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Air pollution and hospital admissions for respiratory diseases in Lanzhou, China

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ABSTRACT

Lanzhou is among the most seriously air-polluted cities in China as a whole, due to its unique topography, climate, industrial structure and so on. We studied the relationship between different air pollution and respiratory hospitalizations from 2001 to 2005, the total of respiratory hospital admissions were 28,057. The data were analyzed using Poisson regression models after controlling for the long time trend for air pollutants, the "day of week" effect and confounding meteorological factors. Three air pollutants (PM_{10}, SO_2, NO_2) had a lag effect, the lag was 3–5 days for PM_{10}, 1–3 days for SO_2 and 1–4 days for NO_2. The relative risks were calculated for increases in the inter-quartile range of the pollutants (139 $\mu g/m^3$ in PM_{10}, 61 $\mu g/m^3$ in SO_2 and 31 $\mu g/m^3$ in NO_2). Results showed that there were significant associations between air pollutants and respiratory hospital admissions, and stronger effects were observed for females and aged ≥65 yrs in Lanzhou.

1. Introduction

A number of epidemiological studies have observed associations between air pollutants, including particulates, SO_2, CO, NO_2 and O_3, and negative health effects, such as higher mortality levels, greater hospital admissions and increased outpatient visits (Dockery et al., 1994; Kan et al., 2007; Lee et al., 2000; Schwartz, 1999; Yang et al., 2004; Zeka et al., 2005).

The relationship between hospital admissions for respiratory diseases and air pollution has been assessed in the developed countries of Europe and in the United States (Atkinson et al., 2001; Medina-Ramón et al., 2006; Schwartz, 1994, 1996; Wilson et al., 2005; Zanobetti et al., 2000). For example, the study evaluated the effect of PM_{10} on respiratory hospital admissions in 36 US cities, finding that a 10 $\mu g/m^3$ increase in PM_{10} during the warm season resulted in a 1.47% increase in chronic obstructive pulmonary disease admissions and a 0.84% increase in pneumonia admissions (Medina-Ramón et al., 2006). The APHEA 2 project investigated the short-term health effects of particulates in eight European cities. When PM_{10} increased by 10 $\mu g/m^3$, admissions for chronic obstructive pulmonary disease plus asthma and total respiratory diseases in patients ≥65 yrs increased by 1.0% and 0.9%, respectively (Atkinson et al., 2001). Positive associations between air pollutants and respiratory disease hospital admissions have also been reported in Asia (Chang et al., 2003; Wong et al., 1999; Xu et al., 1995; Zhou et al., 1997). For example, in Hong Kong, NO_2, SO_2 and PM_{10} increases of 10 $\mu g/m^3$ were associated with total respiratory disease hospitalization increased by 2.0%, 1.3% and 1.6%, respectively, and chronic obstructive pulmonary disease increased by 2.9%, 2.3% and 1.9%, respectively (Wong et al., 1999).

Lanzhou (102°35′55″–104°34′29″E, 35°34′20″–37°07′N) is located in the semi-arid region of northwest China, situated in a typical valley basin with low rainfall, high evaporation, low wind speeds, high calm wind frequency and a thick inversion layer (An et al., 2006). Lanzhou is also an industrial city with significant petrochemical, metallurgical and mechanical sectors. These factors combine to make Lanzhou one of the most seriously air-polluted cities in China and the world as a whole, and top PM_{10}-contaminated city in China (WHO, 2011). The objective of our time-series analysis was to assess the acute effects of air pollutants on total respiratory diseases hospital admissions, upper respiratory tract infection, pneumonia and chronic obstructive pulmonary disease in Lanzhou, by using day-to-day air pollutants concentrations after controlling long-term trends and confounding effects of weather.

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We performed the study on the daily hospital admissions of 4 major hospitals and the air pollutant concentrations from 3 air quality monitoring stations from 2001 to 2005. The total of respiratory hospital admissions were 28,057.

2. Materials and methods

2.1. Hospital admissions

We obtained admission records for respiratory diseases (from 1 January 2001 to 31 December 2005) from 4 general hospitals, representing the majority of hospital admissions in Lanzhou. These records contain the date of admission, age, gender, and discharge diagnosis from the tenth revision of the international classification of diseases (ICD-10, Ministry of Health Statistical Information Center, 2001) for each patient. The following disease categories were analyzed separately: total respiratory disease (ICD-10:J00-99), upper respiratory tract infection (ICD-10:J00-06), pneumonia (ICD-10:J12-18) and chronic obstructive pulmonary disease(COPD) (ICD-10:J40-44).

2.2. Air pollution and meteorological data

Three air quality monitoring stations have been established in Lanzhou city by the Lanzhou Environmental Protection Administration (Fig. 1). These monitoring stations are fully automated and provide daily readings of SO_2 (by ultraviolet fluorescence), PM_{10} (by beta-ray absorption), and NO_2 (by chemiluminescence) levels. For each day of the study period, air pollution data were obtained from the Environmental Monitoring Station. When the data were missing for a particular monitoring station on a given day, the values from the remaining stations were used to compute the average. Daily meteorological data, including mean temperature (°C), minimum and maximum temperatures (°C), average pressure (hPa), relative humidity (%), wind speed (m/s), and visibility (m), were provided by the Gansu Meteorological Administration.

2.3. Method of analysis

The descriptive statistics and correlation patterns were examined for hospital admissions, air pollutants and meteorological factors using SPSS version 13.0 (SPSS Inc., Chicago, IL, USA) software. The relative risks of admission for the different respiratory diseases due to air pollution for the total population, males, females, and the <65 yrs and ≥65 yrs age groups were determined using generalized additive Poisson regression models (GAM). Each GAM (Schwartz et al., 1996; Wood and Augustin, 2002; Neuberger et al., 2004) was fit to the logarithm of the expected number of hospital admissions due to the different respiratory diseases as the sum of the smoothed and linear functions of the predictor variables.

The MGCV package in R was applied to construct the models. We used smoothing spline functions of calendar time, temperature, pressure, wind speed, visibility and relative humidity to adjust for long-term trends and to control for the potential confounding effects of weather. A smoothed function is a non-parametric tool that captures the nonlinear relationship between the time varying covariates such as temperature, calendar time and daily hospital admissions, and it was used to ensure that there were no patterns in the residuals indicative of a poor fit in certain time periods or in certain temperature or humidity ranges. Degrees of freedom (df) of smoothed functions were determined by the Akaike's information criterion (Akaike, 1987). If there was overdispersion in the variance, we applied a partial autocorrelation function (PACF) to guide the selection of df until the absolute values of the sum of PACF for lags up to 30 days reached a minimum. We also included dummy variables for day of the week.

Daily air pollutant (PM_{10}, SO_2 and NO_2) data for the same day (lag0), the previous day (lag1) and 2–6 day lags were analyzed in association with daily hospitalizations. The base model was determined by finding the appropriate lag effect of each pollutant on hospitalizations. The lag times were selected the Akaike's information criterion and the significant association ($P < 0.01$). All results were presented as the percentage change of relative risk (RR) of hospitalizations and its 95% confidence interval (CI) in association with an inter-quartile range (IQR) increase in all 5 years air pollutants.

$$\mathrm{Log}[E(Y_k)] = \alpha + \mathrm{DOW} + \beta X_k + s(\mathrm{time}, \mathrm{df}) + s(Z_k, \mathrm{df})$$

where k is the day of the study; $E(Y_k)$ is the expected number of daily respiratory hospital admissions at day k; α is the intercept term; DOW is the indicator variable for the day of the week, as the dummy variable; β is the regression coefficient; X_k is the pollutant concentrations at day k; s(time, df) denotes the smoothed function of calendar time (df = 4); $s(Z_k, \mathrm{df})$ denote smoothed functions of the meteorological variables such as average temperature (df = 3), pressure (df = 5), relative humidity (df = 3), wind speed (df = 5) and visibility (df = 3), respectively.

3. Results

No air pollutant's daily mean, with the exception of PM_{10}, exceeded that of China's national air quality secondary standards (PM_{10}:150 μg/m^3, SO_2: 150 μg/m^3, NO_2: 80 μg/m^3) (Table 1). The PM_{10} and SO_2 concentrations both exceeded the 24-h means of the WHO air quality guidelines (PM_{10} IT-1: 70 μg/m^3, SO_2: 20 μg/m^3), and the NO_2 concentrations exceeded the annual mean of the WHO guidelines (NO_2: 40 μg/m^3).

A certain degree of positive correlation did exist among the pollutants, especially between SO_2 and NO_2 ($r = 0.715$) but also between PM_{10} and both SO_2 ($r = 0.390$) and NO_2 ($r = 0.396$). Correlations between all of the meteorological factors except average pressure and each pollutant were strong and negative ($r = -0.602$ to -0.130). The correlations of average pressure with each pollutant were positively related (Table 2).

During the 5 years of the study, there were a total of 28,057 respiratory hospital admissions at the 4 large-scale general hospitals (Table 3); the number of male hospitalizations was twice as great as that of female hospitalizations, and admissions for patients <65 yrs comprised 2/3 of the total. The subgroups of the respiratory diseases, upper respiratory tract infection, pneumonia and COPD, represented 21.5%, 16.2% and 18.9% of the total respiratory hospitalizations, respectively. An average of 12.59 respiratory disease hospital admissions per day occurred in the city over the study period.

The associations between each air pollutant and the number of hospital admissions divided by gender and age in a single-pollutant model (Fig. 2). Three air pollutants had lag effects, PM_{10} with a lag of 3–5 days, SO_2 with a lag of 1–3 days and NO_2 with a lag of 1–4 days (Table 4). Total respiratory disease hospitalizations were significantly increased by 2.4% (95%CI: 0.5, 4.2), 3.4% (95%CI: 0.2, 6.7) and 3.3% (9.5%CI: 0.7, 5.9) per inter-quartile range increase in PM_{10}, SO_2 and NO_2 respectively. For upper respiratory tract infection, these were increased by 3.8% (95%CI: 0.8, 6.8), 6.9% (95%CI: 1.5, 26.0) and 7.4% (9.5%CI: 3.2, 11.9) per inter-quartile range increase in PM_{10}, SO_2 and NO_2 respectively. For COPD, these were increased by 2.8% (95%CI: 0.0, 5.6), 5.3% (95%CI: 0.6, 10.3) and 4.8% (95%CI: 0.3,

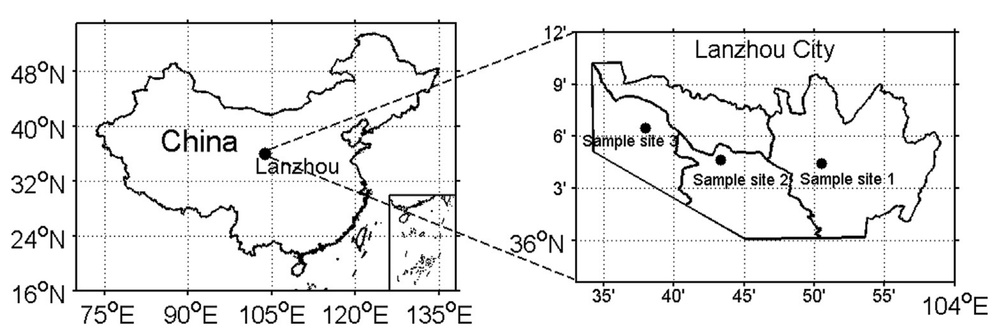

Fig. 1. Locations of air pollutant monitoring stations in Lanzhou.

Table 1
Descriptive statistics for meteorological factors and air pollutants for Lanzhou (2001–2005).

Variables		$\bar{x} \pm s$	Min	Max	IQR	N
Air pollutants	PM_{10} (μg/m$^{3)}$	196.63 ± 169.51	16.00	256.10	139.00	1825
	SO_2 (μg/m^3)	79.09 ± 61.46	2.00	37.10	69.00	1824
	NO_2 (μg/m^3)	45.84 ± 29.29	4.00	26.00	31.00	1824
Meteorological factors	Average temperature (°C)	11.19 ± 9.93	−12.20	30.10	17.90	1801
	Minimum temperature (°C)	6.53 ± 9.79	−15.20	26.70	17.20	1801
	Maximum temperature (°C)	16.79 ± 10.35	−8.90	36.60	17.70	1801
	Average pressure (hPa)	846.52 ± 5.46	831.20	864.30	8.10	1801
	Relative humidity (%)	50.66 ± 14.03	15.90	89.80	20.10	1801
	Wind speed (m/s)	0.99 ± 0.60	0.00	3.50	0.88	1817
	Visibility (km)	19.13 ± 5.12	5.13	30.00	7.57	1807

9.5) per inter-quartile range increase in PM_{10}, SO_2 and NO_2 respectively. For pneumonia, these were increased by 5.3% (95% CI: 1.3, 9.5), 11.0% (95%CI: 3.5, 19.1) and 11.6% (95%CI: 5.2, 18.3) per inter-quartile range increase in PM_{10}, SO_2 and NO_2 respectively.

Regarding age, the relative risk estimates for total respiratory disease and COPD hospitalizations due to each pollutant tended to be smaller for patients aged <65 yrs than those aged ≥65 yrs, and the same pattern was observed for pneumonia and PM_{10}. However, this trend was not observed for upper respiratory tract infection and pneumonia hospitalizations associated with SO_2 or NO_2.Regarding gender, the relative risk estimates for total respiratory disease and pneumonia hospitalizations tended to be smaller for males than for females, and this pattern was also observed for upper respiratory tract infection or COPD hospitalizations associated with SO_2 or NO_2.However, this trend was not observed for upper respiratory tract infection or COPD hospitalizations associated with PM_{10}.

PM_{10}, SO_2 and NO_2 were included in a "multi-pollutant model" (Table 5). For total respiratory disease, PM_{10} and NO_2 were significantly associated with hospitalizations of male patients and those aged ≥65 yrs, while PM_{10} was associated with hospitalizations of female patients and NO_2 with hospitalizations of patients aged <65 yrs. For upper respiratory tract infection, all pollutants were significantly associated with hospitalizations for all patients, with the exceptions of PM_{10} for female patients and NO_2 for patients aged <65 yrs. For COPD, PM_{10} and NO_2 were significantly associated with female hospitalizations, and PM_{10} was also associated with male hospitalizations and NO_2 with hospitalizations of patients aged ≥65 yrs. For pneumonia, all pollutants were significantly associated with male hospitalizations, while PM_{10} and NO_2 were associated with female hospitalizations and only NO_2 with hospitalizations of patients aged ≥65 yrs.

4. Discussion

Since the 1990s, time series analysis based on the generalized additive model (GAM) has been widely used to study the health effects of acute exposure to air pollution. Close relationships have been confirmed between air pollution and mortality rates, the

Table 3
Descriptive statistics of daily respiratory hospitalizations for Lanzhou (2001–2005).

Hospitalization counts	N	$\bar{x} \pm s$	Min	Median	Max	IQR
Total respiratory diseases	28,057	12.59 ± 8.46	1	14	51	11
Male	18,542	10.10 ± 5.93	0	9	41	7
Female	9510	5.19 ± 3.40	0	5	19	4
<65yrs	20,030	10.92 ± 6.11	0	10	37	8
≥65 yrs	8023	4.37 ± 3.22	0	4	22	4
Upper respiratory tract infection	6042	3.30 ± 2.66	0	3	18	4
Male	3732	2.04 ± 1.84	0	2	11	2
Female	2324	1.27 ± 1.38	0	1	8	2
<65yrs	371	0.20 ± 0.47	0	0	4	0
≥65 yrs	5676	3.11 ± 2.55	0	3	17	3
Pneumonia	4559	2.31 ± 2.19	0	2	15	2
Male	2875	1.45 ± 1.59	0	1	11	2
Female	1683	0.86 ± 1.08	0	1	7	1
<65yrs	3434	0.43 ± 0.70	0	0	5	1
≥65 yrs	777	1.88 ± 1.94	0	1	12	3
COPD	5301	2.00 ± 2.18	0	3	13	3
Male	3663	2.00 ± 1.71	0	2	13	2
Female	1638	0.90 ± 1.01	0	1	6	1
<65yrs	3379	1.84 ± 1.65	0	2	12	2
≥65 yrs	1922	1.05 ± 1.15	0	1	7	2

Note: N, observations of valid days during 5 years; $\bar{x} \pm s$, daily mean ± standard deviation.

Table 2
Pearson correlation coefficients between daily meteorological factors and air pollutants for Lanzhou (2001–2005).

	Tmax	Tmin	Tave	Average pressure	Relative humidity	Visibility	Wind speed	SO_2	NO_2	PM_{10}
Tmax[a]	1.000									
Tmin[b]	0.918[d]	1.000								
Tave[c]	0.973[d]	0.980[d]	1.000							
Average pressure	−0.670[d]	−0.640[d]	−0.670[d]	1.000						
Relative humidity	−0.138[d]	0.048[e]	−0.043	0.172[d]	1.000					
Visibility	0.664[d]	0.681[d]	0.694[d]	−0.393[d]	−0.173[d]	1.000				
Wind speed	0.333[d]	0.383[d]	0.372[d]	−0.376[d]	−0.219[d]	0.374[d]	1.000			
SO_2	−0.513[d]	−0.602[d]	−0.572[d]	0.241[d]	−0.187[d]	−0.540[d]	−0.369[d]	1.000		
NO_2	−0.398[d]	−0.517[d]	−0.477[d]	0.227[d]	−0.130[d]	−0.515[d]	−0.412[d]	0.715[d]	1.000	
PM_{10}	−0.300[d]	−0.370[d]	−0.352[d]	0.151[d]	−0.228[d]	−0.523[d]	−0.215[d]	0.390[d]	0.396[d]	1.000

[a] Maximum temperature.
[b] Minimum temperature.
[c] Average temperature.
[d] $P < 0.01$.
[e] $P < 0.05$.

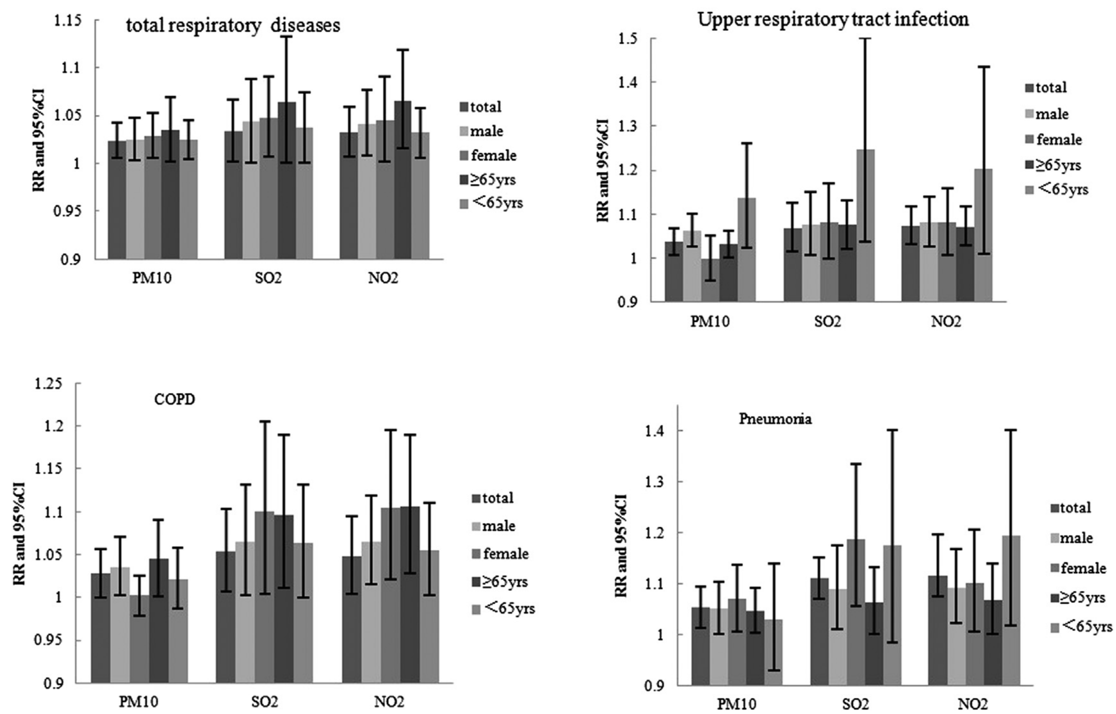

Fig. 2. RRs (95%CIs) of hospitalization in associations with an inter-quartile range increase in air pollutants in Lanzhou, 2001–2005. RRs, Relative risks are adjusted for time trend, day of the week, temperature, pressure, relative humidity, visibility and wind speed.

number of outpatient visits and the amount of hospital admissions for heart and lung disease. Previous studies have obtained similar results despite being conducted in different locations with different atmospheric pollution backgrounds different local populations (Stieb et al., 2002; Thurston, 1996; Xu et al., 1995).

Lanzhou is one of the most seriously polluted cities on the planet. This study explored the relationship between air pollutant (PM_{10}, SO_2, NO_2) exposure and hospital admissions for respiratory diseases in Lanzhou. We found that there were significant associations between air pollutants and hospital admissions, and our results are similar to those of previously reported work. The results of this study showed that total respiratory diseases hospitalizations were increased by 0.2%, 0.5% and 1.1% for 10 $\mu g/m^3$ increases in PM_{10}, SO_2 and NO_2, respectively . In other cities from China, total respiratory diseases hospitalizations were increased by 0.4–1.6%, 1.3–3.0% and 1.8–3.0% for 10 $\mu g/m^3$ increases in PM_{10}, SO_2 and NO_2, respectively (Li et al., 2009; Wang et al., 2008; Wong et al., 1999; Xie et al., 2010). In Europe and USA, a 10 $\mu g/m^3$ increased in PM_{10}, SO_2 and NO_2 resulted in 1.0–2.4%, 0.6–1.6% and 0.9–1.1% increase in total respiratory diseases hospitalizations (Atkinson et al., 1999; Leitte et al., 2009; Moolgavkar et al., 1997; Schwartz, 1995, 1996; Wordley et al., 1997). Although PM_{10} is the primary pollutant and a very serious concern (daily mean was 197 $\mu g/m^3$ during 2001–2005) in Lanzhou, its relative risks for respiratory diseases were lower than those observed in other cities from China or Europe and the United States. The local population has been exposed to high levels of air pollution for a long

Table 4
Relative risk (95%CIs) (%) of different respiratory diseases hospitalizations per IQR in air pollutants in single model in Lanzhou, China, 2001–2005.

Pollutant	Class	Total respiratory diseases	Lag	Upper respiratory tract infection	Lag	COPD	Lag	Pneumonia	Lag
PM_{10}	Total	2.4 (0.5, 4.2)	4	3.8 (0.8, 6.8)	4	2.8 (0.0, 5.6)	3	5.3 (1.3, 9.5)	5
	Male	2.5 (0.3, 4.7)	4	6.3 (2.6, 10.1)	4	3.6 (0.2, 7.1)	3	5.2 (0.2, 10.4)	5
	Female	2.9 (0.6, 5.3)	4	0.0 (−4.9, 5.2)[a]	4	4.3 (0.2, 8.5)	3	6.9 (0.5, 13.7)	5
	≥65 yrs	3.5 (0.2, 6.9)	4	3.1 (0.1, 6.3)	4	4.5 (0.1, 9.1)	3	4.6 (0.3, 9.1)	3
	<65yrs	2.5 (0.5, 4.6)	4	13.7 (2.5, 26.2)	4	2.2 (−1.3, 5.8)[a]	3	2.9 (−0.7, 13.9)[a]	5
SO_2	Total	3.4 (0.2, 6.7)	1	6.9 (1.5, 26.0)	3	5.3 (0.6, 10.3)	2	11.0 (3.5, 19.1)	2
	Male	4.4 (0.1, 8.8)	1	7.7 (0.7, 15.1)	3	6.5 (0.3, 13.2)	3	9.1 (0.0, 19.0)	3
	Female	4.8 (0.7, 9.1)	1	8.2 (0.0, 17.0)	3	10.0 (0.4, 20.6)	1	18.7 (5.6, 33.4)	2
	≥65 yrs	6.4 (0.0, 13.2)	1	7.5 (2.1, 13.1)	3	9.6 (1.0, 18.9)	3	9.0 (1.1, 17.6)	3
	<65yrs	3.7 (0.1, 7.4)	3	24.8 (3.9, 49.9)	3	6.4 (0.0, 13.2)	1	17.4 (−1.7, 40.2)[a]	3
NO_2	Total	3.3 (0.7, 5.9)	1	7.4 (3.2, 11.9)	4	4.8 (0.3, 9.5)	3	11.6 (5.2, 18.3)	2
	Male	4.2 (0.8, 7.6)	1	8.1 (2.6, 13.9)	4	6.5 (1.5, 11.8)	4	9.2 (2.2, 16.7)	2
	Female	4.6 (0.2, 9.1)	4	8.1 (0.8, 15.8)	3	10.5 (2.2, 19.5)	2	10.1 (0.6, 20.5)	2
	≥65 yrs	6.6 (1.6, 11.9)	1	20.3 (0.9, 43.5)	4	10.6 (2.9, 19.0)	3	6.8 (0.2, 13.8)	2
	<65yrs	3.2 (0.6, 5.8)	4	7.2 (2.9, 11.6)	4	5.5 (0.3, 11.0)	4	19.4 (1.8, 40.1)	3

Relative risk is adjusted for temperature, pressure, visibility, wind speed, relative humidity, day of the week and time trend; CI, confidence interval; Relative risk is expressed per IQR(PM_{10}, SO_2, NO_2) change; lag, lag time.
[a] $P > 0.05$.

Table 5
Relative risk (95%CIs) (%) of different respiratory diseases hospitalizations per IQR in air pollutants in multi-pollutant models in Lanzhou, China, 2001–2005.

Disease	Class	PM_{10}	Lag	SO_2	Lag	NO_2	Lag
Total respiratory diseases	Total	2.6 (0.8, 4.5)[a]	4	1.2 (−3.0, 5.7)	1	2.6 (−0.8, 6.3)	1
	Male	3.1 (0.7, 5.5)[a]	4	0.8 (−4.6, 6.6)	1	4.6 (0.0, 9.4)[a]	1
	Female	0.5 (−2.8, 3.9)	4	3.3 (−2.2, 9.1)	1	5.0 (0.2, 10.0)[a]	4
	≥65 yrs	3.9 (0.6, 7.3)[a]	4	1.0 (−6.9, 9.4)	1	6.9 (0.2, 14.1)[a]	1
	<65yrs	1.4 (−0.8, 3.6)	4	3.1 (−0.4, 6.8)	3	2.8 (0.0, 5.6)[a]	4
Upper respiratory tract infection	Total	4.0 (0.5, 7.5)[a]	4	7.0 (1.5, 12.7)[a]	3	6.3 (1.9, 10.8)[a]	4
	Male	5.8 (1.4, 10.4)[a]	4	7.6 (0.6, 15.0)[a]	3	6.9 (1.3, 12.9)[a]	4
	Female	−0.4 (−6.6, 6.2)	4	8.4 (0.2, 17.3)[a]	3	8.4 (0.0, 17.6)[a]	3
	≥65 yrs	3.5 (0.1, 7.1)[a]	4	13.3 (8.4, 18.3)[a]	3	12.6 (8.1, 17.2)[a]	4
	<65yrs	14.7 (2.0, 28.9)[a]	4	25.6 (4.4, 51.1)[a]	3	11.0 (−7.8, 33.5)	4
COPD	Total	2.9 (0.0, 5.9)[a]	3	1.9 (−3.9, 8.0)	2	−0.1 (−4.8, 4.1)	3
	Male	3.7 (0.0, 7.6)[a]	3	4.1 (−2.5, 11.2)	3	5.4 (−0.5, 11.7)	4
	Female	4.2 (0.0, 8.6)[a]	3	5.5 (−4.1, 15.9)	1	10.9 (2.5, 20.0)[a]	2
	≥65 yrs	1.2 (−3.7, 6.3)	3	7.8 (−0.9, 17.3)	3	9.9 (1.8, 18.6)[a]	3
	<65yrs	3.3 (−0.6, 7.3)	3	6.1 (−4.5, 17.8)	1	5.5 (−3.5, 15.4)	4
Pneumonia	Total	5.8 (1.7, 10.0)[a]	5	1.5 (−8.0, 11.8)	2	11.7 (2.9, 21.3)[a]	2
	Male	6.0 (0.8, 11.4)[a]	5	9.6 (0.4, 19.6)[a]	3	11.6 (3.6, 20.2)[a]	2
	Female	7.3 (0.8, 14.2)[a]	5	15.4 (−1.1, 34.8)	2	3.6 (−8.3, 17.0)	2
	≥65 yrs	8.3 (0.3, 16.9)[a]	3	5.7 (−0.9, 12.8)	3	8.3 (0.3, 16.9)[a]	2
	<65yrs	18.9 (−0.6, 42.2)	5	2.1 (−12.6, 19.2)	3	4.1 (−0.4, 8.8)	3

Relative risk is adjusted for temperature, pressure, visibility, wind speed, relative humidity, day of the week and time trend; CI, confidence interval; Relative risk is expressed per IQR(PM_{10}, SO_2, NO_2) change; lag, lag time.
[a] $P < 0.05$.

time, possibly reducing its susceptibility to pollution, and a particle source analysis of Lanzhou demonstrated that its air particles arise primarily from ground dust (Wei et al., 2001; Wu and Hu, 2001), which is composed mainly of inorganic minerals with less toxicity. PM_{10} particles in developed countries and regions arise primarily from motor vehicle emissions with significant amounts of secondary aerosol, which are of higher toxicity (Sun et al., 2010).

The relative risks of exposure to all of the pollutants for males are smaller than those for females for all respiratory diseases, with the exceptions of PM_{10} and NO_2 exposure and upper respiratory tract infection. The relative risks of aged <65yrs are smaller than those for patients aged ≥65 yrs for both total respiratory disease and COPD, and the relative risks of aged <65yrs are larger than those for patients aged ≥65 yrs for both upper respiratory tract infection and pneumonia, with the exceptions of NO_2 exposure for upper respiratory tract infection and PM_{10} exposure for pneumonia. This agrees with the results from previous studies that suggested that females and the aged people were more vulnerable to outdoor air pollution (Kan et al., 2008; Prescott et al., 1998; Spix et al., 1998). They were usually susceptible to air pollution as the high-risk group compared with male and younger people.

5. Conclusions

Associations between air pollutants and respiratory hospitalizations do exist with a lag effect in Lanzhou, which is one of the most seriously air-polluted cities in the world. The lag was 3–5 days for PM_{10}, 1–3 days for SO_2 and 1–4 days for NO_2, and the aged and female patients are shown to be more vulnerable to air pollutants.

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