



Effects of variations in meteorological factors on daily hospital visits for asthma: A time-series study

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ARTICLE INFO

Keywords:

Temperature
Barometric pressure
Wind speed
Humidity
Air pollution
Time series

ABSTRACT

Few studies have explored the relationships between meteorological factors and asthma. This study explored the associations between daily variations in meteorological factors and hospital visits for asthma among different ages, genders, and asthma subtypes in Shenyang, China. A distributed lag non-linear model with Poisson regression was used; confounding factors included day of the week, holidays, and seasonal patterns, and long-term trends and air pollutants were adjusted using natural cubic splines. The meteorological factor with the largest cumulative effect was barometric pressure, which increased the risk of hospital visits for adult asthma (relative risk [RR] = 2.414), followed by maximum wind speed, which increased hospital visits for asthma for children aged 0–5 years old (RR = 1.47), and pressure, which increased hospital visits for bronchial asthma (RR = 1.298). Meteorological factors showed stronger associations with asthma than air pollutants. Further research should focus more on the effects of meteorological factors on asthma.

1. Introduction

Asthma is one of the most common chronic diseases in children and is affected by complicated environmental and hereditary factors (Yang et al., 2017; Guarnieri and Balmes, 2014). Childhood asthma that is well controlled is mostly transient, but it may become irreversible adult asthma. Previous studies (D'Amato et al., 2015; NEWELL and SWAFFORD, 1963; Da et al., 2018; Hu et al., 2019; Kadhim Yousif and Al Muhyi, 2019; Zhao et al., 2019; Tikkakoski et al., 2019) have revealed associations between meteorological factors, including temperature, humidity, barometric pressure, wind speed, and wind direction, and the epidemiology of asthma in children and adults with relatively non constant results and conclusions. Human experiments in environmental chambers (Eschenbacher et al., 1992) found that temperature and humidity changes can decrease forced expiratory volume and increase specific airway resistance. Animal experiments also found High and low temperatures aggravate airway inflammation of asthma in a mouse model (Deng et al., 2020). Researchers in Spain and America (Hervas et al., 2015; Jayawardene et al., 2013) have developed reliable models based on meteorological and air pollution factors to forecast asthma exacerbations. Of all the meteorological factors, temperature has been studied the most, mainly in time-series studies. Still, discrepancies (Xu

et al., 2018) remain in reports of associations between ambient temperature and childhood asthma, and air pollutants were not adjusted when studying meteorological factors. Other meteorological factors are seldom studied alone and should always be adjusted factors in time-series research of air pollution and asthma (Rodopoulou et al., 2015; Alhanti et al., 2016). As such, some relationships between meteorological factors and asthma morbidity and exacerbations are evident but, at present, are not clearly defined. Original, specific studies on the association between meteorological factors and asthma are limited.

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<https://doi.org/10.1016/j.envres.2020.109115>

Received 22 July 2019; Received in revised form 28 December 2019; Accepted 2 January 2020

Available online 03 January 2020

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In this study, we aimed to explore the relationships between daily variations in meteorological factors (daily average temperature, average humidity, barometric pressure, maximum wind speed, and air quality index [AQI]) and hospital visits for asthma in different age groups, genders, and asthma subtypes in Shenyang, China. Effects of other factors were adjusted when specified meteorological factors were studied. Integrated effects of air pollutants were represented by AQI, which is a combined measurement of the degree of air pollution. This is the first study to comprehensively assess and compare the effects of meteorological factors and air pollution on asthma.

2. Methods

2.1. Data collection

Our study area was in Shenyang, the capital city of Liaoning Province, which is located in northeast China. The city covers an area of 12,948 km² and had a population of 8.29 million people in 2016.

Daily outpatient hospital visits for asthma from September 17, 2011 to January 10, 2018 were retrieved from the computerized database of the Health Statistical Information Center (HSIC) of Liaoning Province. The data comprised respiratory hospital admission records from 28 hospitals in Shenyang. All the hospitals in Shenyang provide inpatient records to HSIC through the provincial health information platform every day. According to the codes defined in the International Classification of Diseases, 10th revision, information for asthma (J45) and related diseases were collected. Two subtypes of childhood asthma were common in Shenyang: bronchial asthma (J45.901) and cough-variant asthma (J45.101). Data cleaning processes were completed separately by two persons, and a clinician was invited to decide disease type when disputes occurred. Since all the data fields (admission date, diagnosis, diagnosis code, discharge date, departments, gender, and age) included were anonymous, the study was qualified as negligible-risk research and was, therefore, exempt from the ethical review of the Human Research Ethics Committee of the Shengjing Hospital of China Medical University.

Meteorological data from September 17, 2011 to January 10, 2018 were obtained from meteorological monitoring stations of the China Bureau of Meteorology in Shenyang. The data included daily average temperature, maximum and average wind speed, highest and lowest relative humidity, and barometric pressure.

AQI data were obtained from the Environmental Protection Bureau in Shenyang. The daily AQI value represents the major air pollutants and air quality. AQI is the maximum value of individual air quality indexes (IAQI) of regularly monitored air pollutants (fine particulate matter, inhalable particulate matter, sulfur dioxide, nitrogen dioxide, ozone, and carbon monoxide). IAQI was calculated as follows:

$$IAQI_p = \frac{IAQI_{Hi} - IAQI_{Lo}}{BP_{Hi} - BP_{Lo}} (C_p - BP_{Lo}) + IAQI_{Lo}$$

IAQI_p: IAQI of air pollutant p

C_p: Quality concentration value of a specified air pollutant

BP_{Hi}: High value close to C_p in AQI and air pollutant concentration comparison table

BP_{Lo}: Low value close to C_p in AQI and air pollutant concentration comparison table

IAQI_{Hi}: IQAI value corresponding to BP_{Hi} in AQI and air pollutant concentration comparison table

IAQI_{Lo}: IQAI value corresponding to BP_{Lo} in AQI and air pollutant concentration comparison table

2.2. Data analysis

Outpatient hospital visits due to childhood asthma are small-probability events and, thus, follow a Poisson distribution. We explored the relationships between daily meteorological factors (average temperature, average humidity, pressure, and maximum wind speed) and hospital visits for asthma in different age groups, genders, and asthma types using a distributed lag non-linear model (DLNM) with Poisson regression. Confounding factors included day of the week, holidays, and seasonal patterns, and long-term trends and air pollutants were adjusted using natural cubic splines. The derived equation was as follows:

$$\log[E(Y_k)] = \alpha + CB(\text{indicators: lag10}) + \text{as. factor}(D) + \text{ns}(t, df) + \text{ns}(Z_k, df)$$

where Y_k is the total daily outpatient hospital visits for asthma on day k; E(Y_k) is the expected value of Y_k; indicators included daily mean temperature, humidity, pressure, maximum wind speed and AQI; ns is the natural spline-smoothing function; df is degrees of freedom (degrees were 24, 3, 3, 6, 3, 3 for time, temperature, humidity, pressure, wind speed and AQI, respectively); D represents weekday, holiday, and seasonal dummy variables; t is calendar time; Z_k represents other indicators on day k; and α is the residual value. The optimal degree for temperature, humidity, pressure, and AQI were calculated on the basis of the minimum Akaike's Information Criterion (Gasparrini et al., 2010); residuals were included in the models to eliminate first-order autocorrelations. Models were built for each meteorological factor separately. We estimated the daily and cumulative relative risk (RR) of ambient temperature lag for 10 days using the cross-basis function in DLNM models. The cumulative RRs and 95% confidence intervals (CIs) of each cause-specific case were estimated by comparing the risk associated with the extreme meteorological factor value of the 95th percentile with that of the indicator value associated with the lowest cause-specific asthma hospital visits.

3. Results

3.1. Summary of indicators and asthma events

Table 1 shows the characteristics of the study population and meteorological factors from September 17, 2011 to January 10, 2018 (2302 days). During the study period, there were a total of 173,747 outpatient hospital visits for asthma. There were more hospital visits for childhood asthma (148,760) than for adult asthma, and the majority of childhood asthma was acute bronchial asthma (124,616). More males had hospital visits for asthma than females (sex ratio: 1.76:1). Daily mean temperature variation, average humidity, pressure, maximum wind speed, and AQI were −0.01 °C (range, −11.5–13 °C), 61.99% (range, 19–97%), 1016.34 Pa (range, 985.81–1039.02 Pa), 21.42 km/h (range, 1–54 km/h), and 92.05 (range, 0–500).

3.2. Cumulative and lag effects

Fig. 1 shows the cumulative effects of daily average temperature and barometric pressure variations on asthma hospital visits stratified by age, gender, and asthma subtypes. (For effects of other factors, see supplemental materials [Fig. S1].) Table 2 shows the cumulative effects

Table 1

Descriptive statistics of daily asthma admissions, meteorological factors, and air quality in Shenyang from 2011 to 2017.

Asthma counts	Min.	Median	Mean	IQR	95th Percentile	Max.	N
Total(N = 173,747)	1.00	63.00	75.48	89.00	184.00	273.00	2302.00
0–5yrs(n = 74,526)	0.00	23.00	32.37	43.00	101.00	181.00	2302.00
6–14yrs(n = 74,234)	0.00	22.00	32.25	38.00	94.00	157.00	2302.00
15 + yrs(n = 24,987)	0.00	9.00	10.85	12.00	26.00	61.00	2302.00
Male(n = 94,854)	0.00	34.00	41.21	50.00	104.00	164.00	2302.00
Female(n = 53,901)	0.00	20.00	23.41	29.00	60.00	98.00	2302.00
type 1(n = 124,616)	0.00	47.00	54.13	68.00	140.00	220.00	2302.00
type 2(n = 24,144)	0.00	8.00	10.49	13.00	29.00	50.00	2302.00
Temperature(°C)	−21.50	10.00	8.50	24.5	26.00	31.00	2302.00
Humidity (%)	19.00	62.00	61.99	19.00	84.00	97.00	2302.00
Pressure(Pa)	985.81	1016.44	1016.34	15.76	1031.85	1039.02	2302.00
Max wind(km/h)	7.00	22.00	21.42	11.00	36.00	54.00	2302.00
AQI	0.00	79.00	92.05	45.00	198.00	500.00	2302.00

AQI: air quality index; Temperature: average temperature variation between consecutive days; Type 1: acute bronchial asthma; Type 2: chronic cough-variant asthma; Yrs: years old.

(lag days 0–10) of different meteorological factors on hospital visits for asthma stratified by age, gender, and asthma subtype. RR value and 95% CI of effects of different indicators on asthma hospital visits on current day and lag days 1 through 10 can be found in Table S1 (supplemental material). Fig. 2 shows the significant lag effects of AQI, maximum wind speed, pressure, humidity, and temperature on lag days 0 through 10.

AQI: air quality index.

The cumulative effects of daily average temperature on asthma hospital visits decreased with increasing temperature. Children aged 0–5 years old, males, and people with cough-variant asthma were more susceptible to temperatures below 10 °C, and adults with asthma were susceptible to temperatures below 0 °C. Temperature variation did not show much effect on hospital visits for bronchial asthma, for females, or for children aged 6–14 years old. For lag effects of days 0 through 10,

the largest single-day RRs (the 95th percentile of temperature [26 °C] relative to the lowest cause-specific morbidity temperature [31 °C]) of daily average temperature on hospital visits of 0- to 5-year-old children with asthma, adults with asthma, males, and those with cough-variant asthma were 1.012 (95% CI: 1.001–1.024) on lag day 6, 1.058 (95% CI: 1.005–1.114) on current day, 1.009 (95% CI: 1–1.018) on lag day 5, and 1.028 (95% CI: 1.006–1.051) on lag day 6, respectively. The largest cumulative RRs for hospital visits of children aged 0–5 years old, adults, males, and those with cough-variant asthma were 1.066 (95% CI: 0.998–1.15; lag days 0–10), 1.113 (95% CI: 1.002–1.238; lag days 0–2), 1.056 (95% CI: 1.002–1.114; lag days 0–10), and 1.092 (95% CI: 1.955–1.248; lag days 0–9), respectively.

The cumulative effect of barometric pressure on asthma hospital visits increased with high pressure. The effects on adult asthma and bronchial asthma were significantly positive and the effect on cough-

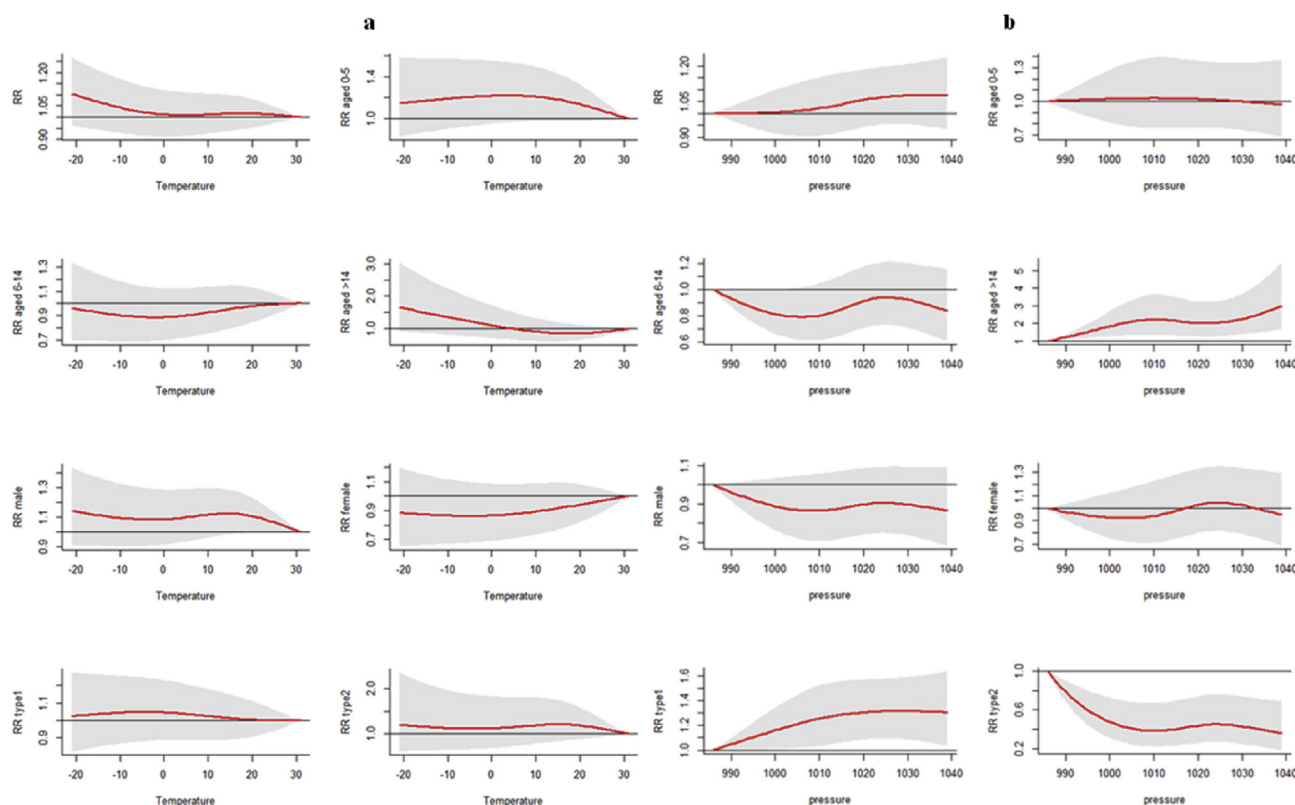


Fig. 1. Cumulative effects of daily average temperature and barometric pressure variations on asthma hospital visits stratified by age, gender, and asthma subtypes (a: temperature; b: pressure).

Table 2

Cumulative relative risk of 95th percentile (P95) versus lowest cause-specific asthma hospital visit indicator value (LCV) in different gender, age, and asthma subtype groups.

Indicators	LCV	P95	Cumulative RRs in asthma subgroups							
			Total	0–5 yrs	6–14 yrs	> 14 yrs	Male	Female	Type 1	Type 2
Temperature	31.000	26.000	1.009	1.066	0.993	0.915	1.056	0.972	1.000	1.092
Pressure	985.810	1031.844	1.069	1.002	0.890	2.414	0.880	1.005	1.298	0.422
Wind speed	54.000	36.000	1.127	1.499	1.048	0.844	1.219	1.147	1.221	0.983
Humidity	50.000	84.975	1.004	0.933	0.962	1.300	0.945	0.991	1.010	0.899
AQI	70.000	197.950	1.035	0.954	1.117	0.902	1.042	1.074	1.016	1.145

AQI: air quality index; Type 1: acute bronchial asthma; Type 2: chronic cough-variant asthma; bold words: P value of confidence interval < 0.05.

variant asthma was significantly negative. For lag effects of days 0 through 10, the largest single-day RRs (the 95th percentile of pressure [1031.844 Pa] relative to the lowest cause-specific morbidity pressure [985.81 Pa]) of daily barometric pressure on hospital visits of adult and bronchial asthma were 1.31 (95% CI: 1.157–1.482) on current day and 1.036 (95% CI: 1.001–1.072) on lag day 9, respectively. The largest cumulative RRs for hospital visits for adults and bronchial asthma were 2.414 (95% CI: 1.446–4.03; lag days 0–10) and 1.298 (95% CI: 1.066–1.579; lag days 0–10), respectively.

The cumulative effect of maximum wind speed on hospital visits decreased with increasing daily maximum wind speed, especially for children aged 0–5 years old, males, and those with acute bronchial asthma. For lag effects of days 0 through 10, the largest single-day RRs (the 95th percentile of wind speed [36 km/h] relative to the lowest cause-specific morbidity wind speed [54 km/h]) of daily maximum wind speed on hospital visits of children aged 0–5 years old, males, and patients with bronchial asthma were 1.061 (95% CI: 1.012–1.113) on lag day 5, 1.035 (95% CI: 1.004–1.067) on current day, and 1.035 (95% CI: 1.002–1.069) on lag day 5, respectively. The largest cumulative RRs for hospital visits of children aged 0–5 years old, males, and patients with bronchial asthma were 1.499 (95% CI: 1.062–2.116; lag days 0–10), 1.249 (95% CI: 1.003–1.554; lag days 0–8), and 1.228 (95% CI: 0.983–1.535; lag days 0–9), respectively.

The cumulative effect of daily humidity on total asthma hospital visits was weak (RR = 1.004). A humidity of 50% was a turning point, after which the effects on 0- to 5-year-old children, males, and patients with chronic cough-variant asthma were negative and the effects on adults and those with bronchial asthma were positive. For lag effects of days 0 through 10, the largest single-day RR (the 95th percentile of humidity [83.975%] relative to the lowest cause-specific morbidity wind humidity [50%]) of daily humidity on hospital visits of adult asthma was 1.032 (95% CI: 1.007–1.058) on lag day 9; the largest cumulative RR for hospital visits for adult asthma was 1.3 (95% CI: 1.12–1.509; lag days 0–10).

The cumulative effect of AQI on hospital visits for asthma increased with AQI, especially when AQI was over 70. Asthma in children aged 6–14 years old was more vulnerable to AQI variation. For lag day effects of 0 through 10, the largest single-day RRs (the 95th percentile of AQI [197.95] relative to the lowest cause-specified morbidity AQI [70]) of daily AQI on hospital visits of 6- to 14-year-old children, males, and females with asthma were 1.049 (95% CI: 1.027–1.072), 1.025 (95% CI: 1.01–1.041) on current day, and 1.013 (95% CI: 1.002–1.023) on lag day 2, respectively. The largest cumulative RRs for hospital visits for 6- to 14-year-old children, males, and females with asthma were 1.22 (95% CI: 1.06–1.187; lag days 0–4), 1.051 (95% CI: 1.013–1.09; lag days 0–3) and 1.081 (95% CI: 1.009–1.158; lag days 0–9), respectively.

4. Discussion

4.1. Major findings of this study

Meteorological factors were significantly associated with asthma

hospital visits, but the effects of each factor were different in various ages, genders, and asthma subtypes. Low temperatures were associated with more asthma hospital visits of 0- to 5-year-old children, males, and patients with cough-variant asthma. Barometric pressure showed positive associations with hospital visits of adults and patients with bronchial asthma. Wind speed showed negative associations with asthma hospital visits of 0- to 5-year-old children, males, and those with bronchial asthma. Humidity showed negative effects on childhood asthma and cough-variant asthma. AQI was positively associated with hospital visits of 6- to 14-year-olds and patients with cough-variant asthma. Compared with air pollutants' effects (represented by AQI), meteorological factors showed stronger associations with asthma hospital visits.

4.2. Comparisons with other studies

Relationships between air pollutant concentration and daily temperature variations and hospital visits for asthma were explored most in previous studies. Our study found that asthma hospital visits increased with decreasing daily average temperature, especially among males, 0 to 5-year-old children, and those with cough-variant asthma. These findings are similar to the conclusions of many previous studies. [Zhang et al. \(2014\)](#) conducted a time-series analysis in Shanghai, China and found that lower temperatures were associated with higher risks of hospital admission for asthma with a high cumulative effect (RR = 1.2, 25th percentile of temperature relative to the median temperature) at lag days 0 through 14, similar results were also found by [Hu Y et al. \(Eschenbacher et al., 1992\)](#) in another study in Shanghai. [Xu et al. \(2013a\)](#) studied the relationship between diurnal temperature range (DTR) and emergency admissions for childhood asthma in Australia and found the greatest RR for lag days 0 through 9 was 1.31 per 5-degree increment of DTR: males and 5 to 9-year-old children with asthma were most vulnerable to the changes in temperature. Two additional studies in Australia ([Xu et al., 2013b](#); [Li et al., 2014](#)) found an increase in DTR induced a reduction in peak expiratory flow and increased the occurrence of respiratory symptoms in children; males and 0- to 5-year-old children were most vulnerable to extreme temperatures. [Kim et al. \(2014\)](#) conducted a similar study in Seoul, Korea and found an increment of 1° in DTR caused a 17.9% increase in asthma admissions among people aged over 65 years, which was different from a study in Hong Kong ([Qiu et al., 2015](#)) that reported a 1-degree change in DTR was associated with a 2.49% increase in childhood asthma admissions. Another similar study by [Lam et al. \(2019\)](#) in Hong Kong found daily temperature change was mainly associated with readmissions of 0- to 5-year-old children with asthma. In the United States, [O'Lenick et al. \(O'Lenick et al., 2017\)](#) found a positive and significant association between daily highest temperature and pediatric asthma morbidity in Atlanta, Georgia (RR = 1.06). [Li et al. \(2016\)](#) conducted a study in Hefei, China and found a 1-degree increase in DTR was associated with a 4.2% increase in hospital visits for childhood asthma. Our study also examined the association between DTR and hospital visits of childhood asthma, results(see supplemental materials) showed adverse

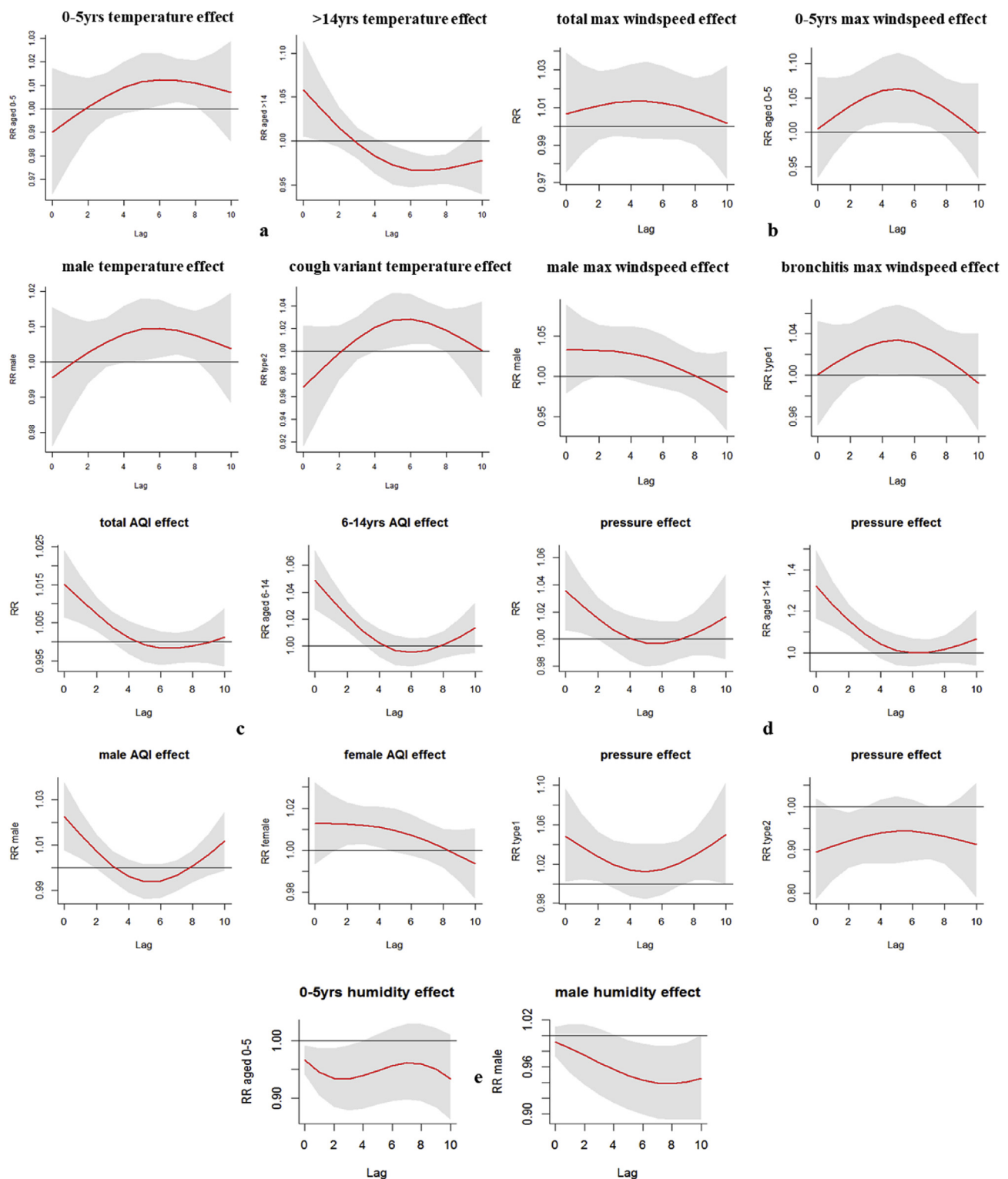


Fig. 2. Variations for lag effects of daily average temperature, pressure, humidity, maximum wind speed, and AQI on lag days 0 through 10 (a: effects of temperature on 0-5 year-olds, > 14 year-olds, males, and patients with cough-variant asthma; b: effects of daily maximum wind speed on total population, 0-5 year-olds, males, and patients with bronchial asthma; c: effects of daily AQI on total population, 6-14 year-olds, males, and females; d: effects of daily barometric pressure on total population, > 14 year-olds, patients with bronchial asthma, and patients with cough-variant asthma; e: effects of daily humidity on 0-5 year-olds and males).

associations except for cough-variant childhood asthma. Taken together, we can conclude that daily temperature was adversely associated with male childhood asthma. Minor differences among various studies may be due to differences of geographical locations and study methods as well as meteorological factors adjusted. No study explored

the different effects on asthma subtypes, and our conclusion (i.e., the strongest association was observed between temperature and cough-variant childhood asthma) needs to be confirmed in future studies.

Our study found significant associations between daily maximum wind speed, barometric pressure, humidity, and AQI and hospital

admission for asthma in different age, gender, and asthma subtype groups. Similar evidence, especially for wind speed, pressure, and humidity, are limited. Lam et al. (2016) conducted a time-series study in Hong Kong and found that high humidity in a hot season and low humidity in a cold season were associated with increased hospital admissions for asthma. Ehelepola et al. (2018) conducted an association analysis study in Sri Lanka and found negative correlations between nighttime humidity and barometric pressure and exacerbations of acute wheezing. Jo et al. (2017) also found a negative association ($RR = 0.994$) between humidity and respiratory disease. An association analysis study in Japan by Ehara et al. (2000) also found negative associations between humidity and asthma hospitalizations; the association with pressure was positive. A case-crossover study in Japan by Yamazaki et al. (2015), which is similar to our study, found hospital visits for childhood asthma were positively associated with pressure (odds ratio [OR] = 1.016 with 1-hPa increase) and negatively associated with humidity (OR = 0.96 with 10% increase) and wind speed (OR = 0.904 with 1-m/s increase). Hu Y et al. (Eschenbacher et al., 1992) conducted a similar study in Shanghai of China and found allergic disease admissions increased with higher air pressure. On the basis of these studies, along with our study results, we concluded that high wind speed and humidity are associated with decreased childhood asthma admissions and high pressure is associated with increased asthma admissions. The specific effects of humidity, wind speed, and barometric pressure on asthma should be studied further.

There is strong evidence that exposure to particulate and traffic-related air pollutants, such as $PM_{2.5}$, NO_2 , and PM_{10} , causes new asthma cases and exacerbates existing asthma. However, the effects of integrated air pollution have not been studied. We used AQI to represent integrated air pollutant exposure in this study, and the results were similar with previous single-pollutant studies (Zheng et al., 2015; Lavigne et al., 2012; Sloan and Johnston, 2016). We concluded that, overall, elevated air pollution exacerbates asthma conditions and causes more hospital visits, the effect of AQI in our study on asthma was very important and was only smaller than max wind speed in our study by comparing standard beta value in the model (see Supplemental Material Table S3). Further investigation of the health effects of integrated air pollution exposure should be conducted.

4.3. Strengths and limitations

Very few studies have been conducted to explore the comprehensive effects of meteorological factors and integrated air pollution on asthma. We categorized outcome measures of asthma hospital visits into different disease types, ages, and gender groups to assess exposure effects more precisely. We were able to control the confounding factors of other meteorological factors and air pollution in our analysis to accurately determine associations between each factor and asthma hospital visits.

There are some limitations to this study. First, we used hospital records instead of individual-level data. We were not able to collect data regarding where people spent most of their time, their work schedules or occupations, or their leisure patterns: these lifestyle characteristics impact exposure to all meteorological and air pollution factors.

5. Conclusion

This is the first comprehensive study of the associations between asthma and meteorological factors in China. We found that 0- to 5-year-old children and males were more vulnerable to low temperatures; cough variant asthma was more vulnerable to temperature than bronchial asthma; adults and patients with bronchial asthma were more vulnerable to barometric pressure; wind speed and humidity were protective factors for childhood asthma; and 6- to 14-year-old children were more vulnerable to air pollution. Meteorological factors of max

wind speed showed stronger associations with asthma than total air pollutants. Further research should focus on the effects of air pollutants on asthma.

Consent for publication

All authors give their consent for publication.

Availability of data and material

Data and material will be available under suitable requirements.

Funding

This work was supported by the National Key R&D Project of China [grant numbers 2017YFC0907402, 2017].

Authors' contributions

Shu Liu, Zongjiao Chen, and Biao Zu completed the data processing; Hehua Zhang analyzed the data and wrote the paper; Yuhong Zhao designed the entire study process and reviewed the work.

We thank the Bureau of Meteorology and the Environmental Protection Bureau in Shenyang for providing original data of daily meteorological parameters and pollutant concentrations.

Declaration of competing interest

The authors declare no competing financial interests.

Acknowledgments

Ethics approval and consent to participate: This study did not involve any human or animal data; it was deemed negligible-risk research and was exempt from ethical review by the Human Research Ethics Committee of Shengjing Hospital of China Medical University and, thus, no consent was required.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envres.2020.109115>.

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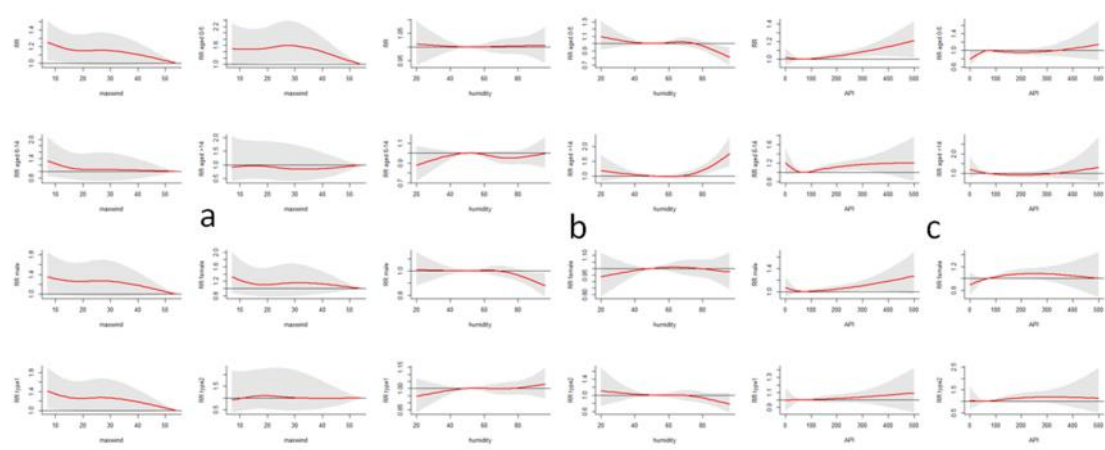


Figure S1. Cumulative effects of daily max wind speed, humidity and AQI variations on asthma hospital visits stratified by age, gender, and asthma subtypes.(a: max wind speed; b: humidity; c: AQI, air quality index)

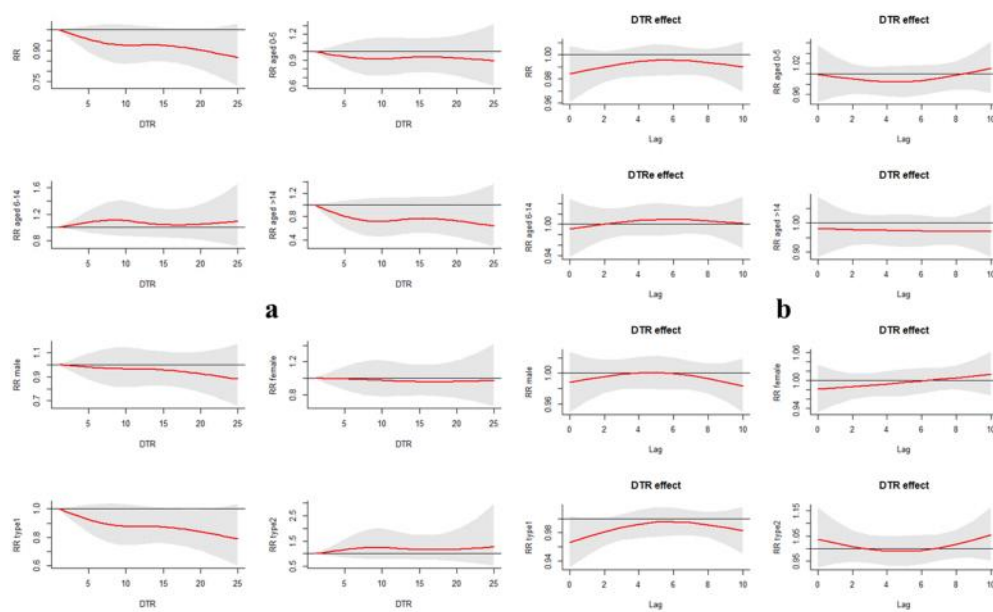


Figure S2. Effects of DTR on asthma hospital visits stratified by age, gender, and asthma subtypes. (a. Cumulative effects of DTR variations on asthma b. Variations for lag effects of DTR on lag days 0 through 10)

Table S3. Standard beta values of climatic factors and AQI in the model

Parameter	Standard β	Standard Error	T value	P value
Pressure	0.025	0.009	2.526	0.013
AQI	0.053	0.022	2.442	0.015
Max windspeed	-0.064	0.019	-3.288	0.001
Humidity	-0.015	0.010	-1.560	0.119
Temperature	0.028	0.017	1.609	0.108

Bold texts: statistically significant.

Table S1. RR value and 95% CI of effects of different indicators on asthma hospital visits on current day and lag days 1 through 10

	Lag day	Total	Aged 0-5	Aged 6-14	Aged >14	Male	Female	type1	type2
Temperature	0	1.003(0.991-1.015)	0.99(0.964-1.017)	0.995(0.968-1.024)	1.058(1.005-1.114)	0.996(0.976-1.015)	0.989(0.963-1.015)	1.007(0.988-1.026)	0.968(0.916-1.023)
	1	1.005(0.985-1.025)	0.986(0.942-1.032)	0.992(0.946-1.04)	1.096(1.006-1.194)	0.995(0.962-1.028)	0.978(0.936-1.022)	1.011(0.98-1.044)	0.952(0.868-1.044)
	2	1.005(0.981-1.03)	0.987(0.932-1.044)	0.989(0.933-1.049)	1.113(1.002-1.238)	0.997(0.957-1.039)	0.969(0.918-1.023)	1.013(0.974-1.053)	0.95(0.848-1.065)
	3	1.006(0.979-1.033)	0.992(0.932-1.055)	0.988(0.928-1.052)	1.111(0.99-1.246)	1.003(0.959-1.048)	0.962(0.907-1.02)	1.012(0.97-1.056)	0.961(0.849-1.088)
	4	1.005(0.978-1.033)	1.001(0.939-1.067)	0.987(0.926-1.052)	1.092(0.971-1.228)	1.011(0.966-1.058)	0.956(0.9-1.015)	1.01(0.967-1.055)	0.982(0.865-1.114)
	5	1.005(0.978-1.033)	1.012(0.949-1.08)	0.987(0.926-1.052)	1.062(0.944-1.195)	1.02(0.974-1.068)	0.952(0.896-1.011)	1.007(0.964-1.052)	1.008(0.888-1.145)
	6	1.004(0.977-1.033)	1.025(0.96-1.095)	0.988(0.926-1.054)	1.028(0.912-1.158)	1.03(0.983-1.078)	0.95(0.894-1.01)	1.004(0.96-1.049)	1.036(0.912-1.178)
	7	1.004(0.977-1.033)	1.037(0.97-1.109)	0.988(0.926-1.055)	0.993(0.88-1.121)	1.039(0.991-1.089)	0.951(0.894-1.012)	1.001(0.957-1.047)	1.062(0.933-1.208)
	8	1.005(0.977-1.034)	1.049(0.98-1.122)	0.99(0.927-1.057)	0.962(0.852-1.086)	1.046(0.998-1.097)	0.955(0.897-1.017)	0.999(0.955-1.046)	1.081(0.949-1.232)
	9	1.006(0.978-1.036)	1.059(0.987-1.135)	0.991(0.926-1.06)	0.936(0.826-1.059)	1.052(1.003-1.105)	0.962(0.902-1.026)	0.999(0.953-1.046)	1.092(0.955-1.248)
Pressure	10	1.009(0.977-1.041)	1.066(0.988-1.15)	0.993(0.922-1.069)	0.915(0.799-1.048)	1.056(1.002-1.114)	0.972(0.906-1.043)	1(0.95-1.052)	1.092(0.943-1.266)
	0	1.024(0.996-1.053)	0.997(0.931-1.069)	0.991(0.93-1.056)	1.31(1.157-1.482)	0.963(0.919-1.009)	1.014(0.952-1.079)	1.036(0.99-1.083)	0.888(0.78-1.011)
	1	1.041(0.992-1.092)	0.992(0.882-1.116)	0.981(0.88-1.092)	1.606(1.302-1.981)	0.932(0.861-1.009)	1.025(0.922-1.14)	1.065(0.986-1.149)	0.802(0.644-0.998)
	2	1.05(0.989-1.116)	0.984(0.848-1.142)	0.968(0.844-1.11)	1.85(1.418-2.413)	0.905(0.819-1.001)	1.035(0.905-1.184)	1.087(0.987-1.198)	0.736(0.558-0.97)
	3	1.053(0.983-1.128)	0.974(0.822-1.155)	0.954(0.815-1.116)	2.017(1.491-2.728)	0.884(0.788-0.991)	1.043(0.894-1.216)	1.104(0.988-1.233)	0.684(0.498-0.938)
	4	1.051(0.974-1.135)	0.965(0.8-1.164)	0.939(0.789-1.117)	2.104(1.511-2.931)	0.867(0.764-0.985)	1.048(0.883-1.242)	1.117(0.988-1.263)	0.642(0.452-0.912)
	5	1.047(0.963-1.139)	0.957(0.778-1.177)	0.925(0.763-1.12)	2.132(1.485-3.063)	0.856(0.744-0.984)	1.05(0.87-1.267)	1.13(0.987-1.293)	0.606(0.411-0.893)
	6	1.044(0.952-1.144)	0.953(0.76-1.195)	0.912(0.739-1.125)	2.135(1.44-3.166)	0.849(0.728-0.99)	1.048(0.853-1.288)	1.145(0.987-1.328)	0.572(0.373-0.877)
	7	1.042(0.944-1.151)	0.954(0.747-1.219)	0.901(0.719-1.13)	2.143(1.404-3.271)	0.848(0.718-1.001)	1.043(0.835-1.303)	1.167(0.995-1.369)	0.537(0.339-0.852)
	8	1.046(0.941-1.161)	0.962(0.742-1.248)	0.894(0.704-1.135)	2.181(1.396-3.407)	0.853(0.715-1.017)	1.035(0.818-1.309)	1.198(1.012-1.419)	0.501(0.308-0.816)
Max wind	9	1.054(0.944-1.178)	0.978(0.742-1.289)	0.89(0.692-1.145)	2.266(1.416-3.627)	0.863(0.717-1.04)	1.022(0.797-1.31)	1.241(1.038-1.485)	0.463(0.277-0.773)
	10	1.069(0.947-1.208)	1.002(0.739-1.359)	0.89(0.676-1.172)	2.414(1.446-4.03)	0.88(0.718-1.08)	1.005(0.766-1.319)	1.298(1.066-1.579)	0.422(0.241-0.741)
Max wind	0	1.011(0.98-1.043)	1.011(0.94-1.088)	1.041(0.966-1.122)	0.934(0.817-1.068)	1.04(0.986-1.096)	0.996(0.929-1.068)	1.001(0.951-1.052)	1.078(0.928-1.252)

Speed	1	1.023(0.97-1.08)	1.037(0.915-1.176)	1.069(0.939-1.216)	0.89(0.707-1.119)	1.079(0.985-1.182)	0.992(0.88-1.119)	1.011(0.927-1.103)	1.116(0.863-1.443)
	2	1.037(0.967-1.112)	1.078(0.917-1.268)	1.081(0.915-1.277)	0.862(0.641-1.158)	1.117(0.993-1.256)	0.989(0.847-1.154)	1.032(0.923-1.154)	1.112(0.799-1.548)
	3	1.052(0.97-1.14)	1.134(0.939-1.368)	1.081(0.891-1.312)	0.847(0.601-1.195)	1.153(1.006-1.322)	0.986(0.823-1.181)	1.061(0.931-1.209)	1.076(0.733-1.578)
	4	1.067(0.974-1.168)	1.2(0.972-1.483)	1.071(0.862-1.332)	0.844(0.574-1.241)	1.186(1.018-1.383)	0.986(0.805-1.207)	1.097(0.947-1.27)	1.019(0.664-1.563)
	5	1.081(0.977-1.197)	1.274(1.006-1.612)	1.056(0.829-1.346)	0.847(0.551-1.301)	1.214(1.024-1.44)	0.99(0.791-1.24)	1.135(0.964-1.336)	0.957(0.596-1.539)
	6	1.095(0.979-1.225)	1.347(1.038-1.747)	1.042(0.797-1.36)	0.852(0.53-1.371)	1.235(1.023-1.491)	1.001(0.781-1.283)	1.171(0.977-1.403)	0.907(0.538-1.529)
	7	1.107(0.98-1.25)	1.412(1.063-1.875)	1.031(0.771-1.378)	0.857(0.511-1.437)	1.247(1.016-1.53)	1.02(0.779-1.336)	1.201(0.987-1.462)	0.878(0.499-1.546)
	8	1.117(0.98-1.272)	1.462(1.08-1.98)	1.027(0.754-1.4)	0.858(0.494-1.491)	1.249(1.003-1.554)	1.05(0.787-1.4)	1.221(0.989-1.507)	0.877(0.48-1.6)
	9	1.123(0.979-1.289)	1.492(1.082-2.058)	1.032(0.744-1.433)	0.854(0.476-1.534)	1.239(0.983-1.563)	1.091(0.804-1.481)	1.228(0.983-1.535)	0.909(0.482-1.716)
	10	1.127(0.972-1.306)	1.499(1.062-2.116)	1.048(0.737-1.49)	0.844(0.45-1.584)	1.219(0.951-1.563)	1.147(0.827-1.593)	1.221(0.961-1.551)	0.983(0.497-1.942)
Humidity	0	0.997(0.986-1.009)	0.966(0.941-0.991)	1.006(0.98-1.033)	1.013(0.964-1.064)	0.992(0.974-1.011)	0.997(0.973-1.022)	1(0.982-1.018)	0.974(0.922-1.029)
	1	0.995(0.977-1.014)	0.945(0.904-0.987)	1.008(0.963-1.055)	1.028(0.946-1.118)	0.984(0.953-1.015)	0.998(0.957-1.041)	0.999(0.97-1.03)	0.957(0.872-1.05)
	2	0.994(0.971-1.018)	0.935(0.885-0.987)	1.006(0.95-1.064)	1.047(0.944-1.161)	0.975(0.937-1.014)	1.002(0.951-1.056)	0.998(0.961-1.036)	0.948(0.844-1.065)
	3	0.994(0.968-1.02)	0.934(0.879-0.992)	1(0.939-1.064)	1.068(0.953-1.198)	0.966(0.924-1.009)	1.008(0.952-1.068)	0.997(0.956-1.039)	0.946(0.833-1.076)
	4	0.994(0.967-1.021)	0.939(0.882-1)	0.992(0.929-1.058)	1.093(0.97-1.232)	0.957(0.914-1.002)	1.016(0.957-1.079)	0.996(0.954-1.04)	0.949(0.831-1.084)
	5	0.994(0.967-1.022)	0.948(0.889-1.011)	0.982(0.919-1.05)	1.12(0.991-1.266)	0.949(0.906-0.995)	1.023(0.962-1.088)	0.995(0.952-1.04)	0.953(0.832-1.092)
	6	0.995(0.967-1.024)	0.957(0.895-1.023)	0.973(0.909-1.042)	1.151(1.015-1.305)	0.943(0.899-0.99)	1.027(0.964-1.094)	0.995(0.951-1.042)	0.955(0.831-1.098)
	7	0.997(0.968-1.027)	0.962(0.898-1.03)	0.966(0.901-1.036)	1.184(1.04-1.347)	0.939(0.894-0.987)	1.027(0.962-1.096)	0.997(0.951-1.044)	0.952(0.826-1.099)
	8	0.999(0.969-1.03)	0.96(0.895-1.03)	0.961(0.895-1.033)	1.22(1.068-1.392)	0.938(0.892-0.987)	1.021(0.956-1.092)	0.999(0.952-1.049)	0.943(0.815-1.091)
	9	1.002(0.971-1.033)	0.951(0.884-1.023)	0.96(0.891-1.034)	1.258(1.097-1.443)	0.94(0.892-0.991)	1.01(0.942-1.082)	1.004(0.955-1.055)	0.925(0.795-1.076)
AQI	10	1.004(0.971-1.039)	0.933(0.862-1.01)	0.962(0.886-1.043)	1.3(1.12-1.509)	0.945(0.893-1.001)	0.991(0.919-1.069)	1.01(0.956-1.066)	0.899(0.763-1.059)
	0	1.019(1.01-1.028)	0.985(0.965-1.005)	1.049(1.027-1.072)	0.995(0.956-1.036)	1.025(1.01-1.041)	1.015(0.995-1.035)	1.016(1.002-1.03)	1.038(0.991-1.088)
	1	1.032(1.017-1.048)	0.975(0.942-1.01)	1.086(1.047-1.127)	0.992(0.926-1.063)	1.042(1.016-1.069)	1.028(0.994-1.063)	1.026(1.002-1.051)	1.068(0.987-1.156)
	2	1.041(1.021-1.061)	0.97(0.928-1.014)	1.11(1.059-1.162)	0.99(0.907-1.08)	1.05(1.017-1.085)	1.041(0.998-1.087)	1.031(1.001-1.063)	1.09(0.987-1.205)
	3	1.045(1.022-1.068)	0.969(0.921-1.019)	1.121(1.063-1.181)	0.987(0.895-1.09)	1.051(1.013-1.09)	1.053(1.004-1.105)	1.032(0.997-1.068)	1.104(0.986-1.235)
	4	1.045(1.021-1.07)	0.97(0.919-1.024)	1.122(1.06-1.187)	0.985(0.885-1.095)	1.046(1.006-1.089)	1.064(1.01-1.121)	1.029(0.991-1.067)	1.111(0.985-1.254)

DTR	5	1.043(1.017-1.07)	0.973(0.918-1.031)	1.116(1.052-1.185)	0.98(0.875-1.098)	1.039(0.996-1.083)	1.073(1.015-1.134)	1.024(0.984-1.065)	1.114(0.98-1.267)
	6	1.04(1.013-1.068)	0.975(0.917-1.037)	1.109(1.041-1.182)	0.973(0.863-1.098)	1.031(0.986-1.078)	1.079(1.018-1.145)	1.018(0.976-1.062)	1.116(0.973-1.28)
	7	1.037(1.008-1.067)	0.975(0.914-1.041)	1.103(1.031-1.18)	0.962(0.847-1.094)	1.026(0.979-1.076)	1.083(1.018-1.152)	1.014(0.97-1.06)	1.118(0.967-1.293)
	8	1.035(1.004-1.066)	0.972(0.908-1.041)	1.102(1.026-1.183)	0.947(0.828-1.083)	1.025(0.976-1.078)	1.083(1.015-1.156)	1.012(0.966-1.06)	1.123(0.965-1.308)
	9	1.034(1.002-1.067)	0.965(0.898-1.037)	1.106(1.026-1.192)	0.927(0.804-1.068)	1.03(0.978-1.086)	1.081(1.009-1.158)	1.012(0.964-1.063)	1.132(0.964-1.329)
	10	1.035(1-1.071)	0.954(0.883-1.031)	1.117(1.029-1.213)	0.902(0.773-1.053)	1.042(0.984-1.103)	1.074(0.997-1.158)	1.016(0.964-1.072)	1.145(0.962-1.364)
	0	0.984(0.961-1.007)	0.999(0.946-1.055)	0.991(0.937-1.048)	0.981(0.884-1.089)	0.988(0.95-1.027)	0.981(0.932-1.033)	0.966(0.931-1.003)	1.037(0.927-1.161)
	1	0.971(0.933-1.011)	0.993(0.905-1.09)	0.987(0.897-1.086)	0.961(0.804-1.149)	0.98(0.916-1.048)	0.965(0.883-1.054)	0.941(0.883-1.003)	1.06(0.874-1.286)
	2	0.962(0.914-1.012)	0.983(0.873-1.108)	0.987(0.874-1.115)	0.939(0.748-1.18)	0.976(0.896-1.063)	0.952(0.85-1.066)	0.923(0.851-1.001)	1.069(0.835-1.368)
	3	0.955(0.9-1.012)	0.97(0.847-1.112)	0.991(0.862-1.139)	0.916(0.706-1.189)	0.974(0.884-1.075)	0.942(0.827-1.072)	0.911(0.83-1)	1.066(0.804-1.413)
	4	0.949(0.89-1.012)	0.955(0.823-1.109)	0.998(0.857-1.162)	0.893(0.672-1.186)	0.975(0.876-1.085)	0.934(0.811-1.076)	0.904(0.816-1.001)	1.056(0.776-1.437)
	5	0.945(0.882-1.013)	0.941(0.8-1.107)	1.007(0.854-1.187)	0.869(0.639-1.181)	0.976(0.869-1.096)	0.93(0.798-1.084)	0.899(0.805-1.004)	1.045(0.75-1.455)
	6	0.941(0.873-1.014)	0.929(0.78-1.106)	1.016(0.852-1.212)	0.844(0.607-1.174)	0.975(0.861-1.105)	0.928(0.787-1.095)	0.895(0.795-1.008)	1.038(0.728-1.48)
	7	0.936(0.865-1.014)	0.921(0.764-1.11)	1.025(0.85-1.236)	0.82(0.578-1.164)	0.972(0.851-1.11)	0.93(0.781-1.109)	0.89(0.784-1.01)	1.042(0.715-1.517)
	8	0.93(0.856-1.011)	0.918(0.754-1.118)	1.032(0.848-1.255)	0.796(0.552-1.15)	0.965(0.84-1.11)	0.936(0.778-1.125)	0.882(0.772-1.008)	1.06(0.715-1.571)
	9	0.923(0.846-1.007)	0.922(0.75-1.133)	1.036(0.844-1.271)	0.773(0.526-1.136)	0.954(0.825-1.104)	0.944(0.779-1.145)	0.87(0.757-1.001)	1.097(0.727-1.654)
	10	0.913(0.832-1.003)	0.932(0.747-1.163)	1.038(0.834-1.292)	0.75(0.496-1.134)	0.939(0.803-1.097)	0.957(0.778-1.176)	0.855(0.737-0.993)	1.155(0.744-1.794)

Table S2. RR value and 95% CI of effects of PM_{2.5} and O₃ on asthma hospital visits on current day and lag days 1 through 10

	Lag	Total	Aged 0-5	Aged 6-14	Aged >14	Male	Female	type1	type2
PM _{2.5}	0	0.99(0.971-1.01)	0.983(0.933-1.036)	1.035(0.979-1.094)	0.919(0.829-1.019)	1.021(0.986-1.058)	0.965(0.92-1.013)	1(0.966-1.034)	0.984(0.878-1.102)
	1	0.981(0.948-1.015)	0.972(0.889-1.062)	1.055(0.96-1.16)	0.862(0.722-1.028)	1.032(0.972-1.095)	0.943(0.868-1.023)	1.001(0.945-1.061)	0.949(0.781-1.152)
	2	0.973(0.931-1.015)	0.965(0.862-1.081)	1.061(0.941-1.196)	0.821(0.656-1.027)	1.032(0.957-1.114)	0.931(0.839-1.033)	1.004(0.933-1.08)	0.898(0.702-1.148)
	3	0.965(0.919-1.013)	0.963(0.849-1.094)	1.055(0.922-1.207)	0.793(0.617-1.02)	1.024(0.941-1.115)	0.929(0.827-1.044)	1.008(0.928-1.094)	0.838(0.636-1.105)
	4	0.957(0.909-1.008)	0.966(0.845-1.105)	1.039(0.9-1.2)	0.771(0.59-1.009)	1.011(0.923-1.106)	0.935(0.826-1.058)	1.013(0.928-1.106)	0.776(0.579-1.042)
	5	0.95(0.9-1.002)	0.973(0.846-1.12)	1.019(0.877-1.185)	0.75(0.566-0.992)	0.994(0.904-1.092)	0.947(0.832-1.078)	1.019(0.93-1.117)	0.72(0.53-0.978)

O ₃	6	0.942(0.891-0.997)	0.985(0.851-1.139)	1(0.854-1.17)	0.721(0.538-0.967)	0.978(0.886-1.079)	0.963(0.841-1.102)	1.026(0.933-1.129)	0.675(0.49-0.929)
	7	0.935(0.882-0.992)	0.999(0.858-1.164)	0.985(0.835-1.161)	0.681(0.501-0.927)	0.966(0.871-1.07)	0.981(0.852-1.13)	1.033(0.935-1.142)	0.645(0.462-0.901)
	8	0.927(0.872-0.986)	1.018(0.867-1.194)	0.977(0.822-1.16)	0.628(0.455-0.867)	0.959(0.861-1.068)	0.999(0.862-1.159)	1.04(0.937-1.155)	0.633(0.446-0.898)
	9	0.919(0.861-0.981)	1.04(0.878-1.232)	0.977(0.815-1.172)	0.563(0.401-0.792)	0.96(0.856-1.076)	1.017(0.87-1.189)	1.047(0.938-1.17)	0.64(0.442-0.927)
	10	0.91(0.848-0.977)	1.066(0.886-1.281)	0.988(0.811-1.204)	0.49(0.339-0.71)	0.968(0.855-1.096)	1.034(0.872-1.226)	1.054(0.935-1.189)	0.669(0.447-1.001)
	0	1.029(1.01-1.049)	1.084(1.032-1.138)	0.979(0.929-1.031)	1.054(0.953-1.166)	1.016(0.983-1.05)	1.044(0.998-1.093)	1.045(1.013-1.079)	0.905(0.809-1.013)
	1	1.049(1.016-1.082)	1.139(1.049-1.237)	0.963(0.883-1.05)	1.091(0.922-1.29)	1.025(0.97-1.083)	1.079(1.001-1.164)	1.079(1.023-1.137)	0.831(0.689-1.001)
	2	1.059(1.018-1.101)	1.163(1.051-1.287)	0.953(0.857-1.059)	1.11(0.904-1.364)	1.027(0.96-1.099)	1.104(1.007-1.211)	1.1(1.031-1.174)	0.773(0.614-0.972)
	3	1.06(1.017-1.106)	1.158(1.037-1.293)	0.948(0.846-1.063)	1.115(0.892-1.393)	1.023(0.951-1.101)	1.119(1.012-1.237)	1.111(1.035-1.191)	0.728(0.568-0.933)
	4	1.056(1.011-1.103)	1.13(1.008-1.267)	0.949(0.844-1.067)	1.11(0.882-1.396)	1.016(0.942-1.095)	1.124(1.014-1.246)	1.112(1.034-1.195)	0.694(0.537-0.896)
	5	1.048(1.002-1.095)	1.089(0.968-1.224)	0.956(0.848-1.077)	1.102(0.871-1.394)	1.008(0.933-1.088)	1.12(1.008-1.244)	1.107(1.028-1.191)	0.668(0.515-0.868)
	6	1.04(0.993-1.089)	1.043(0.924-1.177)	0.969(0.857-1.096)	1.099(0.863-1.401)	1.002(0.926-1.085)	1.108(0.994-1.235)	1.099(1.018-1.185)	0.65(0.496-0.851)
	7	1.035(0.987-1.084)	1.001(0.884-1.133)	0.99(0.872-1.123)	1.109(0.865-1.422)	1.001(0.923-1.086)	1.091(0.976-1.219)	1.091(1.01-1.179)	0.638(0.483-0.841)
	8	1.034(0.987-1.084)	0.967(0.854-1.096)	1.018(0.897-1.155)	1.137(0.886-1.459)	1.008(0.929-1.093)	1.068(0.955-1.194)	1.086(1.005-1.175)	0.63(0.477-0.833)
	9	1.04(0.992-1.09)	0.945(0.833-1.072)	1.054(0.929-1.196)	1.188(0.927-1.523)	1.023(0.943-1.11)	1.041(0.931-1.164)	1.085(1.004-1.174)	0.627(0.474-0.83)
	10	1.053(1.002-1.107)	0.934(0.816-1.068)	1.1(0.963-1.257)	1.267(0.974-1.648)	1.048(0.961-1.143)	1.01(0.897-1.137)	1.089(1.003-1.183)	0.628(0.466-0.846)