-Head and Neck Surgery, Beijing Hospital, Ministry of Public Health. Beijing Hospital, selected for our study is a Class-Three, Grade A level hospital, located in the Dong Cheng district in central Beijing providing on a large-scale integrated health services including comprehensive medical treatment, teaching and education, scientific research and disease prevention. The hospital is open to the general public. The number of children and adolescent consulting Beijing Hospital as outpatients is relatively small, because they are usually treated at specialized pediatric clinics. This age group (non-adult) is therefore underrepresented in this study.

2.2. Study populations and definitions

The study population comprises of all outpatients examined by general practitioners of Beijing hospital, during March 19 2009 to March 18 2010. For this study, AR was defined as having symptoms of sneezing, or a running, itchy or blocked nose when the patient did not have a cold or flu. The diagnosis of rhinitis was based on the evaluation of a patient's medical history, a standardized questionnaire and the relevant test (skin prick test, trying to find the possible allergen).

This study was approved by the Ethics Review Board of the hospital and all patients gave written consent to participate in the study.

2.3. Air pollution, meteorological data

Air Quality data was provided by the Beijing Municipal Environmental Protection Monitoring Center on daily PM₁₀, SO₂, NO₂ concentrations. The data was available as average values derived from the data of 11 state-controlled monitoring stations distributed across Beijing.

Daily maximum, average and minimum temperatures and humidity for Beijing were obtained from the Beijing Meteorological Office.

2.4. Questionnaire

For further examination of any outpatient showing the symptoms of AR, a physician or a qualified research nurse at Beijing hospital used a standardized questionnaire. The questionnaire covered demographic characteristics, family history of allergic diseases, symptoms of rhinitis, wheezing or cough, eczema and burning or itching of the eyes, smoking habits, environmental exposure factors, pet ownership.

2.5. Data analysis

All data was entered into the data base twice by two independent investigators and then validated. The Pearson correlation coefficients among the variables were analyzed using SPSS 13.0 for Windows (Statistical Package for Social Science).

We used the generalized additive model (GAM) with penalized splines to analyze the AR, air pollution, and covariates (meteorological factors, time, and day of the week). Because the daily number of consultations for AR was small and typically followed a Poisson distribution (Dominici et al., 2002; Hajat et al., 2001), the core analysis was a generalized additive model (GAM) with log link and Poisson error that accounted for smooth fluctuations in daily number of consultations for AR patient.

We first built the basic models for daily number of consultations for AR patients excluding the air pollution variables. We incorporated smoothed spline functions of time and weather conditions, which can accommodate non-linear and non-monotonic patterns between daily number of consultations for AR patient and time/weather conditions, offering a flexible modeling tool (Dominici et al., 2002; Hajat et al., 2001). Other covariates, such as day of the week (DOW), were also included in the basic models. Residuals of each model were discernible patterns and autocorrelation by means of residual plots and partial autocorrelation function plots, respectively.

After the establishment of basic models, we introduced the pollutant variables into the models and analyzed their effects on daily number of consultations for AR patients. This number of consultations for AR patients was used as an offset. Goodness of fit for each statistical model was assessed for the model dispersion-penalized AIC (Akaike's Information Criterion) and the partial autocorrelation functions (PACF) to determine the degree of remaining serial correlation (non-independence of adjacent days).

All statistical analyses were carried out by using S-Plus software (Insightful Corp, Seattle, USA). Considering the fact that the default settings in the GAM function of the S-Plus software package do not assure convergence of its iterative estimation procedure and can provide biased estimates of regression coefficients and standard errors, we analyzed the data with more stringent convergence parameters than the default settings when using the GAM function (Dominici et al., 2003).

2.6. Quality control

Uniform examination protocols and standardized patient questionnaires were used for this study. All interviewers (general practitioners or

research nurses) and all performers of the skin tests were carefully trained before the study. Results of patient questionnaire and skin prick test were sent every month to the Institute of Geographic Sciences and Natural Resources Research, CAS. For each patient in this study, the respective patient questionnaire and the skin test report were verified by the centre supervisor. The results were double-checked by the principal investigator. All questionnaire and skin test data was coded and entered into a programmed database by two persons independently. The data was checked for out-of-range values and logical mistakes.

As the control for confounding variables is a critical issue (Hajat et al., 2001). Our statistical models were constructed following an accepted methodology and were checked following accepted standards (Dominici, et al., 2002, 2003) standard to ensure that the model fit was satisfactory.

3. Results

3.1. Characteristics of outpatients reporting AR

This time-series study was conducted for a period of 12 months (March 2009 to March 2010). A total number of 31,829 outpatients attended the Department of Otolaryngology-Head and Neck Surgery at Beijing Hospital during this period. 1506 of these were diagnosed with AR. Table 1 summarizes the main characteristics of the AR patients. The gender distribution was about 1:1. Both groups of male patients and female patients showed increasing trends with age. A large number of patients belonged to age group below 40. The low representation of the age group below 20 years is the result of children and adolescent being treated at pediatric clinics. Three quarters or 74.7% of patients belonged to the age group younger than 60 years.

The statistical characteristics of daily number for AR patients, outpatients and the ratio (ratio = (number of AR patients/number of outpatients) × 100%) are shown in Table 2.

Fig. 1 shows the daily numbers of outpatients (adults) between March 19, 2009, and March 18, 2010. The daily number of patients ranges from 60 to 251. Except for some individual days, such as the National holiday (October 1 to October 7, 2009) and Spring Festival (February 13 to February 10, 2010), the daily number of patients changed little during the study time. The lowest monthly average number of out-patient was in July. During the period of March to April and August to September, the monthly average was higher compared with the rest of the 12 months.

Fig. 2 shows the daily numbers of clinical visit for AR in the study period. As expected, the frequencies show two peaks during the years, one was in late March and early April and another one was in August. The maximum daily numbers of medical consultations for AR were in late March and early April with up to 37 persons per day. June and July showed the sub-minimum numbers of consultations. In August and September, the numbers of consultations were at a sub-maximum with about 18 persons per day. December and January showed the lowest numbers.

Fig. 3 shows the daily variation in AR ratio. It had a similar changeable curve with daily number of consultations for AR. The maximum daily number of morbidity was in March and April. June

Table 2

Characteristics of daily number for patients, air pollutants and meteorological factors.

	Min	Max	Ave	Median	SD
Number of outpatients	60.00	251.00	129.50	127.00	27.26
Number of AR patients	1.00	37.00	6.50	4.00	6.76
Ratio(%)	0.58	24.06	4.80	3.40	4.58
PM ₁₀ (μg/m ³)	7.00	600.00	116.09	104.00	67.72
SO ₂ (μg/m ³)	7.00	1519.50	44.05	21.00	139.32
NO ₂ (μg/m ³)	9.60	152.00	52.74	52.75	22.47
AVET(°C)	−14.00	30.00	11.95	15.00	12.25
MAXT(°C)	−9.00	40.00	17.67	21.00	12.83
MINT(°C)	−19.00	25.00	6.26	8.00	12.10
DEWP(°C)	−28.00	23.00	1.44	3.00	13.90
AVEH	12.00	92.00	53.32	53.00	19.31
MAXH	24.00	100.00	79.95	86.00	16.51
MINH	4.00	80.00	23.82	18.00	18.19
PRESS (hPa)	993.79	1006.31	1041.04	1015.65	470.67
Wind speed (km/h)	3.00	26.00	9.19	8.00	4.91

Note. n = 365. AVET: average temperature; MAXT: maximum temperature; MINT: minimum temperature; DEWP: dew point; AVEH: average humidity; MAXH: maximum humidity; MINH: minimum humidity.

and July had the sub-minimum numbers of morbidity. In August and September, the number of morbidity came to a sub-maximum value. In conclusion, spring and autumn show a higher prevalence of AR than summer and winter.

3.2. Characteristics of air pollutants and meteorological factors

Table 2 summarizes the distribution of the annual mean air pollutant concentrations, temperature, relative humidity and other meteorological factors of Beijing during the study period.

The results show that, monthly average concentrations of PM₁₀ vary from 110 μg/m³ to 125 μg/m³, NO₂ had a similar trend of monthly average concentrations with SO₂. PM₁₀ was the main air pollutant of Beijing, followed by NO₂ generated from road traffic. During the heating period, the concentration of SO₂ was higher. All of three pollutants had a highest monthly average concentration in March.

During our study period, the mean daily temperature and humidity were 11.95 °C and 53.32%, respectively. The mean daily temperature ranged from −14 °C to 30 °C, and the mean daily humidity ranged from 8% to 97%, reflecting the sub-humid warm temperate continental monsoon climate of Beijing.

Table 3 presents the Pearson correlation coefficients between different air pollutants and meteorological variables. Generally, the correlation coefficients between NO₂, SO₂, and PM₁₀ were high and

Table 1
Characteristics of AR patients.

Age	Male	Female	Total	Ratio of age group%
<20	30	26	56	3.72
20–29	155	135	291	19.32
30–39	191	199	390	25.90
40–49	121	167	288	19.12
50–59	106	132	237	15.74
60–69	75	56	131	8.70
≥70	85	28	113	7.50
Total	763	743	1506	100.00

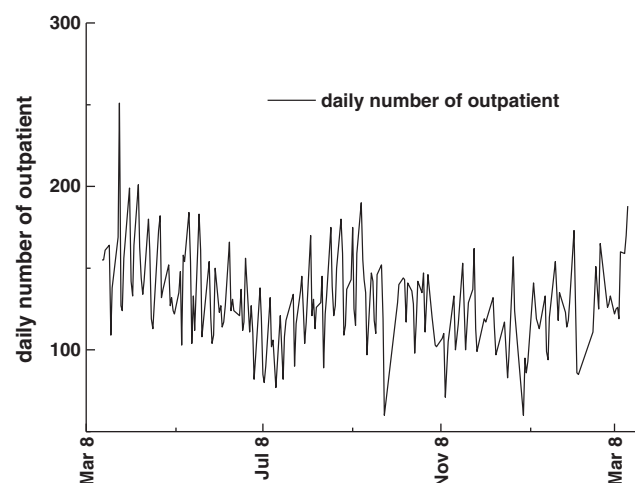


Fig. 1. Daily numbers of outpatient.

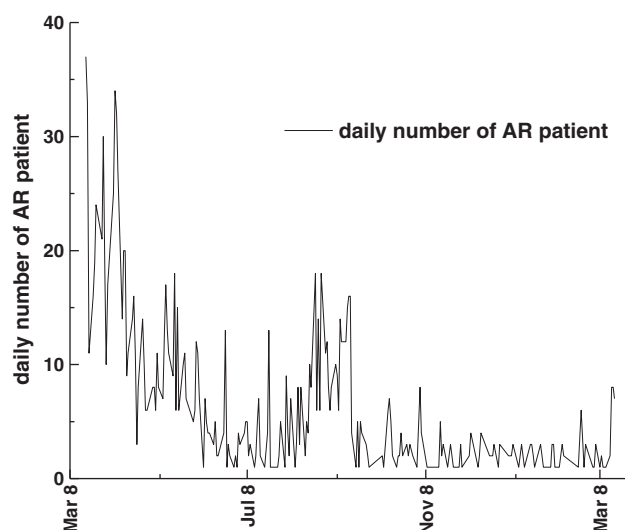


Fig. 2. Daily numbers of consultations for AR patient.

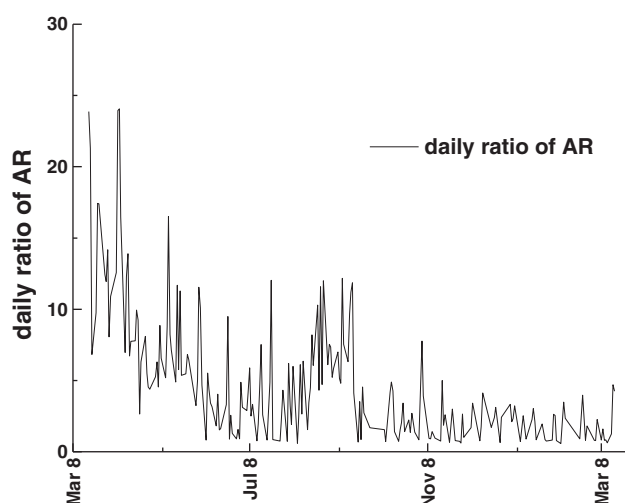


Fig. 3. Daily ratio of AR.

positive ($p < 0.01$). This correlation structure was consistent with the common sources of the traffic-related pollutant (NO_2) and stationary fossil fuel combustion-related pollutants (SO_2 and PM_{10}) (Chan and Yao, 2008). Daily dew point and daily average humidity were positively

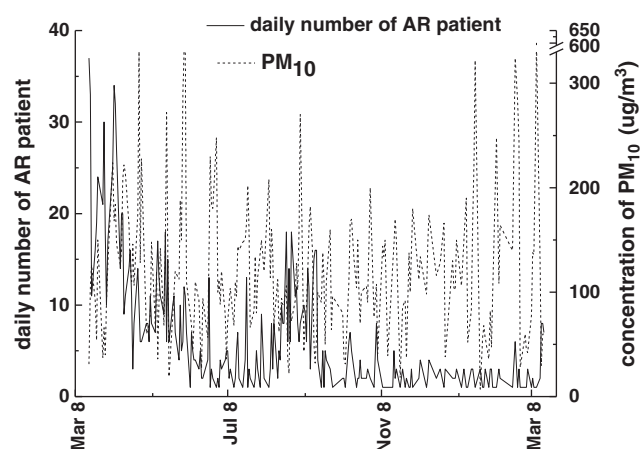


Fig. 4. Daily numbers of consultations for AR patient and daily concentration of PM_{10} .

correlated with PM_{10} . A positive correlation was found between humidity and NO_2 .

3.3. Air pollution and AR

Figs. 4–6 show the daily numbers of clinical consultations for AR and the daily concentration of air pollutants.

Pearson correlation coefficients between air pollutants and number of patients show that the number of medical consultations for AR was significantly correlated with the three air pollutants during March 19th 2009 to September 18th 2009, indicating that the air pollutants had short-term effects on AR, exacerbating symptoms and increasing hospital visits.

Results shown in Figs. 4–6 also indicate that the number of medical consultations was not consistent with PM_{10} , SO_2 and NO_2 concentrations during the entire period of March 19th 2009 to March 18th 2010, especially at some peak values. But positive relationship between daily visits of outpatients and the three air pollutants can still be found.

3.4. Exposure–response associations

After controlling for long term trends, the ‘day of the week’ effect and confounding meteorological factors, we used non-parametric generalized additive model (GAM) to analyze the exposure–response relationship. The results (relative risk, RR for short) obtained were expressed as the change in the number of consultations for AR patients for per $10 \mu\text{g}/\text{m}^3$ increases of air pollutants concentrations (95% CI). In order to elaborate the residual confounding and potential effect modification, we systematically conducted stratified analyses in different categories of gender and age. Table 4 shows the RRs of total AR patients, male

Table 3
Correlation coefficients between air pollutants and meteorological variables.

	PM_{10}	SO_2	NO_2	AVET	DEWP	AVEH	PRESS	Wind speed
PM_{10}	1.000	0.261*	0.673*	0.037	0.144*	0.280*	−0.004	−0.209*
SO_2		1.000	0.393*	−0.203*	−0.165*	−0.009	0.001	0.026
NO_2			1.000	−0.212*	−0.058	0.277*	0.025	−0.374*
AVET				1.000	0.917*	0.296*	−0.028	−0.272*
DEWP					1.000	0.640*	−0.019	−0.476*
AVEH						1.000	−0.004	−0.611*
PRESS							1.000	0.016
Wind speed								1.000

*Correlation is significant at the 0.05 level (2-tailed).

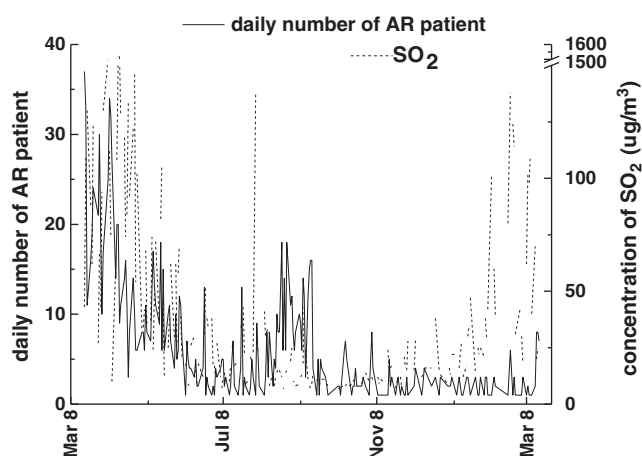


Fig. 5. Daily number of consultations for AR patient and daily concentration of SO₂.

patients, female patients, 20–60 years age group, and over 60 years age group, for an every 10 ug/m³ increase of the single-pollutant concentration. The RRs are based on models adjusted for all factors, including meteorological factors, and weekday effect.

Higher concentrations of particulate matter (PM₁₀), SO₂ and NO₂ were associated with increased likelihood of hospital visits (with every 10 ug/m³ increase of pollutant concentration). Relative risk (RR) for every 10 ug/m³ increase in pollutants level to the total people was 1.0073 for PM₁₀, 1.0010 for SO₂, and 1.0512 for NO₂. The RRs of female for every 10 ug/m³ increase of air pollutants were 1.0101 for PM₁₀, 1.0002 for SO₂, and 1.0538 for NO₂. The RRs of male for every 10 ug/m³ increase of air pollutants were 1.0050 for PM₁₀, 0.9993 for SO₂, and 1.0405 for NO₂. The RRs of young people (20–60 age groups) were 1.0044, 1.0003, 1.0454 for PM₁₀, SO₂, and NO₂, respectively. RRs for old people were 1.0068 for PM₁₀, 0.9993 for SO₂, 1.0474 for NO₂. Females were more sensitive than males to the concentration changes of all the three air pollutants. Old people (age > 60 years) were more sensitive to PM₁₀ and NO₂ than young people.

NO₂ showed a stronger influence on increased likelihood of hospital visits than PM₁₀ and SO₂, with the concentration increasing by every 10 ug/m³.

4. Discussion

This study combined epidemiological and environmental health science research methods to study associations between major air pollutants and AR over a period of 12 months. The patient group in

our survey comprised adult outpatients from one major hospital in central Beijing excluding children and young adolescent. While urban air pollution consists of a complex mixture of compounds, the study focused on SO₂, NO₂ and PM₁₀ (particles with an aerodynamic diameter of ≤ 10 μm). SO₂ is a traditional pollutant of industrial origin related to the combustion of coal and other fossil fuels. While NO₂ is an indicator of pollutants from motor vehicle traffic emissions, and PM₁₀ is reported to be the major air pollutant in Beijing on about 90% of the days in the year 2000 to 2004 (BJEPB, 2005). PM₁₀ has a direct negative bearing on human health (Aubier, 2009; Hou et al., 2010; Lindgren et al., 2009).

The results of this study are unique in the following aspects: 1). To our knowledge, the current study is the first in combining daily visits of patients consulting general practitioners for AR with daily concentration of air pollutants in Beijing; 2). All patients in our study were diagnosed by health professionals of the Department of Otolaryngology-Head and Neck Surgery of Beijing hospital, and all documentations were completed under the supervision of doctors; 3). After controlling for long term trends, the 'day of the week' effect and confounding meteorological factors, non-parametric generalized additive model (GAM) was used to analyze the highly non-linear or non-monotonic exposure–response relationship between air pollutants and daily outpatients clinic for AR.

Consistent with the previous findings, our study demonstrated that the daily number of AR outpatients was positively correlated with the concentration of SO₂ (Hajat et al., 2001; Lindgren et al., 2009); and also showed an association with concentrations of PM₁₀ and NO₂ (Lindgren et al., 2009). All the three air pollutants (PM₁₀, SO₂ and NO₂) were associated with increased likelihood of hospital visits with every 10 ug/m³ increase of pollutant concentration.

For Beijing the primary polluting agent in the air is the particulate matter influenced by natural as well as anthropogenic factors. From June to August the meteorological conditions are conducive to dilute and spread air pollutants, and therefore the air quality is relatively better during this time of a year. Due to the effects of the prevailing weather conditions and the heating period in winter as well as the impacts of the regular dust-storms from northwest in spring, the air quality is comparatively poor during these periods (Guo and Chen, 2009). Daily average concentration of PM₁₀ was high in early spring, and low in summer (Qi et al., 2007), which to some extent explain the phenomenon in our study that daily number of AR patients was very high in March and April. Further during the same period, the concentration of air pollen was also up to peak value due to a high pollen release (Li et al., 2008).

Our study has demonstrated a strong association between SO₂ concentration and the number of consultations for AR. SO₂ could increase the permeability of the mucous membrane in airways, which may favor the penetration of allergens and the development of allergic reactions. A British study provided evidence that the occurrence of general practice consultations due to AR was related to short-term exposure to SO₂ and O₃ (Hajat et al., 2001; Wood and Augustin, 2002). With major changes in urban development and the rapid increase in car ownership (from 0.5 million in 1990 to 4.13 million in 2010) in Beijing, industrial/domestic air pollution from coal smoke has been largely replaced by air pollution now coming from heating sources and automotive exhaust (Qi et al., 2007). The traffic related gaseous pollutants NO₂ is known for its adjuvant effect on respiratory hypersensitivity (Lindgren et al., 2009). Positive statistically significant associations were found between AR and traffic-related NO₂; persistent exposure to NO_x may increase the prevalence of AR in children (Hwang et al., 2006).

Figs. 4–6 show that the numbers of medical consultations were not always consistent with concentrations of some peak values during the entire study period. Urban air pollution constitutes a complex mixture of several compounds and the assessment of the independent effects of different pollutants is a major challenge, which includes both the

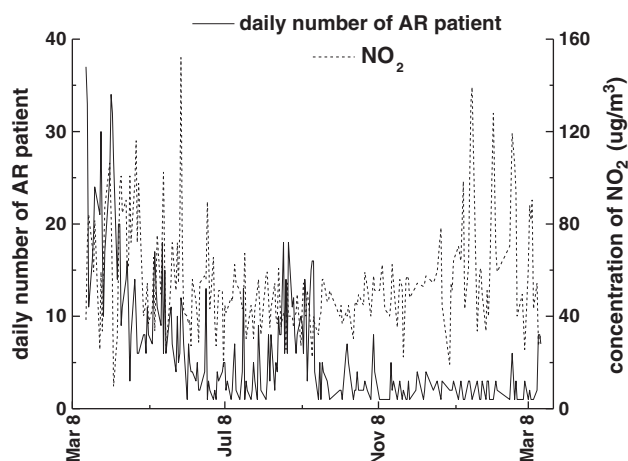


Fig. 6. Daily number of consultations for AR patient and daily concentration of NO₂.

Table 4
RR for AR with every 10 ug/m³ increase in pollutants concentration.

	Total		Male		Female		20–60 years age group		Over 60 years age group	
	RR	CI (95%)	RR	CI (95%)	RR	CI (95%)	RR	CI (95%)	RR	CI (95%)
PM ₁₀	1.0073	1.0066–1.0080	1.0050	1.0042–1.0058	1.0101	1.0092–1.0110	1.0044	1.0036–1.0052	1.0068	1.0055–1.0082
SO ₂	1.0010	1.0005–1.0014	0.9993	0.9989–0.9997	1.0002	0.9997–1.0007	1.0003	0.9997–1.0008	0.9993	0.9985–1.0001
NO ₂	1.0512	1.0483–1.0542	1.0405	1.0375–1.0434	1.0538	1.0501–1.0574	1.0454	1.0422–1.0486	1.0474	1.0425–1.0522

issues of confounding and effect modification (Hajat et al., 2001; Wood and Augustin, 2002). A study conducted in Jinan, Shandong province in China, showed that the best fits for PM₁₀ and NO₂ were same day visit (lag 0), and three days after (lag3), while a four day moving average (avg3) was most suitable for SO₂. Females were more susceptible than males to air pollution (Wang et al., 2008). The lag effect of air pollutants to AR in Beijing should be considered in the further study.

In our study, PM₁₀, SO₂ and NO₂ were associated with increased likelihood of hospital visits with every 10 ug/m³ increase of pollutant concentration. NO₂ showed a strongest influence on increased likelihood of hospital visits than PM₁₀ and SO₂, with every 10 ug/m³ concentration increasing. The RRs of female for every 10 ug/m³ increase of air pollutants were 1.0101 for PM₁₀, 1.0002 for SO₂, and 1.0538 for NO₂ (Table 4). The RRs of male for every 10 ug/m³ increase of air pollutants were 1.0050 for PM₁₀, 0.9993 for SO₂, and 1.0405 for NO₂ (Table 4). Females were more susceptible than males to all the three air pollutants. Compared to young people, old people (age > 60 years) were more susceptible to PM₁₀ and NO₂.

For want of reliable daily data on pollen counts for central Beijing this study did not include this aspect. However, traffic-related pollutants can trigger the release of allergen-containing granules from grass pollen, and increase the bioavailability of airborne pollen allergens. This is a mechanism by which air pollution concurs with the increase in the prevalence of allergic disease (Frei and Gassner, 2008; Motta et al., 2006). As the scope and number of studies on the effects of air pollution on allergy prevalence increases, it becomes more and more clear that gaseous air pollution affects airways by inducing inflammation, and by playing an adjuvant role in respiratory allergy. On the other hand, it also has an effect on airborne allergens themselves. Pollen allergens release is modified by exposure of pollen to environmental pollution (Johnston et al., 2009). Increased humidity or rainy weather conditions can lead to increased aerosolization of pollen fragments, potentially resulting in greater allergen exposure for atopic individuals (Kim and Bernstein, 2009). The increase in atmospheric pollution levels is one of the possible explanations for the current increase in the prevalence of respiratory allergic diseases (Lindgren et al., 2009; Norback et al., 2007). A recent study conducted in Haidian District of Beijing that used medical data from medical insurance indicated that the number of medical consultations for AR correlates with the airborne pollen concentrations in summer–autumn (Li et al., 2008). Data on air pollutants, allergic pollen, and meteorological dates should be collected continuously, to conduct further analysis on the relationship between these factors and the number of clinical visit for AR.

The influence of air pollutants on different age groups showed that people in the age group below 60 years were more sensitive than people in the above 60 years group to the concentration change of SO₂. This can be related to the differences in time-activity for young people and old people. Young people tend to spend more time outside than older people, and have therefore a higher exposure to air pollutants, and also have a higher relative risk to SO₂. Exposure to ambient air pollutants is substantially different for individuals depending on personal activities, living environment and others. Genetic prepositions influence the development of allergies and play also a major role in AR. Further research needs to be conducted with more detailed information on personal exposure, genetic prepositions etc. of populations affected by AR.

In the discussion we have addressed some limitations of our study. Also our findings cannot be generalized for Beijing. However, our study results apply to a growing number of people at risk for developing or already being affected by rhinitis. In addition, the prevalence of AR in the general population in Beijing has been increasing.

In summary, our data from Beijing Hospital confirms previous reports on the adverse effect of ambient air pollution. Similar to the study conducted in London; although our data did not distinguish between first and subsequent consultations, the reports indicate an exacerbating of symptoms by pollutants rather than an initiation of allergies (Hajat et al., 2001). With the continuous rapid urbanization process more people become exposed to high levels of air pollution. The public health impact could be considerable. Additional studies in other geographical areas and longer time series are needed. The authors would wish that this study motivates further research on the prevalence of AR and AR associated factors in China.

Conflicts of interest

All authors declare to have no conflict of interest to disclose in the context with this study.

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References

- Arnedo PA, Garcia ML, Uruena IC, Monge RB, Suarez VMM, Canflanca IM, et al. Air pollution and recent symptoms of asthma, allergic rhinitis, and atopic eczema in schoolchildren aged between 6 and 7 years. *Arch Bronconeumol* 2009;45:224–9.
- Aubier M. Traffic-related pollutants and their impact on allergic respiratory diseases. *Bull Acad Natl Med* 2009;193:1303–13.
- Ballester F, Estarlich M, Iniguez C, Llop S, Ramon R, Esplugues A, et al. Air pollution exposure during pregnancy and reduced birth size: a prospective birth cohort study in Valencia, Spain. *Environ Health* 2010;9.
- Bayentin L, El Adlouni S, Ouara TBMJ, Gosselin P, Doyon B, Chebana F. Spatial variability of climate effects on ischemic heart disease hospitalization rates for the period 1989–2006 in Quebec, Canada. *Int J Health Geogr* 2010;9.
- Bhattacharyya N. Air quality influences the prevalence of hay fever and sinusitis. *Laryngoscope* 2009;119:429–33.
- BJEPB BMEPB. Environmental bulletin of Beijing (2000–2004). Beijing: Beijing Municipal Environmental Protection Bureau; 2005.
- Bousquet J, Khaltaev N, Cruz AA, Denburg J, Fokkens WJ, Togias A, et al. Allergic rhinitis and its impact on asthma (ARIA) 2008 update (in collaboration with the World Health Organization, GA(2)LEN and AllerGen). *Allergy* 2008;63:8–160.
- Chan CK, Yao X. Air pollution in mega cities in China. *Atmos Environ* 2008;42:1–42.
- Damalas D, Megalofonou P. Environmental effects on blue shark (*Prionace glauca*) and oilfish (*Ruvettus pretiosus*) distribution based on fishery-dependent data from the eastern Mediterranean Sea. *J Mar Biol Assoc UK* 2010;90:467–80.

- D'Amato G. Urban air pollution and the increasing trend of allergic respiratory diseases. *Asthma Genes Clin Manage* 2003;131–141:250.
- Dominici F, McDermott A, Zeger SL, Samet JM. On the use of generalized additive models in time-series studies of air pollution and health. *Am J Epidemiol* 2002;156:193–203.
- Dominici F, McDermott A, Zeger SL, Samet JM. Airborne particulate matter and mortality: Timescale effects in four US cities. *Am J Epidemiol* 2003;157:1055–65.
- Frei T, Gassner E. Trends in prevalence of allergic rhinitis and correlation with pollen counts in Switzerland. *Int J Biometeorol* 2008;52:841–7.
- Grize L, Gassner M, Wuthrich B, Bringolf-Isler B, Takken-Sahli K, Sennhauser FH, et al. Trends in prevalence of asthma, allergic rhinitis and atopic dermatitis in 5–7-year old Swiss children from 1992 to 2001. *Allergy* 2006;61:556–62.
- Guo J, Chen J. Patterns of seasonal changes in air pollution and suggestions on pollution control in Beijing (in Chinese). *Ecol Environ Sci* 2009;18:952–6.
- Guo YM, Jia YP, Wang JJ, Zhao AL, Li GX, Pan XC. Relationship between ambient air pollution and the hospital emergency room visits for hypertension in Beijing, China. *Int J Cardiol* 2009;137:S126–S126.
- Gutierrez EJC, Bilton DT. A heuristic approach to predicting water beetle diversity in temporary and fluctuating waters. *Ecol Model* 2010;221:1451–62.
- Hajat S, Haines A, Atkinson RW, Bremner SA, Anderson HR, Emberlin J. Association between air pollution and daily consultations with general practitioners for allergic rhinitis in London, United Kingdom. *Am J Epidemiol* 2001;153:704–14.
- Hajat S, Anderson HR, Atkinson RW, Haines A. Effects of air pollution on general practitioner consultations for upper respiratory diseases in London. *Occup Environ Med* 2002;59:294–9.
- Hou Q, An XQ, Wang Y, Guo JP. An evaluation of resident exposure to respirable particulate matter and health economic loss in Beijing during Beijing 2008 Olympic Games. *Sci Total Environ* 2010;408:4026–32.
- Hsu SP, Lin KN, Tan CT, Lee FP, Huang HM. Prenatal risk factors and occurrence of allergic rhinitis among elementary school children in an urban city. *Int J Pediatr Otorhinolaryngol* 2009;73:807–10.
- Hwang BF, Jaakkola JJ, Lee YL, Lin YC, Guo YL. Relation between air pollution and allergic rhinitis in Taiwanese schoolchildren. *Respir Res* 2006;7:23.
- Jiang LL, Zhang YH, Song GX, Chen GH, Chen BH, Zhao NQ, et al. A time series analysis of outdoor air pollution and preterm birth in Shanghai, China. *Biomed Environ Sci* 2007;20:426–31.
- Johnston FH, Hanigan IC, Bowman DM. Pollen loads and allergic rhinitis in Darwin, Australia: a potential health outcome of the grass-fire cycle. *Ecohealth* 2009;6:99–108.
- Kim H, Bernstein J. Air pollution and allergic disease. *Curr Allergy Asthma Rep* 2009;9:128–33.
- Kim HC, Leem JH, Lee JY, Kwon HJ, Hong SJ, Lee DH. Allergic rhinitis, allergic sensitization, and exposure to traffic-related air pollution in school children. *Epidemiology* 2009;20:S120–S120.
- Kramer U, Koch T, Ranft U, Ring J, Behrendt H. Traffic-related air pollution is associated with atopy in children living in urban areas. *Epidemiology* 2000;11:64–70.
- Lee Y, Shaw C, Su H, Lai J, Ko Y, Huang S, et al. Climate, traffic-related air pollutants and allergic rhinitis prevalence in middle-school children in Taiwan. *Eur Respir J* 2003;21:964.
- Leung R, Ho P, Lam CWK, Lai CKW. Sensitization to inhaled allergens as a risk factor for asthma and allergic diseases in Chinese population. *J Allergy Clin Immunol* 1997;99:594–9.
- Li J, Wang H, Zhang Z, Wang Q. Association between airborne pollen concentrations and human respiratory disease (in Chinese). *J Environ Health* 2008;156:510–3 565.
- Li J, Sun B, Huang Y, Lin X, Zhao D, Tan G, et al. A multicentre study assessing the prevalence of sensitizations in patients with asthma and/or rhinitis in China. *Allergy* 2009;64:1083–92.
- Lindgren A, Strohm E, Nihlen U, Montnemery P, Axmon A, Jakobsson K. Traffic exposure associated with allergic asthma and allergic rhinitis in adults. A cross-sectional study in southern Sweden. *Int J Health Geogr* 2009;8–.
- Luke C, Rea W, Smith WP, Fenyes E, Pan Y. Adverse health effects of outdoor air pollutants. *Environ Int* 2006;32:815–30.
- Makra L, Tombacz S, Balint B, Sumeghy Z, Santa T, Hirsch T. Influences of meteorological parameters and biological and chemical air pollutants on the incidence of asthma and rhinitis. *Climate Res* 2008;37:99–119.
- Medina S, LeTertre A, Quenel P, LeMoullec Y, Lameloise P, Guzzo JC, et al. Air pollution and doctors' house calls: Results from the ERPURS system for monitoring the effects of air pollution on public health in Greater Paris, France, 1991–1995. *Environ Res* 1997;75:73–84.
- Meng Z, Zhang J, Geng H, Lu B, Zhang Q. The influence of dust storms on daily respiratory and circulatory outpatient number (in Chinese). *China Environ Sci* 2007;27:116–20.
- Mentzakis E, Delfino D. Effects of air pollution and meteorological parameters on human health in the city of Athens, Greece. *Int J Environ Pollut* 2010;40:210–25.
- Mosges R, Klimek L. Today's allergic rhinitis patients are different: new factors that may play a role. *Allergy* 2007;62:969–75.
- Motta AC, Marliere M, Peltre G, Sterenberg PA, Lacroix G. Traffic-related air pollutants induce the release of allergen-containing cytoplasmic granules from grass pollen. *Int Arch Allergy Immunol* 2006;139:294–8.
- Norback D, Zhao ZH, Wang ZH, Wieslander G, Mi YH, Zhang Z. Asthma, eczema, and reports on pollen and cat allergy among pupils in Shanxi province, China. *Int Arch Occup Environ Health* 2007;80:207–16.
- Penard CM, Charpin D, Raheison C, Kopferschmitt C, Caillaud D, Lavaud F, et al. Long-term exposure to background air pollution related to respiratory and allergic health in schoolchildren. *Clin Exp Allergy* 2005;35:1279–87.
- Polosa R. The interaction between particulate air pollution and allergens in enhancing allergic and airway responses. *Curr Allergy Asthma Rep* 2001;1:102–7.
- Powell M, Accad A, Austin MP, Choy SL, Williams KJ, Shapcott A. Predicting loss and fragmentation of habitat of the vulnerable subtropical rainforest tree *Macadamia integrifolia* with models developed from compiled ecological data. *Biol Conserv* 2010;143:1385–96.
- Qi J, Yang LS, Wang WY. Environmental degradation and health risks in Beijing, China. *Arch Environ Occup Health* 2007;62:33–7.
- Ramador M, Burel C, Lanteaume A, Vervloet D, Charpin D, Brisse F, et al. Prevalence of asthma and rhinitis in relation to long-term exposure to gaseous air pollutants. *Allergy* 2000;55:1163–9.
- Ramsay TO, Burnett RT, Krewski D. The effect of concavity in generalized additive models linking mortality to ambient particulate matter. *Epidemiology* 2003;14:18–23.
- Tsai DH, Wang JL, Chuang KJ, Chan CC. Traffic-related air pollution and cardiovascular mortality in central Taiwan. *Sci Total Environ* 2010;408:1818–23.
- Villeneuve PJ, Doiron MS, Stieb D, Dales R, Burnett RT, Dugandzic R. Is outdoor air pollution associated with physician visits for allergic rhinitis among the elderly in Toronto, Canada? *Allergy* 2006;61:750–8.
- Wang W, Krafft T, Kraas F. Global change, urbanization and health. Beijing: China Meteorological Press; 2006.
- Wang Y, Zhang Y, Li X. The effect of air pollution on hospital visits for respiratory symptoms in urban areas of Jinan (in Chinese). *China Environ Sci* 2008;28:571–6.
- Wood SN, Augustin NH. GAMs with integrated model selection using penalized regression splines and applications to environmental modelling. *Ecol Model* 2002;157:157–77.
- Zhang L, Han DM, Huang D, Wu YF, Dong Z, Xu G, et al. Prevalence of self-reported allergic rhinitis in eleven major cities in China. *Int Arch Allergy Immunol* 2009;149:47–57.
- Zhao J. Relating factors in Beijing school children with allergic rhinitis. *Allergy* 2008;63:418–9.
- Zhao TB, Wang HJ, Chen YZ, Xiao ML, Duo LK, Liu G, et al. Prevalence of childhood asthma, allergic rhinitis and eczema in Urumqi and Beijing. *J Paediatr Child Health* 2000;36:128–33.