



Association between air pollution and emergency department visits for upper respiratory tract infection in Lanzhou, China

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Received: 13 July 2021 / Accepted: 30 November 2021 / Published online: 6 January 2022
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Abstract

There is limited evidence regarding the associations between air pollution and emergency hospital visits for upper respiratory tract infection (URTI) in the arid regions of northwest China. We collected daily emergency department (ED) visits for URTI from three hospitals in Lanzhou during January 2014 and December 2018, as well as daily air pollutants and meteorological factors. In the present study, generalized additive model with quasi-Poisson regression was used to evaluate the relationship between short-term exposure to ambient pollutants and daily emergency hospital visits for URTI in Lanzhou, China. Furthermore, subgroup analyses were conducted by gender (male and female), age (0–14, 15–64, and ≥ 65 years), and season (cold season, warm season). The results of the single-pollutant model show that the associations of $PM_{2.5}$, PM_{10} , SO_2 , NO_2 , and CO with URTI ED visits were all statistically significant, whereas we observed insignificant associations of O_3 8h. The highest association of each pollutant with hospital emergency visits was observed with $PM_{2.5}$ (5.302% (95% CI: 3.202, 7.445)), PM_{10} (0.808% (95% CI: 0.291, 1.328)), SO_2 (10.607% (95% CI: 5.819, 15.611)), and NO_2 (5.325% (95% CI: 2.379, 8.357)) at lag 07 for an increase of 10 $\mu\text{g}/\text{m}^3$ in concentrations of the pollutants. Percentage increase for each 1- mg/m^3 increase in CO was 20.799% (95% CI: 11.834, 30.482) at lag 07. In the stratification analyses, females were more susceptible to $PM_{2.5}$ and PM_{10} , while males were more sensitive to the effects of SO_2 , NO_2 , and CO, and the higher association effect of four pollutants ($PM_{2.5}$, SO_2 , NO_2 , and CO) on hospital visits for URTI among children (0–14 years). The associations appeared to be stronger in the cool season than in the warm season. This study suggests that short-term exposure to air pollution, especially to SO_2 and CO, was associated with increased risk of hospital emergency visits for URTI in Lanzhou, China. Relevant strategies and health interventions should be strengthened to reduce the air pollution level in the future.

Keywords Air pollution · Lanzhou · Time-series study · Upper respiratory tract infection

Introduction

Upper respiratory tract infection (URTI) is a common disease in all age groups, with typical symptoms including cough, stuffy nose, sniffing, and sore throat. The Global Burden of Disease study identified URTI as one of the leading causes of medical consultation, even higher than dental caries and diarrhea (Vos et al. 2017). A previous study found that about 70–80% of respiratory outpatients to general practitioners and primary care physicians every year are related to URTI (Lo et al. 2011). Cross-sectional studies showed that URTI accounted for 30.1% of respiratory disorders and 26.4% of all hospital outpatient cases in Hong Kong (Nelson et al. 2007). Although mortality from upper respiratory tract is lower, it would have adverse effects on daily life, resulting in days lost from work and school (Mourtzoukou and Falagas 2007).

Responsible editor: Lotfi Aleya

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Occurrence of URTI is more common in cold weather (Liu et al. 2015; Lin et al. 2013). Moreover, air pollutants, including SO₂, NO₂, and particulate matter less than 2.5 µm in aerodynamic diameter (PM_{2.5}), were also reported correlated with an increased risk for URTI (Zhang et al. 2019). Some epidemiological studies have reported significant associations between air pollution and hospital visits for URTI (Arbex et al. 2011; Lin et al. 2013; Darrow et al. 2014; Tam et al. 2014; Li et al. 2017, 2018; Zheng et al. 2017; Song et al. 2018; Zhang et al. 2021). Arbex et al. observed a harmful effect for relatively low levels of ambient particulate matter and gaseous pollutants and to emergency department (ED) visits for acute upper respiratory tract infections (AURI) in young children (Arbex et al. 2011). Studies conducted in Taipei, Taiwan, China, have also demonstrated a positive relationship between NO₂ and URTI (Lin et al. 2013). Moreover, an 18-year time-series study in the Atlanta indicated PM_{2.5}, PM₁₀, NO₂, and SO₂ was associated with the increased emergency department visits for AURI among children (Darrow et al. 2014). In Hong Kong, general practitioner visits for AURI infections were reported associated with ambient PM_{2.5}, PM₁₀, NO₂, and O₃ (Tam et al. 2014). In Mainland China, some Chinese researchers have revealed the detrimental effects of air pollutants on respiratory infection. And they also found positive associations between PM_{2.5}, PM₁₀, SO₂, NO₂, and hospital visits for URTI (Li et al. 2017, 2018; Zhang et al. 2018, 2021; Song et al. 2018).

To date, most of the research on air pollution and its adverse effects on URTI in China have focused on megacities and heavily polluted cities including Taipei (Lin et al. 2013), Hong Kong (Tam et al. 2014), Beijing (Li et al. 2017), Shanghai (Zhang et al. 2018), and Wuhan (Zhang et al. 2018), and few studies were available in the arid inland cities of northwest China, where the sources of air pollutants, air pollution levels, weather patterns, and population characteristics differ from those of eastern/southern Chinese cities. In terms of negative health impacts caused by air pollutants, PM_{2.5}, PM₁₀, SO₂, and NO₂ were most selected as the research object (Kermani et al. 2020a, 2020b). However, studies have rarely focused on O₃8h and CO, which may be more detrimental to respiratory health. In addition, the majority of previous studies were conducted mainly in children, who are more susceptible to URTI due to their immature respiratory systems and exposure-relevant behaviors. Few studies have qualified the real impact on different age groups, particularly in adults and elderly. Air pollution and demographic characteristics vary from city to city (Kermani et al. 2021a; Kermani et al. 2021b; Vahidi et al. 2020). For the above reasons, the effect size of air pollution of one city cannot reflect that of another. Therefore, based on generalized additive models (GAM), we carried out time-series research to estimate the associations between six ambient air pollutants (PM_{2.5}, PM₁₀, SO₂, NO₂, O₃8h, and CO) and

emergency department (ED) visits for URTI in Lanzhou during 2014–2018. The stratification analysis was performed in different subgroups (gender, age, season).

Materials and methods

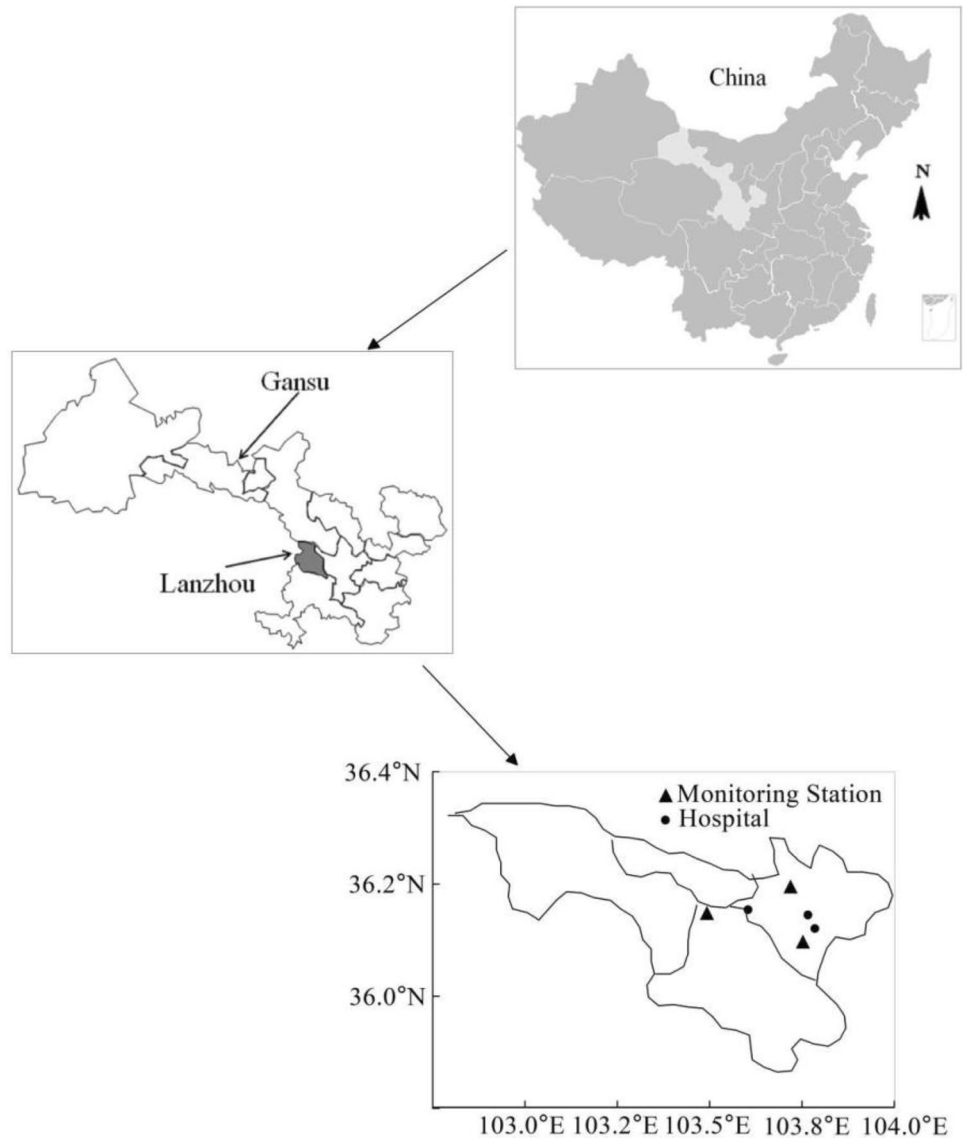
Study area

Lanzhou (103° 40' E, 36° 30' N), the capital of Gansu Province, is an industrial city in Northwest China. The total area of the city is 1100 km² comprising 4 urban districts, with a population of 3.8 million in 2017. Lanzhou is located in a semi-arid area and belongs to a typical temperate continental climate. The city is located in a narrow valley basin surrounded by mountains to the north and south forming a semi-closed dumbbell (see Fig. S1). Relevant meteorological statistics show that the static wind days accounted for 11.39%, the small wind days less than 1.5 m/s accounted for 68.78%, while the days with more than 1.5 m/s accounted for only 19.82%, less than one-fifth of the total, and the north and northwestern winds have the dominant wind directions in Lanzhou (Filonchik and Yan 2018). The meteorological conditions are characterized by low wind speed and a stable atmosphere, which are not conducive to the spreading of air pollutants. Many industries, such as petrochemical, metallurgical, and mechanical industries, have developed in the city (Chai et al. 2020). Although the government has taken many measures to improve the local air quality, the level of air pollutants concentration (the average annual PM_{2.5}, PM₁₀, and NO₂ concentrations during 2014–2018 in Lanzhou were 51.33 µg/m³, 120.50 µg/m³, 46.90 µg/m³, respectively) exceeded the national level II (the average annual standards for PM_{2.5} is 35 µg/m³, PM₁₀ is 70 µg/m³, and NO₂ is 40 µg/m³). Only 85 and 5 days of O₃ and CO concentrations exceeded the daily limit (O₃, 160 µg/m³; CO, 4 mg/m³). And SO₂ concentration did not exceed the guidelines in China (SO₂, 60 µg/m³).

Data collection

Daily data about ED visits related to URTI were extracted from 1 February 2014 to 31 December 2018 in the three largest hospitals in Lanzhou (Fig. 1). These three hospitals were located in the east and west of Lanzhou city with convenient transportation and were surrounded by densely populated residential areas in Lanzhou. We selected these three hospitals for this study mainly due to their advanced equipment, complete medical departments, and strong technical capabilities. These hospitals are famous for their good medical treatment of respiratory diseases. To some extent, we think that these hospitals account for most of the emergency room visits by the population. The extracted data included

Fig. 1 The locations of air pollutants monitoring stations and hospitals



the date of the visit, gender, age, address, and the principal discharge diagnosis to according the International Classification of Diseases, Tenth Revision (ICD-10) for URTI ((ICD-10 Codes: J00-J06 and J30-J39). All patients who were not resident in the city or were dispatched from other cities were excluded from the study.

Hourly air pollution data, including $PM_{2.5}$, PM_{10} , SO_2 , NO_2 , O_3 , and CO, were obtained from the website of China's National Urban Air Quality Real Time Publishing Platform (<http://106.37.208.233:20035/>). The platform is under the management of Ministry of Environmental Protection in China. Pollutants were measured using different methods: the method of tapered element oscillating microbalance for $PM_{2.5}$ and PM_{10} , the ultraviolet fluorescence method for SO_2 and O_3 , the chemiluminescence method for NO_2 , and the infrared

absorption method for CO. All these measurements were carried out in strict accordance with the China Technical specifications for operation and quality control of ambient air quality automated monitoring system for particulate matter (HJ817-2018) and gaseous pollutant (HJ818-2018). In Lanzhou, there are three monitoring stations in the urban area of Lanzhou. The location of these monitoring stations is far away from the emission sources (traffic, industry, boilers, etc.); thus, these monitoring results reflect the general air pollution level in the city (Masroor et al. 2020). Then, the daily average concentrations of $PM_{2.5}$, PM_{10} , SO_2 , NO_2 , and CO were calculated by the data collected from the above three monitoring sites; for O_3 , the maximum 8-h mean concentration of ozone was calculated at the same monitoring sites. Daily meteorological data, including temperature, relative humidity, air pressure,

Table 1 Descriptive statistics of emergency department visits for URTI, air pollutant levels and meteorological variables in Lanzhou during 2014~2018

	$\bar{X} \pm S$	Minimum	Percentile			Maximum
			P_{25}	P_{50}	P_{75}	
Emergency department visits						
Total	56 ± 38	1	30	46	69	333
Male	31 ± 21	1	17	26	38	195
Female	25 ± 18	1	13	20	32	147
0–14	38 ± 30	1	20	32	50	324
15–65	15 ± 12	1	8	12	17	102
≥ 65	3 ± 2	1	1	1	2	19
Meteorological factors						
Mean temperature (°C)	11.34 ± 9.90	-12.30	2.30	12.70	19.84	30.40
Pressure (hpa)	848.43 ± 5.68	826.35	844.20	848.30	852.53	866.43
Relative humidity (%)	50.91 ± 15.11	18.00	39.00	50.75	62.00	96.09
Wind speed (m/s)	1.23 ± 0.39	0.00	1.00	1.13	1.40	2.90
Air pollutants						
PM _{2.5} (µg/m ³)	51.33 ± 26.92	11.00	33.36	44.18	62.35	269.43
PM ₁₀ (µg/m ³)	120.50 ± 83.17	18.98	75.32	104.77	142.00	1484.54
SO ₂ (µg/m ³)	21.81 ± 14.22	3.54	10.66	17.78	30.00	81.87
NO ₂ (µg/m ³)	46.90 ± 16.83	7.80	36.29	45.61	53.91	146.60
O ₃ 8h (µg/m ³)	86.54 ± 38.02	8.00	57.00	81.00	110.00	221.00
CO (mg/m ³)	1.28 ± 0.72	0.30	0.80	1.03	1.60	4.65

and wind speed, were collected through daily monitoring by the Gansu Meteorological Bureau, which is part of the nationwide network of monitoring stations and strictly implements relevant national technical requirements.

Statistical analyses

Because daily hospital visits approximately follow an over-dispersed Poisson distribution, we used the generalized additive model (GAM) based on the quasi-Poisson distribution to assess the association between each air pollutant and daily hospital ED visits for URTI. In GAM, we used a natural spline smooth function to control for long-term

trends, seasonal patterns, and the meteorological factors. Four meteorological factors including temperature, relative humidity, air pressure, and wind speed were employed (Li et al. 2018). Besides, indicators for the weekends (DOW) and the public holidays (holiday) were incorporated into the models as a covariate to control for the impact of day of the week and the holiday effects. The model is as follows:

$$\log [E(Y_t)] = \alpha + \beta Z_t + s(\text{time}, df = 7) + s(\text{temperature}, df = 4) + s(\text{humidity}, df = 4) + s(\text{pressure}, df = 4) + s(\text{windspeed}, df = 4) + DOW_t + \text{holiday}$$

where Y_t is number of daily ED visits for URTI on day t ; $E(Y_t)$ is the expected daily ED visits for URTI on day t ; α is

Table 2 Spearman’s correlation coefficients between daily air pollutants and weather conditions in Lanzhou, 2014–2018

	PM _{2.5}	PM ₁₀	SO ₂	NO ₂	CO	O ₃ 8h	Temperature	Relative humidity	Pressure	Wind speed
PM _{2.5}	1	0.84*	0.65*	0.43*	0.69*	-0.37*	-0.49*	-0.13*	0.19*	-0.29*
PM ₁₀		1	0.57*	0.42*	0.52*	-0.17*	-0.36*	-0.38*	0.15*	-0.18*
SO ₂			1	0.46*	0.81*	-0.47*	-0.64*	-0.24*	0.30*	-0.31*
NO ₂				1	0.52*	0.20*	-0.25*	-0.17*	0.19*	-0.36*
CO					1	-0.45*	-0.55*	-0.14*	0.22*	-0.42*
O ₃ 8h						1	0.61*	-0.31*	-0.40*	0.22*
Temperature							1	-0.19*	-0.70*	0.24*
Relative humidity								1	0.12*	-0.22*
Pressure									1	-0.26*
Wind speed										1

* $p < 0.01$

the intercept of the model; Z_t is the air pollutant on day t ; β is the regression coefficient; $s(\cdot)$ is the non-parametric spline function of calendar time, temperature, humidity, pressure and wind speed; Dow_t is the day of the week effect; and $holiday$ is the holiday effect. In our model, optimal degrees of freedom were calculated for each variable based on the minimized value of the Quasi Akaike information criterion (QAIC) (Li et al. 2018); we initialized the df as 7 df /year for time and 4 df for temperature, humidity, pressure, and wind speed.

To analyze the potential delayed effects of air pollution on ED visits for URTI, we estimated the effect using different models, including both single-day lag (from lag0 to lag7) and multi-day lag (lag 01 and lag 07). For example, lag0 referred to the concentration of air pollutants at the current day and lag1 referred to the previous-day air pollutant concentration and so on. lag01 meant the average concentration of air pollutants at the current and previous day, and lag07 corresponded to the eight-day moving average value of the current and previous 7 days.

As the maximum effect of $PM_{2.5}$, PM_{10} , SO_2 , NO_2 , and CO appeared at lag 07, we applied lag 07 to check the stability of our model. Moreover, subgroup with different stratified by season were tested at lag07. We further plotted the exposure–response (E–R) relationship curves between each air pollutants and hospital ED visits for URTI by including a natural spline function of pollutant concentrations with 3 degrees of freedom. We also conducted subgroup analyses by gender (female and male), age (0–14, 15–64, and ≥ 65 years), and season (warm, April to September; and cool, October to March).

In addition, to assess the robustness of the model, two sensitivity analyses were conducted. First, two-pollutant models were built to examine the stability of the effect estimates after adjustment for co-pollutants. Second, changing df were selected with 6–10 per year for the smoothness of time trends.

All of the data analyses were performed in R Programming Language (version 3.4.4; R Core Team 2017) using the “mgcv” packages. The results are presented as the excess risk (ER) and 95% CIs for daily ED visits for URTI, per 10- $\mu\text{g}/\text{m}^3$ increase in $PM_{2.5}$, PM_{10} , SO_2 , NO_2 , and O_3 8h and per 1- mg/m^3 increase in CO.

Results

The statistical characteristics of hospital ED visits, meteorological data, and air pollutants were described in Table 1. From January 1, 2014, to December 31, 2018, a total of 101,804 emergency room visits for URTI were recorded, with 70,807 in children (0–14 years), 26,460 in adults (15–64 years), and 4,537 in elderly (≥ 65 years) in this area.

On average, there were approximately 56 hospital ED visits, per day. Also, the number of ED visits was more for male than female (about 55,785 vs 45,929). The daily average concentrations for $PM_{2.5}$, PM_{10} , SO_2 , NO_2 , O_3 8h, and CO were 51.33 $\mu\text{g}/\text{m}^3$, 120.50 $\mu\text{g}/\text{m}^3$, 21.81 $\mu\text{g}/\text{m}^3$, 46.90 $\mu\text{g}/\text{m}^3$, 86.54 $\mu\text{g}/\text{m}^3$, and 1.28 mg/m^3 , respectively. The values for mean daily temperature, pressure, relative humidity, and wind speed were 11.34 °C, 848.43 hpa, 50.91%, and 1.23 m/s, respectively.

Table 2 provides the Spearman’s correlation coefficients between air pollutants and weather conditions. $PM_{2.5}$ was positively correlated with PM_{10} ($r=0.84$; $p=0.000$), SO_2 ($r=0.65$; $p=0.000$), NO_2 ($r=0.43$; $p=0.000$), CO ($r=0.69$; $p=0.000$), pressure ($r=0.19$; $p=0.000$), but inversely correlated with O_3 8h ($r=-0.37$; $p=0.000$), temperature ($r=-0.49$; $p=0.000$), relative humidity ($r=-0.13$; $p=0.000$), and wind speed ($r=-0.29$; $p=0.000$). PM_{10} was positively correlated with SO_2 ($r=0.57$; $p=0.000$), NO_2 ($r=0.42$; $p=0.000$), CO ($r=0.52$; $p=0.000$), pressure ($r=0.15$; $p=0.000$), but inversely correlated with O_3 8h ($r=-0.17$; $p=0.000$), temperature ($r=-0.36$; $p=0.000$), relative humidity ($r=-0.38$; $p=0.000$), and wind speed ($r=-0.18$; $p=0.000$). SO_2 was positively correlated with NO_2 ($r=0.46$; $p=0.000$), CO ($r=0.81$; $p=0.000$), and pressure ($r=0.30$; $p=0.000$), but inversely correlated with O_3 8h ($r=-0.47$; $p=0.000$), temperature ($r=-0.64$; $p=0.000$), relative humidity ($r=-0.24$; $p=0.000$), and wind speed ($r=-0.31$; $p=0.000$). NO_2 was positively correlated with CO ($r=0.52$; $p=0.000$), O_3 8h ($r=0.20$; $p=0.000$), and pressure ($r=0.19$; $p=0.000$), but inversely correlated with temperature ($r=-0.25$; $p=0.000$), relative humidity ($r=-0.17$; $p=0.000$), and wind speed ($r=-0.36$; $p=0.000$). CO was positively correlated with pressure ($r=0.22$; $p=0.000$), but inversely correlated with O_3 8h ($r=-0.45$; $p=0.000$), temperature ($r=-0.55$; $p=0.000$), relative humidity ($r=-0.14$; $p=0.000$), and wind speed ($r=-0.42$; $p=0.000$). O_3 8h was positively correlated with temperature ($r=0.61$; $p=0.000$) and wind speed ($r=0.22$; $p=0.000$), but inversely correlated with relative humidity ($r=-0.31$; $p=0.000$) and pressure ($r=-0.40$; $p=0.000$). Temperature was inversely correlated with relative humidity ($r=-0.19$; $p=0.000$) and pressure ($r=-0.70$; $p=0.000$), but positively correlated with wind speed ($r=0.24$; $p=0.000$). Relative humidity was inversely correlated with wind speed ($r=-0.22$; $p=0.000$), but positively correlated with pressure ($r=0.12$; $p=0.000$). Pressure was inversely correlated with wind speed ($r=-0.26$; $p=0.000$).

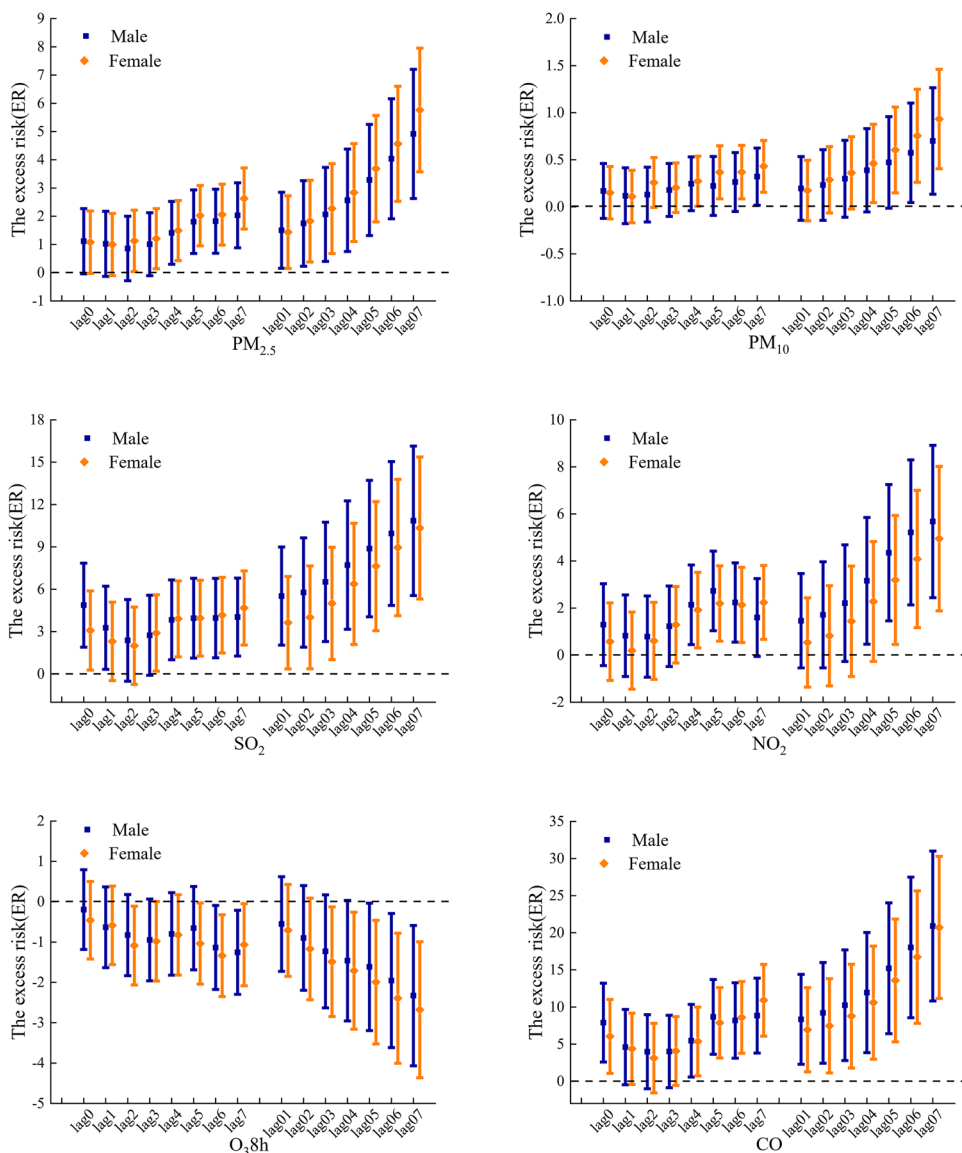
As shown in Table 3, the results of single-pollutant models are presented using different lag days. With the exception of O_3 8h, significant results were identified between five other air pollutants and hospital ED visits for URTI: specifically, lag0, lag3–lag7, and lag01–lag07 for $PM_{2.5}$; lag5–lag7 and lag04–lag07 for PM_{10} ; lag0, lag1, lag3–lag7,

Table 3 Percent change (95% CI) of single-pollutant model results in emergency department visits with URTI associated with a 10-µg/m³ increase in air pollutant concentrations with different lag days

Lag days	PM _{2.5}		PM ₁₀		SO ₂		NO ₂		O ₃ 8h		CO ^a	
	ER	95% CI	ER	95% CI	ER	95% CI	ER	95% CI	ER	95% CI	ER	95% CI
lag0	1.104	(0.037, 2.182)	0.169	(-0.109, 0.431)	4.045	(1.340, 6.822)	0.955	(-0.639, 2.573)	-0.329	(-1.248, 0.598)	7.034	(2.273, 12.017)
lag1	1.013	(-0.048, 2.085)	0.114	(-0.159, 0.387)	2.823	(0.144, 5.573)	0.526	(-1.069, 2.137)	-0.629	(-1.559, 0.309)	4.490	(-0.089, 9.279)
lag2	0.982	(-0.071, 2.045)	0.190	(-0.074, 0.454)	2.209	(-0.427, 4.916)	0.702	(-0.880, 2.309)	-0.957	(-1.892, -0.013)	3.580	(-0.905, 8.267)
lag3	1.100	(0.073, 2.138)	0.192	(-0.068, 0.449)	2.808	(0.218, 5.465)	1.247	(-0.322, 2.841)	-0.958	(-1.900, -0.007)	4.026	(-0.381, 8.628)
lag4	1.453	(0.428, 2.489)	0.259	(-0.002, 0.520)	3.861	(1.280, 6.509)	2.043	(0.491, 3.619)	-0.815	(-1.767, 0.146)	5.408	(0.993, 10.017)
lag5	1.906	(0.871, 2.951)	0.291	(0.009, 0.574)	3.943	(1.360, 6.593)	2.476	(0.928, 4.047)	-0.837	(-1.798, 0.133)	8.279	(3.742, 13.014)
lag6	1.924	(0.880, 2.979)	0.313	(0.039, 0.597)	4.047	(1.476, 6.682)	2.182	(0.636, 3.751)	-1.239	(-2.208, -0.261)	8.349	(3.755, 13.147)
lag7	2.301	(1.246, 3.367)	0.372	(0.097, 0.647)	4.313	(1.789, 6.899)	1.881	(0.364, 3.429)	-1.176	(-2.146, -0.196)	9.767	(5.182, 14.552)
lag01	1.476	(0.235, 2.732)	0.185	(-0.127, 0.498)	4.642	(1.494, 7.888)	1.027	(-0.805, 2.892)	-0.644	(-1.733, 0.456)	7.688	(2.27, 13.393)
lag02	1.787	(0.393, 3.200)	0.258	(-0.087, 0.604)	4.958	(1.454, 8.583)	1.293	(-0.762, 3.399)	-1.045	(-2.249, 0.175)	8.403	(2.354, 14.809)
lag03	2.163	(0.632, 3.718)	0.327	(-0.049, 0.703)	5.820	(2.001, 9.783)	1.842	(-0.420, 4.155)	-1.364	(-2.663, -0.048)	9.558	(2.922, 16.622)
lag04	2.696	(1.029, 4.391)	0.422	(0.016, 0.831)	7.097	(2.988, 11.370)	2.746	(0.291, 5.260)	-1.592	(-2.976, -0.188)	11.321	(4.122, 19.017)
lag05	3.475	(1.664, 5.317)	0.533	(0.088, 0.981)	8.304	(3.934, 12.857)	3.810	(1.173, 6.515)	-1.808	(-3.271, -0.322)	14.452	(6.640, 22.836)
lag06	4.283	(2.329, 6.273)	0.658	(0.175, 1.144)	9.490	(4.886, 14.297)	4.683	(1.878, 7.566)	-2.177	(-3.714, -0.615)	17.415	(9.017, 26.459)
lag07	5.302	(3.202, 7.445)	0.808	(0.291, 1.328)	10.607	(5.819, 15.611)	5.325	(2.379, 8.356)	-2.511	(-4.119, -0.876)	20.799	(11.834, 30.482)

^aNoting: except CO, CO Units: 1-mg/m³ increase in CO

Fig. 2 Percent increase (95% CI) of daily emergency department visits for URTI associated with an increase of 10 µg/m³ in air pollutants (and 1 mg/m³ in CO) at different lag days by gender

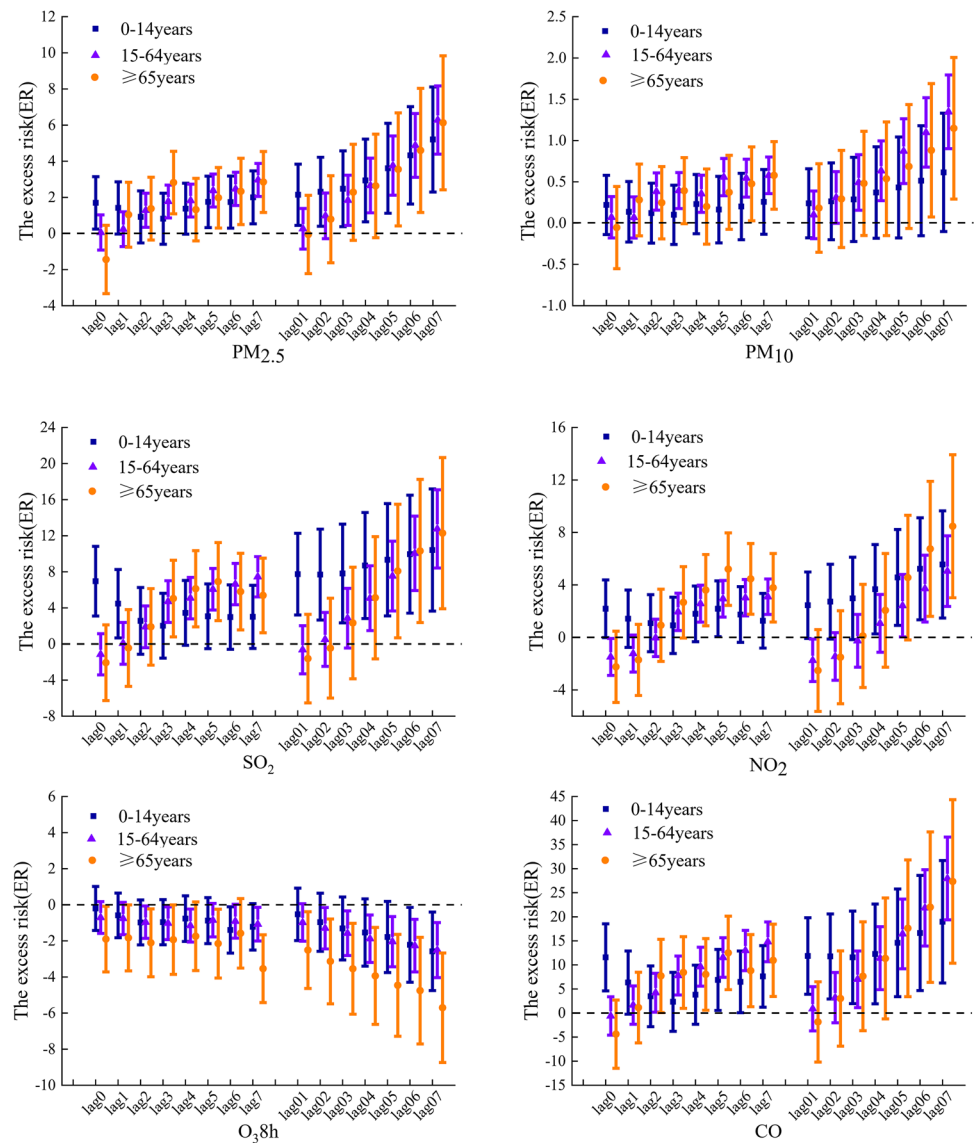


and lag01–lag07 for SO₂; lag4–lag7 and lag04–lag07 for NO₂; and lag0, lag4–lag7, and lag01–lag07 for PM_{2.5}. The cumulative effects of these five air pollutants were more significantly associated with percent increment in URTI numbers than single, and all reached peak values at lag 07. A 10-µg/m³ increase of PM_{2.5}, PM₁₀, SO₂, and NO₂ and 1-mg/m³ increase in CO were associated with 5.302% (95% CI, 3.202%, 7.445%), 0.808% (95% CI, 0.291%, 1.328%), 10.607% (95% CI, 5.819%, 15.611%), 5.325% (95% CI, 2.379%, 8.357%), and 20.799% (95% CI 11.834%, 30.842%) increases in hospital ED visits for URTI at lag 07, respectively. The significant ERs started from lag0 for PM_{2.5}, SO₂, and CO indicating an acute effect on hospital ED visits for URTI since the day of exposure; the cumulative effects for these three air pollutants had been continuously increasing from 1 day after exposure to 7 days after exposure. Associations between O₃8h at different lag days and hospital ED

visits for URTI s were insignificant, and the relevant reasons need further analysis.

Figure 2 summarizes the gender-specific analysis results in different lag days. In males, we found significant positive associations for PM_{2.5} at lag 4, 5, 6, 7 day, and in all cumulative lags, for PM₁₀ at lag 7, lag06, and lag07; for SO₂ at all the lag days except lag 2, 3 day; for NO₂ at lag 4, lag 5, lag6, and lag04, lag05, lag06, lag07; and for CO at all the lag days except lag 1, 2, 3 day. No associations between O₃8h and males for URTI were detected. For females, statistically significant associations were observed for PM_{2.5} at lag 2, 3, 4, 5, 6, 7 day, and in all cumulative lags, for PM₁₀ at lag 4, lag 5, lag6, lag7, and lag04, lag05, lag06, lag07; for SO₂ at all the lag days except lag 1, 2 day; for NO₂ at lag 4, lag 5, lag6, lag7, and lag05, lag06, lag07; and for CO at all the lag days except lag 1, 2, 3 day. There was no obvious association observed between O₃8h and females for URTI. Except for

Fig. 3 Percent increase (95% CI) of daily emergency room visits for URTI associated with an increase of 10 µg/m³ in air pollutants (and 1 mg/m³ in CO) at different lag days by age



O₃8h, the most obvious and statistically significant association between air pollutants and males and females with upper sensation were appeared on the lag07. In addition, we observed differences between male and female sensitivity to different air pollutants. From our analysis, males suffered more from the harmful effects of SO₂, NO₂, and CO than females, who seemed more vulnerable to exposure to PM_{2.5} and PM₁₀.

Results of stratified analyses by age based on GAM model were shown in Fig. 3. The impact of air pollutants on different ages mainly occurs in patients younger than 14 years old. For children aged 0 to 14, the association of PM_{2.5}, SO₂, NO₂, and CO were detected at lag 0 day and showed an increasing trend; the most significant positive relationship appeared at lag 07 for above air pollutants. Meanwhile, in the adults (aged 15–64), both PM_{2.5}, PM₁₀, and CO showed positive correlation in both single-lag models (lag 2 to lag

7) and cumulative exposure models (lag 03 to lag 07 for PM_{2.5}, CO and lag 02 to lag 07 for PM₁₀), and the strongest association was at lag 07, while for SO₂, it showed positive significance at lag 3 to lag7, as well as lag04 to lag07. Moreover, the relationship between NO₂ exposure and adults was significant at lag 3-lag7 and lag 05-lag07. In the elderly group (65 years old), both SO₂, NO₂, and CO kept positive significance at lag3-lag7 and lag05-lag07. Different from the gaseous pollutants mentioned above, the statistically significant associations were observed for the 65 and older age group at lag3, lag5, lag6, lag7, lag05, lag06, and lag07 for PM_{2.5} and lag3, lag6, lag7, lag06, and lag07 for PM₁₀. Generally, the highest effect estimates were at lag07 day for PM_{2.5} and PM₁₀ among all day lags. Similar to the associations within the whole population, PM_{2.5}, SO₂, and CO had the same acute effect on the 14 and younger age group on lag 0 day among all single-day lags. Compared with the other

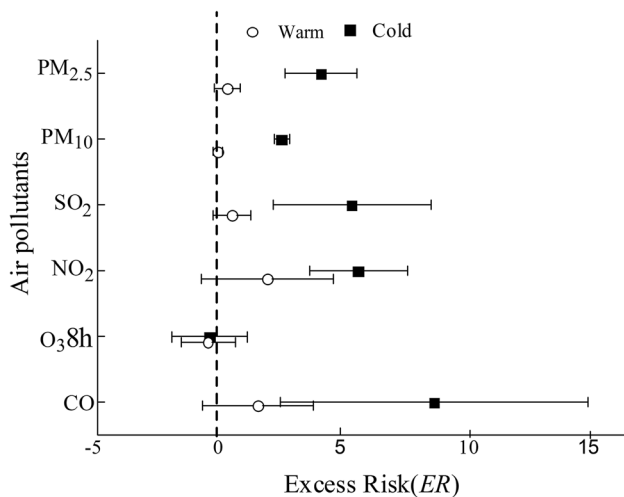


Fig. 4 Percent change (95% CI) of daily emergency department visits for URTI associated with different air pollutants at the moving average of lag 07 days, stratified by season (cool, warm)

two age groups, the effects of PM_{2.5}, PM₁₀, SO₂, and CO in aged ≥ 65 group appeared to be stronger on lag 07 day. Nevertheless, no significant associations were observed among the three age groups, for O₃8h.

Figure 4 also shows season-specific analyses of the effects of different air pollutants on hospital ED visits for URTI at lag 07. The adverse effects of PM_{2.5}, PM₁₀, SO₂, NO₂, and CO were statistically significant only in the cool season, and the effect estimates in the cold season were approximately 3–4 times higher than those in the warm season. None significant effects were observed for O₃8h.

Figure 5 shows the concentration–response relationship between air pollutants and hospital ED visits for URTI at lag 07. The curves of PM_{2.5}, SO₂, NO₂, and CO seem to be almost linear trends when the concentrations were above 75 $\mu\text{g}/\text{m}^3$, 35 $\mu\text{g}/\text{m}^3$, 80 $\mu\text{g}/\text{m}^3$, and 1.8 mg/m^3 , respectively, which indicated that the adverse effects initially increased linearly with its concentrations. The curves associated with PM₁₀ were nearly S-shaped, first rising sharply when the concentration at 150–250 $\mu\text{g}/\text{m}^3$ and then becoming flat for concentrations $> 250 \mu\text{g}/\text{m}^3$. Moreover, there was a positive relationship between O₃8h and hospital ED visits for URTI when concentrations at 40–70 $\mu\text{g}/\text{m}^3$. Once higher than 70 $\mu\text{g}/\text{m}^3$, the positive relationship did not exist.

Table S1 provides the associations between ED visits for URTI in two-pollutant models using exposure at lag 07. The effect estimate of all six pollutants did not change substantially in two-pollutant model. When changing the different df value (5–10 per year) for time trend, the associations between air pollutants and ED visits for URTI were not changed a lot (see Supplementary Table S2). All described above suggest that the model fitted well and results were robust.

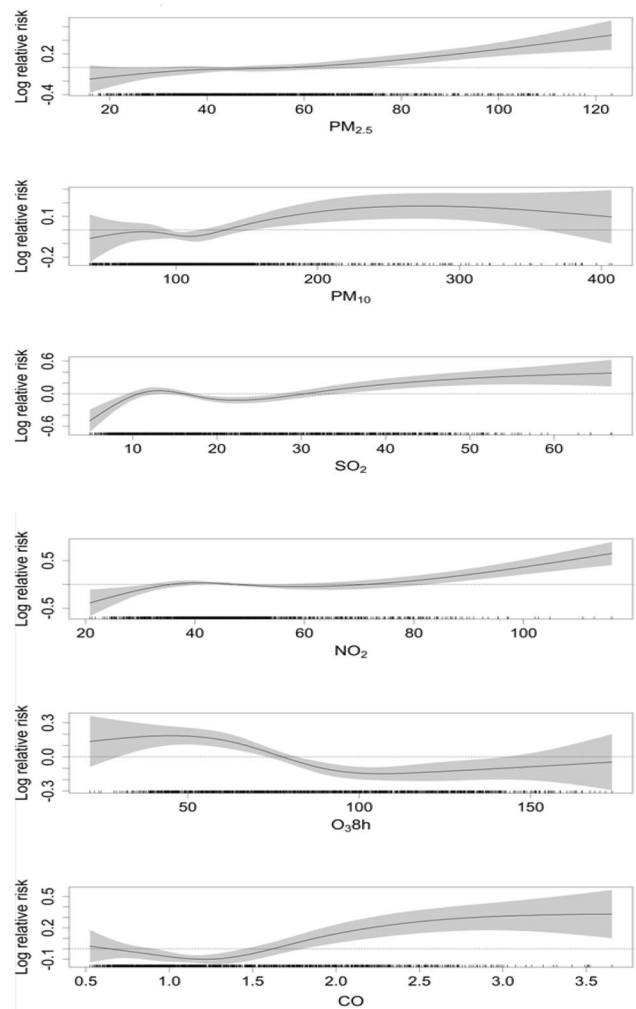


Fig. 5 The exposure–response relationship curves between daily URTI emergency department visits and air pollutants

Discussion

To the best of our knowledge, this is the first attempt to explore the associations between air pollution and hospital ED visits for URTI in the arid inland cities of Northwest China. In this study, we found significant associations between hospital ED visits for URTI and concentrations of all analyzed air pollutants, except for O₃8h, and clear differences by gender, age, and season were observed. Younger children might be more sensitive to atmospheric pollutants. The associations between air pollutants and ED visits for URTI mainly arose in the cold season rather than the warm season. CO was the sole pollutant with the largest risk of hospital ED visits for URTI in both in the single-lag days and cumulative exposure days. These findings could better explain the effect of air pollutants on human health.

Our findings showed that in single-pollutant models, a 10- $\mu\text{g}/\text{m}^3$ increase in PM_{2.5} was associated with a 5.302%

increase in hospital ED visits for URTI at lag07, which were consistent with some previous studies (Darrow et al. 2014; Zheng et al. 2017; Li et al. 2018; Zhang et al. 2021). A study in Atlanta, USA, conducted by Darrow et al., found that per $10 \mu\text{g}/\text{m}^3$ increasing in concentrations of $\text{PM}_{2.5}$ at lag06 were associated with an increase of 1.724% in ED visits for URTI (Darrow et al. 2014). Another study conducted by Zheng's team, which specifically focused on Ningbo city, China, found an increase of 3.460% (range 2.18–4.76%) per $10\text{-}\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ level in emergency department visits for AURI among children. Also, other studies from China such as Li et al.'s study from Hefei (Li et al. 2018) and Zhang et al.'s study from Wuhan (Zhang et al. 2021) reported that an increase of $10 \mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$ corresponded to a 380%, and 0.740% increase of hospital visits for URTI, respectively. On the other hand, some studies did not show significant correlations between $\text{PM}_{2.5}$ and hospital visits for URTI (Li et al. 2017; Song et al. 2018). The composition and sources of atmospheric particulates in different regions were different, which might be the reason for the inconsistent estimated effects of atmospheric particulates in distinct areas. Another possible explanation might be the difference in the structure and characteristics of the population.

For every $10\text{-}\mu\text{g}/\text{m}^3$ increase in PM_{10} levels in the ambient air of Lanzhou, China, the risk of emergency department visits for URTI increased 0.808%. The result of our study is similar to previous studies in this field. For example, a study by Arbex et al. in 2011 showed a 3.149% increase in the risk of URTI ED visits for $10 \mu\text{g}/\text{m}^3$ (Arbex et al. 2011). Tam et al. in the metropolitan city of Hong Kong showed a 0.50% increase in the risk of upper respiratory tract infections per $10\text{-}\mu\text{g}/\text{m}^3$ increase in PM_{10} (Tam et al. 2014), and Zheng et al. in 2017 showed a 2.810% increase in the risk of URTIs visits for $10\text{-}\mu\text{g}/\text{m}^3$ increase in PM_{10} concentration (Zheng et al. 2017). Moreover, other studies from Hefei, Shijiazhuang, and Wuhan in China reported that a $10\text{-}\mu\text{g}/\text{m}^3$ increase in PM_{10} was associated with a 0.15%, 0.07%, and 0.61% increase in emergency room visits for URTI (Li et al. 2018; Song et al. 2018; Zhang et al. 2021). Our results showed that the effect of PM_{10} on emergency room visits for URTI was similar to that reported in Hong Kong and Wuhan (Tam et al., 2014; Zhang et al. 2021), based on the same method of analysis. The effect of PM_{10} on URTI ED visits in São Paulo, Brazil (Arbex et al. 2011) and Ningbo in China (Zheng et al. 2017) was of greater magnitude than in our study. However, these inconsistent results can be due to the short study period (2 or 3 years) and use of limited data for above researcher's literature.

For SO_2 , the results of our study showed that SO_2 in the single pollutant model were strongly associated with emergency department visits for URTI, with the effect estimates of 10.607% for every $10 \mu\text{g}/\text{m}^3$ increments in SO_2 ;

our findings were consistent with those reported in various studies (Zheng et al. 2017; Zhang et al. 2021). In Ningbo, the risk estimates of per $10\text{-}\mu\text{g}/\text{m}^3$ increased to SO_2 were 15.170% on URTI emergency room visits (Zheng et al. 2017). Zhang et al. studied the impact of air pollution on URTI visits in Wuhan, China, and it was found that for every $10\text{-}\mu\text{g}/\text{m}^3$ increase in SO_2 concentration, URTI visits increased by 9.180% (Zhang et al. 2021). In contrast, other studies using the same method also found the lower estimates (Tam et al. 2014; Li et al. 2018; Song et al. 2018). As we observed from above study, the effect sizes of SO_2 on URTI emergency room visits differed from the previous studies. This can be explained that health effects of air pollution are influenced by various factors (e.g., air pollution concentration, population characteristics, and the duration and intensity of exposure to air pollutant).

The association of NO_2 with URTI varies in different studies. A study in São Paulo (Arbex et al. 2011) found that every $10\text{-}\mu\text{g}/\text{m}^3$ increase in NO_2 concentration is associated with a 0.630% increase in URTI visits on lag0. Another study in Hong Kong (Tam et al. 2014) and Ningbo reported that every $10\text{-}\mu\text{g}/\text{m}^3$ increase in NO_2 causes a 1.00% increase in emergency room visits with URTI and a 11.270% increase in pediatric emergency visits for URTI (Zheng et al. 2017). Additionally, in a study by Song et al. (2018) in Shijiazhuang, Li et al. (2018) in Hefei, and Zhang et al. (2021) in Wuhan, it is also reported that the effects of NO_2 on emergency URTI visits cause an increase in the number of hospital visits by 2.2502%, 4.470%, and 3.40%, respectively. In the present study, a $10\text{-}\mu\text{g}/\text{m}^3$ increase in NO_2 was associated with a 5.325% increase in URTI emergency visits at lag07. If we compare the results of our study with different studies, the effect values in our study were higher than those reported by Song et al. (2018) in Shijiazhuang, Li et al. (2018) in Hefei, and Zhang et al. (2021) in Wuhan, but less than Zheng et al. (2017) in Ningbo. These inconsistencies may be caused by variations in population susceptibility, emission resources to air pollution, and method and route of exposure among different areas.

In this study, we found statistically non-significant association of O_3 per $10\text{-}\mu\text{g}/\text{m}^3$ increase with URTI visits. However, the association between O_3 and emergency URTI visits remains controversial. Some studies demonstrated the detrimental effect of O_3 exposure leading to ED visits for URTI visits (Tam et al. 2014; Zhang et al. 2021). On the other hand, other study did not find a positive effect between O_3 and URTI visits (Song et al. 2018; Li et al. 2018). As an unstable gaseous pollutant, it can react with other air pollutants to produce new compounds. Therefore, the effect of O_3 exposure should be interpreted with caution. The mechanism of O_3 in human body is still worthy of further study.

Of the six pollutants included in the current study, CO had the greatest adverse effect on URTI visits. We observed

that an increment of 20.799% at lag07 was mostly strongly associated with per 1-mg/m³ increase in CO. In this regard, the result of our study was similar to two earlier studies. For example, in a study by Arbex et al. in 2011 in São Paulo, Brazil, the results showed an 1.50% increase in risk of URTI emergency department (ED) visits for each IQR increase in CO concentration (Arbex et al. 2011). And a study by Li et al. in Hefei, China, showed a 0.498% increase in the risk of URTIs for 1-mg/m³ increase in CO concentration (Li et al. 2018). The results of toxicology studies suggest that exposure to CO may not directly affect respiratory tract, but it can greatly reduce the oxygen-carrying capacity of red blood cells and inhibits the release of oxygen. As a result, symptoms of respiratory diseases can be exacerbated. CO is still an environmental issue in Lanzhou, but now no study has investigated its health effects on URTI emergency department (ED) visits. Therefore, the present study can provide the scientific evidence of CO effects on human health in Lanzhou.

When URTI visits were stratified by gender, our study found that females were more susceptible to PM_{2.5} and PM₁₀, while males were more sensitive to the effects of SO₂, NO₂, and CO. However, this result was not consistent with two previous epidemiology study. For example, Zhang et al. found a stronger association of UTRT visits with SO₂ and NO₂ in female than in male (Zhang et al. 2021). Conversely, Zheng et al. concluded that males were more susceptible to the effect of ambient air pollutants on hospital visits for URTI (Zheng et al. 2017). These differences may be due to gender-linked biological (e.g., structure of the lungs, immune, and inflammatory responses) and work-related exposure patterns etc., which could affect the effects of pollutants in male and female. For example, men spend more time in outdoor activities because of the demands of their jobs, which may result in the higher effects of air pollutants on them. The findings of gender-specific are still unclear and warranted to further investigate this issue.

In terms of age stratification, the higher association effect of four pollutants (PM_{2.5}, SO₂, NO₂, and CO) on hospital visits for URTI among children (0–14 years) was consistent with previous studies (Zheng et al. 2017; Li, et al. 2018). Possible reasons may be that children are more vulnerable to the health effects of air pollutant because of their narrower airways, developing lungs, rates of breathing, immature central nervous system, and immune system. The stronger estimated effects were observed in the aged 15–64 group for PM_{2.5}, PM₁₀, SO₂, NO₂, and CO. We speculate that this result might be due to the different chance of exposure between these three age groups, as adults may be engaged in more outdoor activities, resulting in exposure to higher frequency of air pollution. In addition, we also found that elderly (aged ≥ 65) was more vulnerable to exposure to PM_{2.5}, PM₁₀, SO₂, NO₂, and CO, mainly due to their weak

immune and respiratory systems and comorbidity. Therefore, people may be exposed to the same air pollutants but may have different health effects. These effects may also manifest differently, complicating the sensitivity of ambient air pollution.

Our seasonal analysis showed that adverse impacts of PM_{2.5}, PM₁₀, SO₂, NO₂, and CO on URTI emergency department (ED) visits were statistically significant in the cold season and insignificant in the warm season, which were consistent with some previous studies (Li et al. 2017; Zheng et al. 2017). There were several potential explanations proposed for this increased association on cold days. First, low annual temperature in Lanzhou resulting in burning fossil fuels for heating for up to 5 months a year and burning biomass or other fuels released a large number of particles or gaseous pollutants. As a result, the concentrations of PM_{2.5}, PM₁₀, SO₂, NO₂, and CO were remarkably higher during winters. Similarly, the urban area is located in the valley basin covering 1100 km², and the special landform of this area makes the air hard to circulate, which may help the accumulation of air pollutants in winter. Second, meteorological factors might affect the health effect of air pollutants. For example, we found that the action of temperature, relative humidity, air pressure, and wind speed have effect on concentrations of air pollutants in winter. The impact of air temperature on the concentration of five pollutants indicated a weak or moderate negative correlation with coefficients −0.49, −0.36, −0.64, −0.25, and −0.55, for PM_{2.5}, PM₁₀, SO₂, NO₂, and CO, respectively. Mainly due to the low temperature when coal heating and discharge, there were a lot of air pollutants. Relative humidity was negatively correlated with five pollutants; correlation coefficients were −0.13, −0.38, −0.24, −0.17, and −0.14, for PM_{2.5}, PM₁₀, SO₂, NO₂, and CO, respectively. Due to the lack of precipitation and dry climate in Lanzhou in winter, the effect of humidity is limited. In contrast, we found a positive association between air pollutant and air pressure in the Spearman correlation model, except for O₃8h. At the same time, due to the lower temperature in winter, higher air pressure caused the atmospheric mixing height to become lower, and the boundary layer declined with the appearance of inversion temperature. Wind is known to affect the dilution and diffusion of air pollutant, possibly because wind is negatively correlated with air pollutant. PM_{2.5}, PM₁₀, SO₂, NO₂, and CO had a negative association with wind. The correlation indicated that the small wind speed in winter made it difficult for the pollutants to migrate horizontally, thereby increasing the concentration of pollutants. O₃8h concentration was negatively correlated with PM_{2.5}, PM₁₀, SO₂ (Spearman correlation coefficients ranged from −0.47 to −0.17), moderately negative correlated with relative humidity, and strongly correlated with temperature ($r=0.61$, $p=0.000$). Hence, higher O₃ concentrations in the warm season were likely caused by

increased sunlight. This is because sunshine might be the main promoter of O₃ because O₃ enhanced by photochemical factors and RH can affect sunshine duration. Meteorological factors can influence air pollution, thereby impacting health (Kermani et al. 2020c).

Exploring the concentration–response curves of air pollution is crucial to the formation of public health policies. In present study, the curves may vary by air pollutants, and the curves for PM_{2.5}, SO₂, NO₂, and CO were positive linear, with an estimated threshold of 75 µg/m³ for PM_{2.5}, 35 µg/m³ for SO₂, 80 µg/m³ for NO₂, and 1.8 mg/m³ for CO, respectively. In addition, the exposure–response curves of PM₁₀ and O₃8h were positive when concentrations at in moderate PM₁₀ (150 to 250 µg/m³) and O₃8h (40 to 70 µg/m³) levels. However, a study conducted in a different Chinese city found the linear curve for PM₁₀ and SO₂, but the S-shaped curve for PM_{2.5} and NO₂ (Zhang et al. 2021). In the mentioned study in Wuhan, China, a threshold relationship between O₃ and clinic visits for URTI were observed and whose curve remained flat and then rose rapidly after the concentration was above 100 µg/m³, which is inconsistent with our studies. Differences in the shape of exposure–response curves may be a result of differences in numerous factors such as population sensitivity, air pollutant mixture and locations, etc.

This study has several strengths. Firstly, this is the first time-series study on the associations between air pollution and emergency department visits for URTI in Northwest China. Secondly, this study is the first to report associations between URTI and all six critical ambient pollutants according to optimal GAM time-series modeling. Thirdly, this finding provided the scientific literature on health effects of ambient gaseous pollutants, especially O₃8h and CO in Northwest China. To date, there is no study in Northwest China. Fourthly, this is the first study investigating the concentration–response functions of all six critical ambient pollutants with URTI visits in Northwest China.

Conclusions

Our study demonstrated that short-term exposure to air pollutants were significantly associated with emergency department visits for URTI, except for O₃8h. And gaseous pollutants (SO₂, CO) had more negative health impact than particulate matters. Furthermore, gender, age, and season may be the potential effect modifiers on the association between air pollution and URTI visits. Our findings suggest local authorities take more effective measure to protect vulnerable groups from being adversely affected by the gaseous air pollution.

Abbreviations GAM: Generalized additive model; ER: Excessive risk; ED: Emergency department; QAIC: Quasi Akaike information criterion; URTI: Upper respiratory tract infection

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11356-021-17932-2>.

Author contribution Jiyuan Dong contributed to the conception or design of the work. Yurong Liu, Yanru Wang, and Jiancheng Wang contributed to the acquisition, analysis, or interpretation of data for the work. Jiyuan Dong drafted the manuscript. Hairong Bao, and Guangyu Zhai critically revised the manuscript. All gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

Funding This study was supported by the National Natural Science Foundation of China (71861026), and the Natural Science Foundation of Gansu Province, China (Grant No. 21JR7RA864).

Data availability The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality agreements but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The present study is considered exempt from institutional review board approval since the data used was collected for administrative purpose without any personal identifiers.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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