



RESEARCH ARTICLE

WILEY

The effects of air pollution on length of hospital stay for adult patients with asthma

Li Luo¹ | Jing Ren¹ | Fengyi Zhang¹ | Wei Zhang² | Chunyang Li² | Zhixin Qiu³ | Debin Huang⁴

¹Business School, Sichuan University, Chengdu, China

²West China Biomedical Big Data Center, West China Hospital, Sichuan University, Chengdu, China

³Respiratory and Critical Care Medicine, West China Hospital, Sichuan University, Chengdu, China

⁴Chengdu Medical Insurance Administration, Chengdu, China

Correspondence

Fengyi Zhang, Business School, Sichuan University, Chengdu, Sichuan 610000, China.
Email: zhangfengyi90@163.com

Funding information

National Natural Science Foundation of China, Grant/Award Numbers: 71532007, 71131006 and 71172197

Summary

Length of hospital stay (LOS) of asthma can be a reflection of the disease burden faced by patients, and it is also sensitive to air pollution. This study aims at estimating and validating the effects of air pollution and readmission on the LOS for those who have asthma, considering their readmission history, minimum temperature, and threshold effects of air pollutants. In addition, sex, age, and season were also constructed for stratification to achieve more precise and specific results. The results show that no significant effects of PM_{2.5} and NO₂ on LOS were observed in any of the patients, but there were significant effects of PM_{2.5} and NO₂ on LOS when a stratifying subgroup analysis was performed. The effect of PM₁₀ on LOS was found to be lower than that of PM_{2.5} and higher than that of NO₂. SO₂ did not have a significant effect on LOS for patients with asthma in our study. Our study confirmed that the adverse effects of air pollutants (such as PM₁₀) on LOS for patients with asthma existed; in addition, these effects vary for different stratifications. We measured the effects of air pollutants on the LOS for patients with asthma, and this study offers policy makers quantitative evidence that can support relevant policies for health care resource management and ambient air pollutants control.

KEYWORDS

air pollution, asthma, length of hospital stay

1 | BACKGROUND

Asthma is one of the most common chronic diseases, associated with a substantial increase in health care costs and economic burden for patients. It affected 300 million people worldwide¹ in 2004; in addition, China has approximately 30 million patients with asthma.² According to World Health Organization estimates, the number of asthma patients will increase by 100 million by 2025. While the prevalence of asthma is increasing, evidence also suggests that per-patient costs are increasing, resulting in a significant upward trend in the overall burden of asthma.³ Barnett and Nurmagametov⁴ found that between 2002 and 2007, the annual direct cost per patient for asthma increased by \$3259 (\$2009) in the United States. In 2007, the total incremental cost of asthma to society was \$56 billion in the United States. Length of hospital stay (LOS), which refers to the length of time between the date of hospital admission and the date of discharge,¹¹ can be a reflection of the disease burden faced by patients. For patients, a shorter LOS is associated with improved patient outcomes and reducing costs⁵; furthermore, it can mean less time away from home and fewer opportunities to develop a hospital-acquired complication.⁶ To some extent, LOS reflects resource consumption and efficiency of a hospital and has an impact on health care planning and policy. Even a small reduction in LOS can dramatically relieve the economic burden of patients. However, little is known about the determinants of LOS.⁷

From the view of health care resource management, identifying the factors associated with LOS for patients with asthma can be very effective for implementing improved care. Studies show that parameters such as demographic factors, hospital type, and temporal factors do not have a strong correlation with the LOS associated with asthma.^{8,9,26} Arnold et al¹⁰ sought to identify the key clinical predictors for acute asthma exacerbations in pediatric patients and also identified the clinical determinants of LOS. Soyiri et al¹¹ used a negative binomial regression to model the effect(s) of demographic, temporal, and diagnostic factors on the LOS by using hospital admission records of patients in London in 2001–2006, taking into account the cluster effect of each patient's hospital attendance. These researchers suggested that respiratory-related secondary diagnoses, age, sex, and day of the week and year of admission were important predictors of LOS. Shanley et al⁷ performed a bivariate and generalized estimating logistic regression analysis to identify factors associated with LOS, after adjusting for severity of illness. Sociodemographic, temporal, and health status factors were examined. Although the above mentioned researchers analyzed factors associated with the LOS for patients with asthma, these studies did not take into account the effects of air pollution on LOS for patients with asthma.

Today, in industrialized countries, especially in the low- and middle-income populations, the association between respiratory diseases and environmental pollution represents a relevant social and physical health problem. With rapid developments in industrialization and urbanization, air pollution has increased during the past few decades in Asian countries, making many Asian cities among the most polluted cities in the world. Subsequently, ambient air pollution has become one of the major health concerns of the general population.¹² Increasing evidence supports the fact that air pollutants are associated with asthma. It was estimated that ambient particulate matter (PM) pollution was responsible for approximately 3.1 million deaths worldwide¹³ in 2010. Atmospheric aerosol particles, also known as atmospheric PM, PM, particulates, or suspended PM, are microscopic solid or liquid matter suspended in Earth's atmosphere. PM_{2.5} (fine particles with a diameter of 2.5 μm or less) has most often been associated with asthma morbidity.¹⁴ In Hungary, the level of air pollution is one of the highest in Europe; approximately 16 000 annual premature deaths are attributable to exposure to ambient PM₁₀ (inhalable coarse particles, which are coarse particles with a diameter less than 10 μm) concentrations.¹⁵ In 2011, Roy et al¹⁶ conducted bivariate analyses using Spearman correlations and multivariable analyses using Poisson regression, which included the LOS for patients with asthma, controlling for patient demographics, hospital characteristics, and month of admission. The predictors in their research were the average concentration of 6 pollutants—PM_{2.5}, PM₁₀, SO₂ (sulfur dioxide), NO₂ (nitrogen dioxide), CO (carbonic oxide), and O₃ (ozone)—near the hospital during the month of admission. However, they found that no pollutants were significant predictors of LOS. Furthermore, this study did not consider threshold effects, which are of potential importance for exploring the associations between concentration of air

pollution and LOS. Therefore, further work can be done by taking threshold effects into consideration, which can generate a more accurate result.

The aim of this exploratory study is to measure the effects of air pollutants on the LOS for patients with asthma considering threshold effects and readmission. Considering that acute effects studies have found that the concentrations of PM_{2.5}, PM₁₀, SO₂, and NO₂ have effected disease exacerbations, emergency admission, hospitalizations, and mortality,¹⁷ we predicted that ambient air pollutant concentrations of NO₂, SO₂, PM_{2.5}, and PM₁₀ can also have similar effects. Threshold effects have a distinct relevance in air pollution epidemiology: They have a plausible biological basis, and their results are easy to communicate and interpret since the regression coefficients show effects occurring above a certain concentration¹⁸; therefore, discontinuities in the concentration-response relationship are avoided. That is also why in this study, threshold effects are taken into account. In addition, readmission is a factor that cannot be ignored, and patients with readmission records have a longer LOS. Previous research has not taken the readmission factor into consideration to accurately measure the effects of air pollution. To accomplish our study, we linked 3 representative databases: a hospitalization information database, an environmental monitoring database, and a meteorological database.

In addition, we also took minimum temperature into consideration. Stratified models of season, sex, and age were constructed to achieve systematic research. Relative risk (RR) was used to describe the effects of air pollutants on LOS, since this approach is straightforward. Our study results provide quantified evidence to reinforce the need for ongoing efforts to reduce levels of air pollutants and the need for further research regarding asthma and ambient air pollution. In addition, our research accurately measured the burden of asthma caused by ambient air pollution, thus laying a solid foundation for environmental protection and health care policy makers. Policy changes to reduce ambient pollutant exposure may lead to reduced LOS for patients with asthma and substantial savings in health care spending.

2 | METHOD

2.1 | Data

This study collected hospitalization information on adult residents between January 1, 2014, and December 31, 2014 (365 days), with a primary diagnosis of asthma (International Classification of Diseases, Tenth Revision, codes J45.001, J45.005, J45.901, and J45.903). Our study covered several regions of Sichuan province, China. Approximately 12 million residents were covered during this period. The data were also stratified by season, sex, medical insurance type, and readmission. Warm season was defined as the days from April to September, and cool season was defined as the days from October to March. Children under 15 years were excluded from our study.

Daily (24-h average) air pollution concentration data including PM_{2.5}, PM₁₀, SO₂, and NO₂ from January 1, 2014, to December 31, 2014, were obtained from the website of the Environmental Monitoring Center database. To adjust for the effect of weather on the LOS for patients with asthma, we obtained meteorological data (daily minimum temperatures) from the website of the meteorological bureau.

2.2 | Statistical analysis

We used Pearson correlation to measure the unadjusted association among all 4 pollutants, recognizing that pollutants arising from similar sources can be highly correlated.^{19,20} The main source of exposure in the general population included combustion processes, traffic, automobile service stations, gasoline transfer, exhaust fumes from motor vehicles, and industrial emissions. In our early study, we found that the distribution of the LOS for patients with asthma was extremely narrow. We used Poisson regression to estimate the effects of air pollution levels on the LOS for patients with asthma since the limited distribution of LOS might make detection of pollutant effects unlikely. We also included covariates associated with LOS: readmission, minimum temperatures, and threshold results in our

model. We estimated the effects in single-pollutant models. The single-pollutant additive model was used in the following form:

$$\log(Y) = \beta_0 + \beta_1 \text{Con} + \beta_2 (\text{Con} - \xi)^+ + \beta_3 \text{Readmission} + \beta_4 \text{Mtemp}, \quad (1)$$

where Y is the LOS of one patient with asthma, Con is the air pollutant concentration, and $(\text{Con} - \xi)^+ = \max(\text{Con} - \xi, 0)$. Readmission was used as a binary variable. If one patient had a readmission history, the bivariate variable was equal to 1; otherwise, it was equal to 0. Mtemp represents the minimum temperature of the event day.

We measured the effects of air pollutants with different lags from Lag0 (current day) to Lag0-15 (the recent 15 days). Lag0-15 represented the 15-day moving average of air pollutant concentration of the most recent 15 days. We used moving averages because the single-day model may have underestimated the cumulative effects of pollutants. We assessed the risk of single-pollutant models by using RR and the corresponding 95% confidence intervals.

Stratified analyses of exposure on the average exposure from Lag0 to Lag0-15 based on sex, season, and age group were performed to evaluate the effect modification. Analysis stratified by season was justified, given that air pollution composition can vary with meteorologic influences and, thus, effects can vary.²¹ The results of the analyses were expressed as an RR to quantify the percent change in the LOS for patients with asthma based on a corresponding increased exposure of $10 \mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$, PM_{10} , SO_2 , and NO_2 . In this way, we were able to explore the effects of air pollutants on the LOS for patients with asthma. Analyses were conducted using R software.

3 | RESULTS

Descriptive analyses of asthma events stratified by age group, sex, month of admission, quarter of admission, medical insurance type, and readmission history are shown in Table 1. A total of 4651 asthma events were observed in our study sample in 2014, representing an average rate of 12.7 events per day; the mean LOS was found to be 9.12 days. We observed that the number of female asthma admissions was higher than male admissions in our study. On average, there were approximately 5 males and 8 female patients per day admitted for asthma. There were 2 types of medical insurance used, the Urban Employee Basic Medical Insurance (UEBMI) and the other Urban Resident Basic Medical Insurance (URBMI). UEBMI is mainly targeted to all employers and employees in urban areas, and URBMI is mostly for minor residents and unemployed residents of working age. The reimbursement proportion of UEBMI is higher than the reimbursement proportion of URBMI. The patients with UEBMI were found to have more asthma admissions and longer mean LOS compared with the patients with URBMI. The mean LOS for patients with asthma showed a strong seasonal pattern, with a longer LOS found during the cool season. One finding indicated that the mean LOS of those who had a readmission history was longer than those who did not have a readmission history.

Table 2 summarizes the basic statistics for air pollutants ($\text{PM}_{2.5}$, PM_{10} , SO_2 , and NO_2) and meteorological data from January 1, 2014, to December 31, 2014. In 2014, the mean daily air pollutant levels were $72 \mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$, $116 \mu\text{g}/\text{m}^3$ for PM_{10} , $17 \mu\text{g}/\text{m}^3$ for SO_2 , and $52 \mu\text{g}/\text{m}^3$ for NO_2 . Generally, there were higher correlation coefficients among the 4 air pollutants. Table 3 shows the Pearson correlation coefficient values. There was a high correlation among several pollutants; in particular, $\text{PM}_{2.5}$ and PM_{10} were highly correlated during our study period.

Table 4 shows results from the unadjusted Spearman correlation coefficients between the LOS for patients with asthma and $\text{PM}_{2.5}$, PM_{10} , SO_2 , and NO_2 . We found that only $\text{PM}_{2.5}$ had a positive impact on LOS, and the effect was weak and happened from Lag0-13 to Lag0-15. Table 5 presents the concentration threshold of the Chinese ministry of environmental protection for each pollutant. Our study used the "Primary Standard" to evaluate the threshold effects.

The results of the single-pollutant generalized additive models for the 4 pollutants are illustrated in Table 6 and show the percent increase in LOS per $10\text{-}\mu\text{g}/\text{m}^3$ increase in air pollution. As the moving average of days increased, the RR increased for 4 pollutants. For PM_{10} , the significant effects on LOS for patients with asthma were observed

TABLE 1 The demographic and clinical characteristics of this study population from January 1, 2014, to December 31, 2014

Variable	Mean LOS	Admissions	Proportion, %	P
Total	9.12	4651	100	
Age				.000
15-65	8.52	3496	75.17	
65+	10.92	1155	24.83	
Sex				.566
Male	9.18	1788	38.44	
Female	9.08	2863	61.56	
Month				.005
1	9.44	383	8.23	
2	9.45	333	7.16	
3	9.74	343	7.37	
4	9.20	414	8.90	
5	8.91	370	7.96	
6	9.32	330	7.10	
7	9.09	385	8.28	
8	8.80	470	10.11	
9	8.76	441	9.48	
10	8.96	450	9.68	
11	9.58	375	8.06	
12	8.44	357	7.68	
Quarter				.003
1	9.54	1059	22.77	
2	9.14	1114	23.95	
3	8.87	1296	27.86	
4	9.00	1182	25.41	
Medical insurance type				.000
URBMI	7.69	1846	39.69	
UEBMI	10.06	2805	60.31	
Readmission				.008
0	9.07	4199	90.28	
1	9.53	452	9.72	

Abbreviations: LOS, length of stay; UEBMI, Urban Employee Basic Medical Insurance; URBMI, Urban Resident Basic Medical Insurance.

P represents the discrepancy of LOS between variables after stratifying; if $P < .05$, the discrepancy of LOS between variables is statistically significant, on the contrary not statistically significant.

only on Lag0-9 and Lag0-11 and from Lag0-13 to Lag0-15. A $10\text{-}\mu\text{g}/\text{m}^3$ increase in concentration of PM_{10} corresponds to a 1.55% increase in LOS for patients with asthma. For $\text{PM}_{2.5}$, SO_2 , and NO_2 , a $10\text{-}\mu\text{g}/\text{m}^3$ increase in concentration of each corresponds to approximately 1% increase in LOS for patients with asthma. Table 6 also presents the effects of readmission on LOS for patients with asthma by using the percent increase in LOS when one patient had a readmission history. Readmission was considered a binary covariate in the 4 single pollutant models. We found that if one patient had a readmission history, the patients LOS would increase by 1.06%. We performed sex-specific, season-specific, and age-specific analyses, to assess the differences in effects of air pollutants in these subgroups. The results of the stratification models are presented in Tables A1, A2, A3, A4, A5, A6.

TABLE 2 Summary statistics of daily air pollutant concentrations and weather conditions from January 1, 2014, to December 31, 2014

	N	Mean	SD	Min ^a	Q1 ^a	Q2 ^a	Q3 ^a	Max ^a	IQR ^a
Air pollution concentrations (24-h average)									
PM _{2.5} , µg/m ³	365	72	52	10	38	55	88	396	50
PM ₁₀ , µg/m ³	365	116	72	20	68	96	147	562	79
SO ₂ , µg/m ³	365	17	10	3	11	15	21	61	10
NO ₂ , µg/m ³	365	52	16	20	41	50	60	109	19
Meteorological measures									
Min temperature	365	13	7	-2	7	15	20	24	13

Abbreviations: NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

^aMin, minimum; Q1, 25th percentile; Q2, 50th percentile; Q3, 75th percentile; Max, maximum; IQR (interquartile range), Q3-Q1.

TABLE 3 Pearson correlation coefficients between daily air pollutant concentrations in Metropolitan from January 1, 2014, to December 31, 2014

	PM _{2.5}	PM ₁₀	SO ₂	NO ₂
PM _{2.5}	1			
PM ₁₀	0.973***	1		
SO ₂	0.626***	0.665***	1	
NO ₂	0.611***	0.669***	0.687***	1

Abbreviations: NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

**P* < .05.

***P* < .01.

****P* < .001.

In the male subgroup, we observed significant effects of PM_{2.5}, PM₁₀, and NO₂ on the LOS for patients with asthma. For PM_{2.5}, significant effects were observed on Lag0-13 and Lag0-14. A 10-µg/m³ increase in concentration of PM_{2.5} corresponded to a 1.64% increase in LOS for patients with asthma. For PM₁₀, the significant effects were observed for Lag0-9 and Lag0-11 and from Lag0-13 to Lag0-15. A 10-µg/m³ increase in concentration of PM₁₀ corresponded to a 1.55% increase in LOS for patients with asthma. For NO₂, the significant effects were observed from Lag0-11 to Lag0-15. A 10-µg/m³ increase in concentration of NO₂ corresponded to a 1.05% increase in LOS for patients with asthma. Regarding the effects of readmission, the value was equal to 1.01 and was still stable but not significant. In the female subgroup, we observed significant effects only for PM₁₀ on the LOS for patients with asthma. For PM₁₀, the significant effects were observed on Lag0-9 and Lag0-11 and from Lag0-13 to Lag0-15. A 10-µg/m³ increase in concentration of PM₁₀ corresponded to a 1.57% increase in the LOS for patients with asthma. For PM_{2.5}, SO₂, and NO₂, the percentage increase was approximately equal to 1% for the 3 air pollutants. If one patient had a readmission history, the LOS increased by 1.1%. The effects of readmission on the LOS for patients with asthma were found to be steady and significant.

In a nonsenior subgroup, we observed significant effects for PM_{2.5} and PM₁₀ on the LOS for patients with asthma. For PM_{2.5}, significant effects were observed only in Lag0-7. A 10-µg/m³ increase in concentration of PM_{2.5} corresponded to a 1.37% increase in the LOS for patients with asthma. For PM₁₀, significant effects were observed in Lag0-9 and Lag0-11 and from Lag0-13 to Lag0-15. A 10-µg/m³ increase in concentration of PM₁₀ corresponded to a 1.61% increase in the LOS for patients with asthma. For SO₂ and NO₂, the percentage increase

TABLE 4 Spearman correlation coefficients between daily air pollutant concentrations and LOS of asthma from January 1, 2014, to December 31, 2014

	PM _{2.5}	PM ₁₀	SO ₂	NO ₂
Lag0	0.02	0.02	0.03	0.02
Lag0-1	0.03	0.02	0.02	0.02
Lag0-2	0.03	0.02	0.02	0.02
Lag0-3	0.02	0.02	0.01	0.01
Lag0-4	0.02	0.02	0.01	0.01
Lag0-5	0.02	0.01	0.01	0.01
Lag0-6	0.02	0.01	0.01	0.01
Lag0-7	0.02	0.01	0.01	0.01
Lag0-8	0.02	0.01	0.01	0.01
Lag0-9	0.02	0.01	0.01	0.01
Lag0-10	0.02	0.01	0.01	0.01
Lag0-11	0.03	0.02	0.01	0.01
Lag0-12	0.03	0.02	0.02	0.02
Lag0-13	0.03*	0.02	0.02	0.02
Lag0-14	0.03*	0.03	0.02	0.02
Lag0-15	0.03*	0.03	0.02	0.03

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

* $P < .05$.

** $P < .01$.

*** $P < .001$.

TABLE 5 Concentration threshold of Chinese ministry of environmental protection for each pollutant

Pollutant	Concentration Threshold	
	Primary Standard, µg/m ³	Second Standard, µg/m ³
PM _{2.5}	35	75
PM ₁₀	50	150
SO ₂	50	150
NO ₂	80	80

Abbreviations: NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

was approximately equal to 1% in both. The stable effects of readmission were equal to a 1% increase in the LOS, but this was not significant. In the senior subgroup, we observed significant effects for PM₁₀ on LOS for patients with asthma. For PM₁₀, the significant effects were observed in Lag0-9 and Lag0-11 and from Lag0-13 to Lag0-15. A 10-µg/m³ increase in concentration of PM₁₀ corresponded to a 1.55% increase in the LOS for patients with asthma. For PM_{2.5}, SO₂, and NO₂, the percentage increase was approximately equal to 1% in the 3 air pollutants. The significant and stable effects of readmission on LOS were equal to 1.09%.

In the cool temperature subgroup, we observed significant effects for PM_{2.5} and PM₁₀ on the LOS for patients with asthma. For PM_{2.5}, significant effects were observed from Lag0-8 to Lag0-15. A 10-µg/m³ increase in concentration of PM_{2.5} corresponded to a 1.87% increase in the LOS for patients with asthma. For PM₁₀, significant effects were observed from Lag0-6 to Lag0-15. A 10-µg/m³ increase in concentration of PM₁₀ corresponded to a 1.56%

TABLE 6 The percent change in LOS of asthma based on a corresponding increased exposure of 10 µg/m³ of air pollutants and readmission in all subjects from January 1, 2014, to December 31, 2014

	PM _{2.5}	Readmission	PM ₁₀	Readmission	SO ₂	Readmission	NO ₂	Readmission
Lag0	1.01	1.06***	1.02	1.06***	1.01	1.06***	1	1.06***
Lag0-1	0.97	1.06***	0.99	1.06***	1.01	1.06***	1	1.06***
Lag0-2	0.96	1.06***	0.97	1.06***	1.01	1.06***	1	1.06***
Lag0-3	0.95	1.06***	0.9	1.06***	1	1.06***	1	1.06***
Lag0-4	0.99	1.06***	0.91	1.06***	1	1.06***	1	1.06***
Lag0-5	1.03	1.06***	0.96	1.06***	0.99	1.06***	1	1.06***
Lag0-6	1.04	1.06***	0.91	1.06***	0.99	1.06***	1	1.06***
Lag0-7	1.08	1.06***	1.19	1.06***	0.99	1.06***	1	1.06***
Lag0-8	1.11	1.06***	2.89	1.06***	0.99	1.06***	1	1.06***
Lag0-9	1.11	1.06***	1.56***	1.06***	0.99	1.06***	1	1.06***
Lag0-10	1.11	1.06***	80.12	1.06***	0.99	1.06***	1	1.06***
Lag0-11	1.09	1.06***	1.56***	1.06***	1	1.06***	1	1.06***
Lag0-12	1.06	1.06***	6.76	1.06***	1.01	1.06***	1.01	1.06***
Lag0-13	1.04	1.06***	1.55***	1.06***	1.02	1.06***	1.01	1.06***
Lag0-14	1.08	1.06***	1.55***	1.06***	1.02	1.06***	1.02	1.06***
Lag0-15	1.16	1.06***	1.55***	1.06***	1.02	1.06***	1.02	1.06***

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

**P* < .05.

***P* < .01.

****P* < .001.

increase in the LOS for patients with asthma. For SO₂ and NO₂, the percentage increase was approximately equal to 1% in both pollutants. The stable effect of readmission on LOS was equal to 1.09% but not significant. In the warm temperature subgroup, we observed significant effects between PM₁₀ and the LOS for patients with asthma. For PM₁₀, the significant effects were observed in Lag0-9 and Lag0-11 and from Lag0-13 to Lag0-15. A 10-µg/m³ increase in concentration of PM10 corresponded to a 1.58% increase in the LOS for patients with asthma. For PM_{2.5}, SO₂, and NO₂, the percentage increase was approximately equal to 1% for the 3 air pollutants. The stable and significant effects of readmission on the LOS were equal to 1.08%.

4 | DISCUSSION

This study verified that air pollution affects the LOS for patients with asthma. Such effects were observed with PM₁₀ for the different sex subgroups, all the season subgroups, and all the age subgroups, while PM_{2.5} and NO₂ showed no significant effects on LOS for patients with asthma without stratifying the analysis. The effect of PM₁₀ was evidently significant from Lag0-9 to Lag0-15. Regarding readmission, the significant effects were observed among 4 ambient air pollutants and they were the same not only for different lags but also for different air pollutants. Similar effects existed in the female subgroup, senior subgroup, and warm temperature subgroup. We made a comparison among these subgroups to explore the disparity of such effects below.

The effects of air pollution on the LOS for patients with asthma showed a difference between the male subgroup and female subgroup, although Table 1 shows that there was no statistically significant difference in the LOS among different sex subgroups. The PM_{2.5}, PM₁₀, and NO₂ showed significant effects on the LOS in the male subgroup; nevertheless, PM₁₀ showed significant effects on the LOS in the female subgroup. In the male subgroup, the PM_{2.5} as

well as the NO_2 showed significant effects from Lag0-13 to Lag0-14, and the percentage increase of LOS with a $10\text{-}\mu\text{g}/\text{m}^3$ increase of PM_{10} was found to be 1.55% lower than $\text{PM}_{2.5}$ and higher than NO_2 . For the male subgroup and the female subgroup, the effects of PM_{10} were evidently significant in the same lags. In addition, the percentage increase (1.57%) with respect to effects of PM_{10} on the LOS in the female subgroup was not significantly larger than that in the male subgroup (1.55%). Previous studies have found that adult females are more severely affected by asthma.²² In addition, Chen et al²³ conducted an analysis to describe the sex and age differences in asthma hospitalization among a Canadian population and the data suggest that sex is an important risk factor for asthma, and the sex effect varies considerably over a life span. Our results confirmed that the effects of air pollution on the LOS differed by sex, which was consistent with this previous study.

Except for sex, we also observed the season disparity. By comparing the results of the cool temperature subgroup and the warm temperature subgroup, we found that the effects for $\text{PM}_{2.5}$ on the LOS for patients with asthma only existed in the cool temperature subgroup. In the cool temperature subgroup, the $\text{PM}_{2.5}$ and PM_{10} were highly correlated. Both of them showed significant effects on the LOS from Lag0-8 to Lag0-15. In addition, the effects of $\text{PM}_{2.5}$ found in our study were greater than the effects of PM_{10} on the same day of the lag. The maximum percentage increase of the LOS due to $\text{PM}_{2.5}$ and PM_{10} was 1.87% and 1.56%, respectively. Previous studies regarding PM and asthma had found that there are no clear explanations for such a discrepancy regarding the influences of PM_{10} and $\text{PM}_{2.5}$ on asthma hospitalizations. These differences may lie in the variability of population characteristics, natural systems, and the complex mixture of fine particles with a different level and composition over time and space.²⁷ The effects of PM_{10} were different in the season stratification models, and significant effects were found in different lags. The maximum percentage increase for Lag0-6 to Lag0-15 exposure to PM_{10} with an increment of $10\text{ }\mu\text{g}/\text{m}^3$ was 1.56% in the cool temperature subgroup, while the maximum percentage increase for Lag0-9 and Lag0-11 and Lag0-13 to Lag0-15 exposure to PM_{10} with an increment of $10\text{ }\mu\text{g}/\text{m}^3$ was 1.58% in the warm temperature subgroup. Makra et al²⁴ have found that among meteorological elements, temperature and relative humidity are involved with exacerbating asthma attacks. The mean minimum temperature during the cool periods (7°C) was lower than warm periods (19°C).

To explore whether the effects of air pollution differed by age, we conducted an age-specific analysis of the 2 age groups: nonseniors (15-64 years) and seniors (over 65 years). The results indicated that $\text{PM}_{2.5}$ and PM_{10} were found to have significant effects on the LOS for patients with asthma in the nonsenior subgroup; in the senior subgroup, the PM_{10} had positive effects on the LOS for patients with asthma. The significant effect of $\text{PM}_{2.5}$ was found only in Lag0-7; hence, we suggest that this may be a statistical coincidence. As to the PM_{10} , the significant effects were found on the same exposure lags in the 2 age subgroups; however, the percentage increase for exposure to PM_{10} in the nonsenior subgroup and the senior subgroup was 1.61% and 1.55%, respectively. The purpose of the study by Park et al²⁵ was to determine whether air pollution effects on asthmatic hospital admissions were different between 3 age groups: children (under 15 years), adults (15-64 years; reference group), and elderly patients (over 65 years). For adults, the percentage increase of asthma admissions with a $10\text{-}\mu\text{g}/\text{m}^3$ increase of PM_{10} was 1.5% lower than that for children and 1.3% higher than that for the elderly. All results presented here imply that the effects of PM_{10} on asthma were different in age groups and the effects were greater in adults than in elderly patients.

5 | CONCLUSION

In this study, we prospectively analyzed the effects of air pollution on the LOS among the adults suffered asthma. The results showed a correlation between the LOS for patients with asthma and ambient exposure to air pollutants such as PM_{10} , according to hospital admissions that occurred over a 1-year period. We found that the disparity existed in the effects of the LOS in terms of sex, age, and season. The significant effects for NO_2 on the LOS for patients with asthma were only observed in the male subgroup, while the significant effects of $\text{PM}_{2.5}$ were found in male subgroup, nonsenior subgroup, and the cool temperature subgroup. An interesting observation was that if

significant effects of readmission on the LOS were found, then only PM₁₀ of the 4 pollutants had a significant effect on the LOS for patients with asthma.

Our study has some limitations. First, the exposure measurements were crude. Because the patient data were identified, we could not obtain the individual residence of every patient with asthma and information about personal exposure was unavailable. The lack of effects of air pollution on the LOS may be due to the imprecise exposure assessment. Another limitation is that the hospitals information database did not contain details regarding management during hospitalization. When detailed information during hospitalization is provided, we can conduct further research on how air pollution effects the LOS for patients with asthma.

In conclusion, our study has enhanced statistical power for measuring the effects of air pollution on the LOS of patients and for considering threshold effects. The effects based on generalized additive models (without threshold results) may underestimate the actual RR. The consequences of exposure to pollutants are relevant from both a medical and a social perspective. Furthermore, our research measured the influences of air pollutants on the LOS for patients with asthma, and offers policy makers quantitative evidence, that supports relevant policy design for health care resource management and ambient air pollutant control.

ACKNOWLEDGEMENTS

We acknowledge the efforts from the West China Biomedical Big Data Center, West China Hospital, Sichuan University, including providing research data, data extraction, cleaning, and standardization, supervising no sensitive data being reported, and coordination services for the publishing of this article. The study was funded by the National Natural Science Foundation of China (Nos. 71532007, 71131006, and 71172197).

The authors have no competing interests.

ETHICS STATEMENT

The study does not involve human subjects and adheres to all current laws of China.

ORCID

Fengyi Zhang  <http://orcid.org/0000-0002-6261-2171>

REFERENCES

1. Masoli M, Fabian D, Holt S, Beasley R, Global Initiative for Asthma (GINA) Program. The global burden of asthma: executive summary of the GINA Dissemination Committee report. *Allergy*. 2004;59(5):469-478.
2. Liu SG, Wu RH, Li L, et al. The prevalence of anxiety and depression in Chinese asthma patients. *PLoS One*. 2014;9(7): e103014.
3. Ehteshamifshar S, Fitzgerald JM, Doylewaters MM, Sadatsafavi M. The global economic burden of asthma and chronic obstructive pulmonary disease. *Int J Tuberc Lung Dis*. 2016;20(1):11-23.
4. Barnett SB, Nurmagambetov TA. Costs of asthma in the United States: 2002-2007. *J Allergy Clin Immunol*. 2011;127(1):145-152.
5. Wazeka A, Valacer DJ, Cooper M, Caplan DW, DiMaio M. Impact of a pediatric asthma clinical pathway on hospital cost and length of stay. *Pediatr Pulmonol*. 2001;32(3):211-216.
6. Derienzo C, Kohler JA, Lada E, Meanor P, Tanaka D. Demonstrating the relationships of length of stay, cost and clinical outcomes in a simulated NICU. *J Perinatol*. 2016;36(12):1128-1131.
7. Shanley LA, Lin H, Flores G. Factors associated with length of stay for pediatric asthma hospitalizations. *J Asthma*. 2014;52(5):471-477.
8. Callery P, Kyle RG, Campbell M, Banks M, Kirk S, Powell P. Readmission in children's emergency care: an analysis of hospital episode statistics. *Arch Dis Child*. 2010;95(5):341-346.
9. Watson L, Turk FK. Burden of asthma in the hospital setting: an Australian analysis. *Int J Clin Pract*. 2007;61(11):1884-1888.

10. Arnold DH, Gebretsadik T, Abramo TJ, Sheller JR, Resha DJ, Hartert TV. The Acute Asthma Severity Assessment Protocol (AASAP) study: objectives and methods of a study to develop an acute asthma clinical prediction rule. *Emerg Med J*. 2012;29(6):444-450.
11. Soyiri IN, Reidpath DD, Sarran C. Asthma length of stay in hospitals in London 2001-2006: demographic, diagnostic and temporal factors. *PLoS one*. 2011;6(11):e27184.
12. Zhang SQ, Li GX, Tian L, Guo Q, Pan XC. Short-term exposure to air pollution and morbidity of COPD and asthma in East Asian area: a systematic review and meta-analysis. *Environ Res*. 2016;148:15-23.
13. Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the global burden of disease study 2010. *Lancet*. 2012;380(9859):2224-2260.
14. Just J, Ségala C, Sahraoui F, Priol G, Grimfeld A, Neukirch F. Short-term health effects of particulate and photochemical air pollution in asthmatic children. *Eur Respir J*. 2002;20(4):899-906.
15. Barrett K, de Leeuw F, Fiala J, Barmpas F. Health impacts and air pollution: an exploration of factors influencing estimates of air pollution impact upon the health of European citizens. Netherlands: The European Topic Centre on Air and Climate Change (ETC/ACC); 2008.
16. Roy A, Sheffield P, Wong K, Trasande L. The effects of outdoor air pollutants on the costs of pediatric asthma hospitalizations in the United States, 1999 to 2007. *Med Care*. 2011;49(9):810-817.
17. Luginaah IN, Fung KY, Gorey KM, Webster G, Wills C. Association of ambient air pollution with respiratory hospitalization in a government-designated "area of concern": the case of Windsor, Ontario. *Environ Health Perspect*. 2005;113(3):290-296.
18. Li S, Batterman S, Wasilevich E, et al. Association of daily asthma emergency department visits and hospital admissions with ambient air pollutants among the pediatric Medicaid population in Detroit: time-series and time-stratified case-crossover analyses with threshold effects. *Environ Res*. 2011;111(8):1137-1147.
19. Kim E, Hopke PK, Pinto JP, Wilson WE. Spatial variability of fine particle mass, components, and source contributions during the regional air pollution study in St. Louis. *Environ Sci Technol*. 2005;39(11):4172-4179.
20. Morawska L, Thomas S, Bofinger N, Wainwright D, Nealea D. Comprehensive characterization of aerosols in a subtropical urban atmosphere: particle size distribution and correlation with gaseous pollutants. *Atmos Environ*. 1998;32(14-15):2467-2478.
21. Ito K, Thurston GD, Silverman RA. Characterization of PM_{2.5}, gaseous pollutants, and meteorological interactions in the context of time-series health effects models. *J Expo Sci Environ Epidemiol*. 2007;17(Suppl 2):S45-S60.
22. Skobeloff EM, Spivey WH, St Clair SS, Schoffstall JM. The influence of age and sex on asthma admissions. *Jama*. 1992;268(24):3437-3440.
23. Chen Y, Stewart P, Johansen H, McRae L, Taylor G. Sex difference in hospitalization due to asthma in relation to age. *J Clin Epidemiol*. 2003;56(2):180-187.
24. Makra L, Puskás J, Matyasovszky I, et al. Weather elements, chemical air pollutants and airborne pollen influencing asthma emergency room visits in Szeged, Hungary: performance of two objective weather classifications. *Int J Biometeorol*. 2015;59(9):1269-1289.
25. Park M, Sheng L, Kwon J, et al. Effects of air pollution on asthma hospitalization rates in different age groups in metropolitan cities of Korea. *Air Qual Atmos Health*. 2013;6(3):543-551. <https://doi.org/10.1007/s11869-013-0195-x>
26. Lyratzopoulos G, Havelly D, Gemmell I, Cook GA. Factors influencing emergency medical readmission risk in a UK district general hospital: a prospective study. *BMC Emerg Med*. 2005;5(1):4.
27. Tecer LH, Alagha O, Karaca F, Tuncel G, Eldes N. Particulate matter (PM_{2.5}, PM_{10-2.5}, and PM₁₀) and children's hospital admissions for asthma and respiratory diseases: a bidirectional case-crossover study. *J Toxicol Environ Health a*. 2008;71(8):512-520.

How to cite this article: Luo L, Ren J, Zhang F, et al. The effects of air pollution on length of hospital stay for adult patients with asthma. *Int J Health Plann Mgmt*. 2018;1-17. <https://doi.org/10.1002/hpm.2532>

TABLE A1 The percent change in LOS of asthma based on a corresponding increased exposure of 10 µg/m³ of air pollutants and readmission in male subgroup from January 1, 2014, to December 31, 2014

	PM _{2.5}	Readmission	PM ₁₀	Readmission	SO ₂	Readmission	NO ₂	Readmission
Lag0	1	1.01	1	1	1.01	1	1	1
Lag0-1	0.94	1.01	0.99	1.01	1.01	1	0.99	1
Lag0-2	0.95	1.01	1.01	1.01	1.01	1	1	1
Lag0-3	0.98	1.01	1	1.01	1.01	1	1.01	1
Lag0-4	1.05	1.01	1.06	1.01	1	1	1.01	1
Lag0-5	1.06	1.01	1.02	1.01	1	1	1.02	1
Lag0-6	1.1	1.01	1.28	1.01	1	1	1.02	1
Lag0-7	1.2	1.01	1.54	1.01	1.01	1	1.03	1.01
Lag0-8	1.3	1.01	4.18	1.01	1	1	1.02	1.01
Lag0-9	1.32	1.01	1.55***	1.01	0.99	1	1.02	1.01
Lag0-10	1.35	1.01	88713.65	1.01	1	1	1.03	1.01
Lag0-11	1.35	1.01	1.55***	1.01	1.01	1	1.03***	1.01
Lag0-12	1.36	1.01	189.57	1.01	1.03	1	1.04***	1.01
Lag0-13	1.58***	1.01	1.54***	1.01	1.04	1.01	1.04***	1.01
Lag0-14	1.64***	1.01	1.54***	1.01	1.05	1.01	1.04***	1.01
Lag0-15	1.5	1.01	1.54***	1.01	1.06	1.01	1.05***	1.01

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

*P < .05.
**P < .01.
***P < .001.

TABLE A2 The percent change in LOS of asthma based on a corresponding increased exposure of 10 µg/m³ of air pollutants and readmission in female subgroup from January 1, 2014, to December 31, 2014

	PM _{2.5}	Readmission	PM ₁₀	Readmission	SO ₂	Readmission	NO ₂	Readmission
Lag0	1.01	1.1**	1.03	1.1**	1.02	1.1**	1.01	1.1**
Lag0-1	0.99	1.1**	0.99	1.1**	1.01	1.1**	1	1.1**
Lag0-2	0.97	1.1**	0.93	1.1**	1	1.1**	1	1.1**
Lag0-3	0.93	1.1**	0.84	1.1**	1	1.1**	0.99	1.1**
Lag0-4	0.95	1.1**	0.82	1.1**	1	1.1**	0.99	1.1**
Lag0-5	1.01	1.1**	0.93	1.1**	0.99	1.1**	0.98	1.1**
Lag0-6	1.01	1.1**	0.75	1.1**	0.98	1.1**	0.99	1.1**
Lag0-7	1.01	1.1**	0.98	1.1**	0.98	1.1**	0.99	1.1**
Lag0-8	1.01	1.1**	2.68	1.1**	0.98	1.1**	0.98	1.1**
Lag0-9	1	1.1**	1.57**	1.1**	0.98	1.1**	0.98	1.1**
Lag0-10	0.97	1.1**		1.1**	0.99	1.1**	0.98	1.1**
Lag0-11	0.94	1.1**	1.57**	1.1**	0.99	1.1**	0.99	1.1**
Lag0-12	0.89	1.1**	0.03	1.1**	1	1.1**	0.99	1.1**
Lag0-13	0.79	1.1**	1.56**	1.1**	1	1.1**	0.99	1.1**
Lag0-14	0.79	1.1**	1.56**	1.1**	1	1.1**	1	1.1**
Lag0-15	0.93	1.1**	1.56**	1.1**	1	1.1**	1	1.1**

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

*P < .05.
**P < .01.
***P < .001.

TABLE A3 The percent change in LOS of asthma based on a corresponding increased exposure of 10 µg/m³ of air pollutants and readmission in nonsenior subgroup from January 1, 2014, to December 31, 2014

	PM _{2.5}	Readmission	PM ₁₀	Readmission	SO ₂	Readmission	NO ₂	Readmission
Lag0	1.02	1	1.03	1	1.02	1	1.01	1.01
Lag0-1	0.97	1	1.03	1	1.01	1	1	1.01
Lag0-2	0.95	1	1.04	1	1.01	1	0.99	1.01
Lag0-3	0.91	1	0.86	1	1.01	1	0.99	1.01
Lag0-4	0.99	1	0.97	1	1	1	0.99	1
Lag0-5	1.14	1	1.54	1	0.99	1	1	1
Lag0-6	1.17	1	1.19	1	1	1	1.01	1.01
Lag0-7	1.37***	1	3.71	1.01	1	1	1.01	1.01
Lag0-8	1.39	1	3.43	1	0.98	1	1	1
Lag0-9	1.31	1	1.61***	1	0.98	1	1	1
Lag0-10	1.32	1.01	152.59	1	0.98	1	1	1
Lag0-11	1.07	1.01	1.6***	1	0.97	1	0.99	1
Lag0-12	1.02	1.01	9.7	1	0.98	1	0.99	1
Lag0-13	0.86	1.01	1.6***	1	0.99	1	1	1
Lag0-14	0.91	1.01	1.6***	1.01	1	1	1	1
Lag0-15	1.16	1.01	1.6***	1.01	1	1	1	1

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

*P < .05.
**P < .01.
***P < .001.

TABLE A4 The percent change in LOS of asthma based on a corresponding increased exposure of 10 µg/m³ of air pollutants and readmission in senior subgroup from January 1, 2014, to December 31, 2014

	PM _{2.5}	Readmission	PM ₁₀	Readmission	SO ₂	Readmission	NO ₂	Readmission
Lag0	1	1.09***	1.02	1.09***	1.01	1.09***	1	1.09***
Lag0-1	0.96	1.09***	0.97	1.09***	1	1.09***	0.99	1.09***
Lag0-2	0.96	1.09***	0.93	1.09***	1	1.09***	0.99	1.09***
Lag0-3	0.96	1.09***	0.91	1.09***	0.99	1.09***	1	1.09***
Lag0-4	0.97	1.09***	0.9	1.09***	0.99	1.09***	1	1.09***
Lag0-5	0.98	1.09***	0.8	1.09***	0.98	1.09***	1	1.09***
Lag0-6	0.99	1.09***	0.81	1.09***	0.98	1.09***	1	1.09***
Lag0-7	0.97	1.09***	0.84	1.09***	0.98	1.09***	1	1.09***
Lag0-8	1	1.09***	2.24	1.09***	0.98	1.09***	0.99	1.09***
Lag0-9	1.01	1.09***	1.55***	1.09***	0.98	1.09***	0.99	1.09***
Lag0-10	1	1.09***	45.29	1.09***	0.98	1.09***	1	1.09***
Lag0-11	1.03	1.09***	1.54***	1.09***	0.99	1.09***	1	1.09***
Lag0-12	1.02	1.09***	5.01	1.09***	1	1.09***	1.01	1.09***
Lag0-13	1.03	1.09***	1.53***	1.09***	1.01	1.09***	1.01	1.09***
Lag0-14	1.04	1.09***	1.53***	1.09***	1.01	1.09***	1.02	1.09***
Lag0-15	1.06	1.09***	1.53***	1.09***	1.01	1.09***	1.02	1.09***

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

*P < .05.
**P < .01.
***P < .001.

TABLE A5 The percent change in LOS of asthma based on a corresponding increased exposure of 10 µg/m³ of air pollutants and readmission in cool subgroup from January 1, 2014, to December 31, 2014

	PM _{2.5}	Readmission	PM ₁₀	Readmission	SO ₂	Readmission	NO ₂	Readmission
Lag0	1	1.03	1.02	1.03	1.01	1.03	1	1.03
Lag0-1	1.07	1.03	1.09	1.03	1.01	1.03	1	1.03
Lag0-2	0.99	1.03	0.98	1.03	1	1.03	1	1.03
Lag0-3	0.99	1.03	0.98	1.03	1	1.03	1	1.03
Lag0-4	0.98	1.03	0.94	1.03	0.99	1.03	1	1.03
Lag0-5	0.97	1.03	0.88	1.03	0.99	1.03	0.99	1.03
Lag0-6	1.05	1.03	1.56***	1.03	0.98	1.03	1	1.03
Lag0-7	1.43	1.03	1.56***	1.03	0.98	1.03	1	1.03
Lag0-8	1.87***	1.03	1.56***	1.03	0.98	1.03	0.99	1.03
Lag0-9	1.87***	1.03	1.56***	1.03	0.98	1.03	.99	1.03
Lag0-10	1.87***	1.04	1.55***	1.03	0.99	1.03	1	1.03
Lag0-11	1.87***	1.04	1.55***	1.03	0.99	1.03	1	1.03
Lag0-12	1.86***	1.04	1.55***	1.03	1.01	1.03	1.01	1.03
Lag0-13	1.86***	1.04	1.54***	1.04	1.01	1.03	1.01	1.03
Lag0-14	1.86***	1.04	1.54***	1.04	1.02	1.03	1.01	1.03
Lag0-15	1.85***	1.04	1.54***	1.04	1.02	1.03	1.02	1.03

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

*P < .05.
**P < .01.
***P < .001.

TABLE A6 The percent change in LOS of asthma based on a corresponding increased exposure of 10 µg/m³ of air pollutants and readmission in warm subgroup from January 1, 2014, to December 31, 2014

	PM _{2.5}	Readmission	PM ₁₀	Readmission	SO ₂	Readmission	NO ₂	Readmission
Lag0	1.01	1.08***	1.02	1.08**	1.04	1.08**	0.99	1.08***
Lag0-1	0.95	1.08***	0.98	1.08***	1.02	1.08***	0.98	1.08***
Lag0-2	0.95	1.08***	0.97	1.08***	1.02	1.08**	0.99	1.08***
Lag0-3	0.93	1.08***	0.9	1.08***	1.03	1.08***	0.99	1.08***
Lag0-4	0.98	1.08***	0.9	1.08***	1.03	1.08***	0.99	1.08***
Lag0-5	1.04	1.08***	0.97	1.08***	1.01	1.08***	1	1.08***
Lag0-6	1.05	1.08**	0.89	1.08***	1.03	1.08**	1	1.08***
Lag0-7	1.07	1.08***	1.18	1.08**	1.06	1.08**	1.01	1.08***
Lag0-8	1.12	1.08***	2.84	1.08**	1.05	1.08**	1	1.08***
Lag0-9	1.13	1.08***	1.58***	1.08***	1.02	1.08**	1	1.08***
Lag0-10	1.13	1.08***	147.73	1.08***	1.02	1.08***	1	1.08***
Lag0-11	1.1	1.08***	1.57***	1.08***	1.03	1.08***	1.01	1.08***
Lag0-12	1.07	1.08**	8.78	1.08***	1.03	1.08***	1.01	1.08***
Lag0-13	1.04	1.08**	1.57***	1.08***	1.05	1.08***	1.01	1.08***
Lag0-14	1.08	1.08***	1.56***	1.08**	1.07	1.08**	1.01	1.08***
Lag0-15	1.16	1.08***	1.56***	1.08***	1.07	1.08***	1.02	1.08***

Abbreviations: LOS, length of stay; NO₂, nitrogen dioxide; PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter; PM₁₀, particulate matter less than 10 µm in aerodynamic diameter; SO₂, sulfur dioxide.

*P < .05.
**P < .01.
***P < .001.