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RESEARCH ARTICLE

Short-term effects of air pollution on daily hospital admissions for cardiovascular diseases in western China

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Abstract Controlling the confounding factors on cardiovascular diseases, such as long-time trend, calendar effect, and meteorological factors, a generalized additive model (GAM) was used to investigate the short-term effects of air pollutants (PM_{10}, SO_2, and NO_2) on daily cardiovascular admissions from March 1st to May 31st during 2007 to 2011 in Lanzhou, a heavily polluted city in western China. The influences of air pollutants were examined with different lag structures, and the potential effect modification by dust storm in spring was also investigated. Significant associations were found between air pollutants and hospital admissions for cardiovascular diseases both on dust event days and non-dust event days in spring. Air pollutants had lag effects on different age and gender groups. Relative risks (RRs) and their 95% confidence intervals (CIs) associated with a 10 μg/m^3 increase were 1.14 (1.04~1.26) on lag1 for PM_{10}, 1.31 (1.21~1.51) on lag01 for SO_2, and 1.96 (1.49~2.57) on lag02 for NO_2 on dust days. Stronger effects of air pollutants were observed for females and the elderly (≥60 years). Our analysis concluded that the effects of air pollutants on cardiovascular admissions on dust days were significantly stronger than non-dust days. The current study strengthens the evidence of effects of air pollution on health and dust-exacerbated cardiovascular admissions in Lanzhou.

Keywords Air pollution · Hospital admissions · Cardiovascular diseases · Time-series · Dust storm

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Introduction

Ambient air pollution has been found to be associated with a large scope of adverse health effects, including morbidity and mortality of cardiovascular diseases (CVDs) (Brook et al. 2010; Rückerl et al. 2006), hospital admissions for CVDs (Zheng et al. 2013; Dominici et al. 2006), and short-effect of particulate matter (PM) on emergency room visits (Franck et al. 2011; Wang et al. 2013). According to the World Health Organization (WHO), approximately 17.5 million people died from cardiovascular diseases in 2012, accounting for 31% of all global deaths (WHO, 2016). In China, cardiovascular disease has been a major public health problem in adults (≥40) and older, representing nearly 43% of the total mortality (He et al. 2005).

A number of epidemiological studies have reported associations between air pollution and cardiovascular admissions in Europe (Barnett et al. 2006; Larrieu et al. 2007; Fung et al. 2005), the USA (Dominici et al. 2005), and Asia (Ueda et al. 2012). In mainland China, the short-term effects of air pollutants on cardiovascular diseases and mortality have been studied in Beijing (Su et al. 2016; Zhang et al. 2015; Guo et al. 2009), Shanghai (Chen et al. 2010; Kan et al. 2008), and Guangzhou (Yu et al. 2011). A particular feature in the study area is frequent dust storm intrusions from upwind regions in spring time (March to May). There is an increasing evidence of cardiovascular problems associated with dust events. A study in Cyprus in the Eastern Mediterranean reported a higher cardiovascular morbidity on dust storm days than non-storm days (Middleton et al. 2008). Significant increases of cardiovascular mortality associated with $PM_{10-2.5}$ were reported in Spain and Italy (Perez et al. 2012; Alessandrini et al. 2013). Similar findings were reported for cardiopulmonary effects of desert dust at great distances in Taiwan (Chan et al. 2007; Chen and Yang 2005). A study in Minqin, China, found an association between dust events and hypertension in males (Meng et al. 2007). Ueda et al. (2012), working in Nagasaki, Japan, found that heavy Asian dust events associated with 20.8% increase of emergency ambulance dispatches for CVDs. Despite of the above studies, the correlation between air pollution and cardiovascular diseases is still not very clear due to the complexity of the time-series modeling (Barnett et al. 2006).

In the present study, we investigated the short-term health effects of daily levels of PM_{10}, as well as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) on daily cardiovascular admissions in spring in Lanzhou. We performed the study on the daily cardiovascular admissions of three top-level hospitals and concentrations of PM_{10}, SO_2, and NO_2 from four air quality monitoring stations from 2007 to 2011. Moreover, we investigated the associations in different gender and age groups.

Materials and methods

Material sources

Hospital admissions

This study was carried out in Lanzhou, a well-polluted city in western China. Daily data of hospital admissions for cardiovascular diseases were obtained from March 1 to May 31, during 2007 to 2011 from three large general hospitals in Lanzhou. We choose these hospitals because they are comprehensive hospitals and have good reputations for the diagnosis and treatment of cardiovascular diseases. Over 85% of local residents will choose these hospitals for treatment. The other two hospital excluded from our study are specialized in Traditional Chinese Medicine and orthopedic diseases. The records provide information of date of hospital admissions, age, sex, residential address, and diagnostic codes. The records were coded using the International Classification of Diseases, Tenth Revision (ICD-10). The hospital admission data were divided into following disease categories: the total (ICD: A00-R99) and cardiovascular diseases (ICD 10:I00-I99).

Air pollution data

The pollutants considered were PM_{10}, SO_2, and NO_2 from March 1 to May 31, during 2007 to 2011, collected from the Environmental Monitoring Station of Lanzhou (Fig. 1). Daily mean pollutant levels were collected from four air pollution monitoring stations in Lanzhou.

Meteorological data

Meteorological data from 2007 to 2011 were collected from the Gansu Meteorological Bureau, including meteorological factors, such as daily average temperature, as well as relative humidity, wind speed, visibility, and thermal inversion.

Statistical methods

The descriptive statistics were examined for cardiovascular admissions, air pollutants, and meteorological factors. A generalized additive Poisson regression model was set up to explore the short-term effects of daily air pollutant level on cardiovascular admissions. In general, dust events are defined in terms of dust intensity and visibility, including dust storms, blowing dust, and floating dust. Dust storms reduce the horizontal visibility to less than 1000 m, blowing dust reduces the horizontal visibility to 1000–10,000 m, and floating dust reduces the horizontal visibility to less than 10,000 m (Wang et al. 2005). If there is a dust event in spring in Lanzhou, it is defined as a dust day.

A generalized additive model (GAM) was applied to establish a basic model to explore the associations between predictor variable (cardiovascular admissions) and response variables (air pollutants). Adjustments were made for possible confounding effects, including long-term trend effect, day of the week (DOW), holiday effect, and weather effects (temperature and relative humidity) (Cao et al. 2009). The degrees of freedom were selected according to the partial autocorrelation function (PACF), and the selection was guided by the

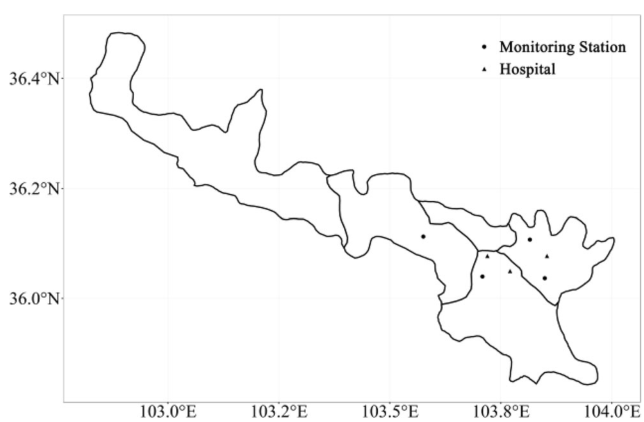

Fig. 1 The locations of air pollutants monitoring stations and hospitals

minimization of the absolute values of the sum of PACF for lags up to 30. The final model was fitted according to the Akaike's Information Criterion (AIC) (Guo et al. 2011). DOW and holiday were adjusted as dummy variables in the basic model. Delayed effects of air pollutants (PM_{10}, SO_2, and NO_2) were performed with different lag days, including single-day lags (from L0 to L7) and cumulative-day lags (from L01 to L07). Single-day lags mean the concentration of air pollutants of the current day (L0) and the previous days (from L1 to L7). Cumulative-day lags were average values of the same day and the previous day's concentrations. The degrees of freedom (df) for time trends were defined for single-day lags ($df = 9$) and cumulative-day lags ($df = 6$) on dust days, and on non-dust days, they were defined for both single-day lags and cumulative-day lags ($df = 8$). The model is described below:

$$\log[E(Yt)] = \alpha + s(\text{time}, df) + DOW + \text{Holiday} + s(\text{temperature}, df) + s(\text{humidity}, df) + \beta Zt \quad (1)$$

In this formula, t refers to the day of the observation: $E(Yt)$ denotes estimated daily hospital admissions counted on day t; α is the intercept; *s()* denotes a regression spline function for nonlinear variables; *time* is the days of calendar time on day t; *df* is the degree of freedom; *DOW* is the day of the week on day t. β represents the log-relative rate of cardiovascular admissions associated with a unit increase of air pollutants; Zt represents major air pollutants concentrations on day t.

We also constructed single-pollutant and multi-pollutant models combining different air pollutants to evaluate the multiple air pollutants effects on cardiovascular admissions. All results were presented as relative risks (RRs) of cardiovascular admissions and their 95% confidence intervals (95% CIs). RR was calculated for a 10 μg/m^3 increase in each air pollutant's concentration. In addition, we also estimated the adverse effects of air pollutants on age (0~45 years, 45~60 years, ≥60 years) and sex (female and male). All analyses were performed using MGCV package in the R software (R 3.1.3).

Results

Descriptive statistical analysis

A total of 11,187 cardiovascular admissions were recorded in spring (460 days) from March 1 to May 31, during 2007 to 2011, accounting for 26.74% of the total admissions. The average cardiovascular admissions per day were approximately 24. The ratio of male and female is 1:1.214. The mean daily levels of air pollutants were 159.2, 45.0, and 42.7 μg/m^3 respectively for PM_{10}, SO_2, and NO_2. The PM_{10} and NO_2 concentrations exceeded the annual mean of National Grade II standard level (PM_{10}: 70 μg/m^3; NO_2: 40 μg/m^3) (Table 1), and SO_2 concentration exceeded the 24-h mean of the WHO air quality guidelines (SO_2: 20 μg/m^3). Mean daily wind speed and thermal inversion are 1.49 m/s and 3373.9 m, respectively, indicating that the atmospheric diffusion conditions in Lanzhou are very poor.

According to Table 2, pollutants' concentrations on dust days are much higher than non-dust days. Compared with pollutants' concentrations on non-dust days, concentrations on dust days were 2.22 times higher for PM_{10}, 1.26 times higher for SO_2, and 1.12 times higher for NO_2.

Table 3 presents the RRs and 95% CIs for cardiovascular admissions at 10 μg/m^3 increments of air pollutants at different lag structures, including single-day lags and cumulative-day lags. In single-day lags, exposure to PM_{10}, SO_2, and NO_2 showed the strongest effects at lag 1 during non-dust days, and the strongest effects for PM_{10} occurred at lag 1, SO_2 at lag 0, and NO_2 at lag 1 respectively during dust days. In cumulative-day lags, exposure to PM_{10}, SO_2, and NO_2 during non-dust days showed the strongest effects at lag 01, lag 03, and lag 02 respectively, while for dust days, they were found at lag 01, lag 01, and lag 02, respectively. The effects of air pollutants on dust days were greater than non-dust days. RR (95% CIs) of admissions for cardiovascular diseases with per 10 μg/m^3 increase in 1 day of PM_{10} (L1), and 1-day average of SO_2 (L01) and 1-day average of NO_2 (L01) were 1.14(1.04~1.26), 1.31(1.21~1.51) , and 1.96(1.45~2.57), respectively, on dust days.

Figure 2 presents the exposure-response relationships between air pollutants and cardiovascular admissions in the single models in spring. The exposure-response curves associated with PM_{10} both during dust and non-dust events and SO_2 during non-dust days showed similar positive linear relationships. Cardiovascular admissions increased obviously with the increments of air pollutant level especially during dust events. Other J-shaped curves tended to become nonlinear and slightly flat at higher pollutants concentrations.

The effects of air pollutants on gender and age groups for cardiovascular diseases were shown in Fig. 3. Three pollutants had certain effects on different groups of cardiovascular admissions, with evident lag effects both on dust and non-dust days. On non-dust days, the effects of PM_{10} and SO_2 were found stronger in adults (45–60) at lag 1 and lag 3, and in females at lag 1 and lag 2 respectively, while the greatest effect of NO_2 was found in the adults (16–45) at lag 1 and in females at lag 2. On dust days, the greatest influences of PM_{10}, SO_2, and NO_2 were pronounced for the elderly (≥60) at lag 1, lag 0, and lag 1, respectively and those in females at lag 1, lag 0 and lag 0. The RRs (95% CIs) values with a 10 μg/m^3 increase in concentrations of PM_{10}, SO_2, and NO_2 were 1.21 (1.06, 1.38), 1.44 (1.16, 1.78), and 1.83 (1.37, 2.44) on dust days and 1.04 (1.01, 1.07), 1.07 (1.01, 1.13), and 1.09 (1.03, 1.16) on non-

Table 1 Descriptive statistics on air pollution levels, meteorological factors, and cardiovascular admissions in Lanzhou from March 1st to May 31st during 2007 to 2011

Daily data	Mean	SD	Min	P25	Median	P75	Max	IQR
Air pollutants concentrations								
PM_{10} (μg/m^3)	159.2	103.0	52.0	94.0	134.0	183.0	600.0	89.0
SO_2 (μg/m^3)	45.0	22.0	10.0	30.0	40.0	60.0	140.0	30.0
NO_2 (μg/m^3)	42.7	22.0	10.0	30.0	50.0	50.0	140.0	20.0
Meteorological factors								
Temperature (°C)	12.9	6.2	−5.1	8.3	13.6	17.9	24.8	12.9
Relative humidity (%)	26.8	14.8	4.0	15.3	23.0	33.0	87.0	26.8
Wind speed (m/s)	1.49	0.36	0.50	1.25	1.50	1.75	2.60	0.50
Thermal inversion (m)	3373.9	2808.7	1860.6	1954.5	1969.9	3579.7	16,243.1	1625.2
Cardiovascular admissions								
Total	91.1	42.4	14.0	57.0	90.0	121.0	223.0	64.0
Cardiovascular	24.3	19.2	2.0	9.0	17.0	40.0	81.0	31.0
Female	13.3	11.0	1.0	5.0	10.0	22.0	50.0	17.0
Male	11.0	8.9	1.0	4.0	8.0	17.0	40.0	13.0

SD standard deviation, *Min* minimum, *P25* 25th percentile, *P75* 75th percentile, *Max* maximum, *IQR* inter quartile range

dust days, respectively. The influences of air pollutants in females were greater than in males, and those were greater in the elders than in the younger. Further, the effects of air pollutants on dust days were significantly stronger than non-dust days.

Table 4 presents the regression results of single-pollutant and multi-pollutant models. Air pollutants (PM_{10}, SO_2, and NO_2) were introduced into the multiple-pollutant models. The increased effect estimates of PM_{10} and SO_2 stayed significant before and after adjustment for other air pollutants except SO_2 on non-dust days. The effect of NO_2 was decreased but stayed significant after adjustment for other pollutants on both dust and non-dust days. The effects of both PM_{10} and NO_2 on dust days were significantly higher than non-dust days, while the effect of SO_2 was smaller on dust days. On dust days, a 10 μg/m^3 increment in concentrations of PM_{10} and NO_2 of cardiovascular admissions in multiple-pollutant models corresponded to RRs (95% CIs) of 1.009 (0.930~1.093) and 1.323 (1.153~1.518), respectively.

Table 2 Comparison of daily air pollutant levels between dust days and non-dust days in Lanzhou from March 1st to May 31st during 2007 to 2011

2007–2011 (March to May)	Dust days	Non-dust days
Days	32	428
PM_{10} (μg/m^3)	324.0 ± 178.0	146.0 ± 83.0
SO_2 (μg/m^3)	54.0 ± 22.0	43.0 ± 22.0
NO_2 (μg/m^3)	46.0 ± 16.0	41.0 ± 22.0

Discussion

Our results showed significant positive relationship between air pollutants (PM_{10}, SO_2, and NO_2) and daily hospital admissions for cardiovascular diseases in Lanzhou from March 1st to May 31st during 2007 to 2011. The higher effects of air pollutants on cardiovascular admissions were observed on dust days. Hospital admissions for cardiovascular diseases increased by 1.36, 10.42, and 20.03% respectively on dust days with a daily increase of 10 μg/m^3 in PM_{10}, SO_2, and NO_2. On non-dust days, per 10 μg/m^3 increment in PM_{10}, SO_2, and NO_2 increased cardiovascular admissions by 0.26, 1.50, and 2.83%, respectively. During 2001–2005, hospital admissions for cardiac diseases increased by 1.66, 2.34, and 3.47%, and admissions for cerebrovascular diseases increased by −1.50, 4.26, and 4.06% for an IQR increase in PM_{10}, SO_2, and NO_2, respectively (Zheng et al. 2013). This proved the fact that dust events exacerbated cardiovascular diseases increase.

Previous studies have produced varied results of adverse effects of dust on health. A study in Spain reported that during Sahara dust days, per 10 μg/m^3 increase in $PM_{10-2.5}$ resulted daily mortality increased by 8.4% compared to the increment of 1.4% during non-Sahara dust days (Perez et al. 2008). A 10 μg/m^3 increase in PM_{10} levels is associated with 2.43% increase in daily cardiovascular admissions on African Dust days (Neophytou et al. 2013). A study in Hong Kong reported a 2% increase in cardiovascular admissions associated with $PM_{10-2.5}$ during Asian dust days (Tam et al. 2012), and 10.4% increase in cardiovascular admissions were found in Cyprus during Sahara dust days (Middleton et al. 2008). A study in Korea suggested about 0.15% increase in total

Table 3 RRs (95% CIs) of hospital admissions for cardiovascular diseases with an increase of 10 μg/m^3 in air pollutants at single-day lags and cumulative-day lags in Lanzhou from March 1st to May 31st, 2007–2011

Lag structures	Non-dust days RR (95%CI)	Dust days RR (95%CI)
PM_{10}	Single-day lag	
0	0.99 (0.96, 1.01)	0.74 (0.62, 0.89)**
1	1.02 (1.00, 1.04)*	1.14 (1.04, 1.26)**
2	0.99 (0.97, 1.01)	0.92 (0.83, 1.02)
3	0.98 (0.96, 0.99)**	0.86 (0.74, 1.00)*
4	0.99 (0.98, 1.01)	0.99 (0.87, 1.12)
5	0.98 (0.97, 1.00)	0.89 (0.83, 0.96)**
6	0.97 (0.96, 0.99)**	0.87 (0.79, 0.96)**
7	0.96 (0.95, 0.98)**	0.86 (0.79, 0.94)**
Cumulative-day lag		
01	1.01 (0.99, 1.03)	1.02 (0.83, 1.26)
02	1.00 (0.98, 1.03)	0.96 (0.80, 1.15)
03	0.98 (0.96, 1.01)	0.93 (0.80, 1.08)
04	0.98 (0.96, 1.01)	0.92 (0.77, 1.10)
05	0.98 (0.95, 1.00)*	0.87 (0.73, 1.04)
06	0.97 (0.94, 0.99)**	0.76 (0.61, 0.96)*
07	0.96 (0.93, 0.98)**	0.77 (0.65, 0.93)**
SO_2	Single-day lag	
0	1.03 (0.96, 1.07)	1.15 (1.03, 1.29)**
1	1.05 (1.01, 1.09)**	1.13 (1.03, 1.25)**
2	1.04 (1.01, 1.08)*	0.92 (0.74, 1.57)
3	1.03 (0.99, 1.06)	0.94 (0.79, 1.14)
4	1.02 (0.98, 1.05)	0.70 (0.60, 0.82)**
5	1.02 (0.98, 1.05)	0.96 (0.84, 1.09)
6	0.98 (0.95, 1.01)	1.02 (0.88, 1.20)
7	0.97 (0.94, 1.00)*	0.99 (0.91, 1.07)
Cumulative-day lag		
01	1.04 (1.01, 1.08)*	1.31 (1.12, 1.53)**
02	1.04 (1.01, 1.08)**	1.20 (1.02, 1.41)*
03	1.05 (1.01, 1.09)**	1.17 (0.95, 1.45)
04	1.04 (1.01, 1.08)*	1.01 (0.83, 1.24)
05	1.05 (1.01, 1.09)*	0.98 (0.81, 1.19)
06	1.04 (1.00, 1.08)	0.99 (0.81, 1.20)
07	1.03 (0.99, 1.07)	0.98 (0.78, 1.22)
NO_2	Single-day lag	
0	1.06 (1.02, 1.05)**	1.40 (1.23, 1.60)**
1	1.06 (1.04, 1.09)**	1.57 (1.24, 1.98)**
2	1.06 (1.04, 1.08)**	1.32 (0.92, 1.90)
3	1.02 (1.00, 1.04)	1.25 (1.01, 1.48)**
4	1.02 (0.99, 1.04)	0.82 (0.64, 1.05)
5	1.03 (1.01, 1.06)**	1.20 (1.04, 1.38)**
6	1.00 (0.98, 1.03)	1.31 (1.12, 1.54)**
7	1.00 (0.98, 1.02)	0.99 (0.81, 1.22)
Cumulative-day lag		
01	1.10 (1.06, 1.34)**	1.84 (1.54, 2.21)**
02	1.11 (1.07, 1.14)**	1.96 (1.49, 2.57)**
03	1.08 (1.05, 1.11)**	1.53 (1.29, 1.92)**
04	1.07 (1.04, 1.11)**	1.45 (1.23, 1.80)**
05	1.08 (1.04, 1.11)**	1.64 (1.31, 2.05)**
06	1.07 (1.04, 1.11)**	1.52 (1.23, 1.85)**
07	1.07 (1.03, 1.11)**	1.46 (1.20, 1.77)**

**$P < 0.01$, *$P < 0.05$

mortality associated with a 10 μg/m^3 increase in PM_{10} in 24 h (Son and Bell 2013).

The associations between air pollutants and age groups were greatly different. On non-dust days, the effects of PM_{10} and SO_2 were found to be higher in females and adults (45–60) than other groups, while the effect of NO_2 was greater in adults (16–45). On dust days, higher influences of PM_{10}, SO_2, and NO_2 were observed in the elderly and female groups than other groups. Generally, the increases in cardiovascular admissions were greater in the elderly than in the younger age group, mostly because the elderly are relatively frailer, and they probably have preexisting heart problems (Barnett et al. 2006). Elderly people are also considered to be susceptible to air pollution than other groups, because physiological processes are gradually declining over time (Sacks et al. 2011).

Higher effects of air pollution on cardiovascular admissions were also found in females than in males. An earlier study in Shanghai also reported that females were more susceptible to ambient air pollution (Kan et al. 2008). Study by Künzli et al. (2005) found that nonsmokers were more vulnerable to air pollution compared to smokers, and evidence existed that smoking rate of females were much lower than males in China (6.7 vs. 57.6%) (Yang et al. 2016). Previous studies also reported that a higher risk of females may be attributed to biological or exposure differences between females and males (Sacks et al. 2011).

On dust days, we found the strongest associations between air pollutants and cardiovascular admissions at different lag days (lag 1 for PM_{10}, lag 01 for SO_2, and lag 02 for NO_2). Study by Feng and Wang (2010) suggested that the heavy concentration of PM_{10} in Lanzhou was mostly attributed to the frequent sand dust invasion from the upstream area and amount heavy polluted gas from local industry. Results of the current study confirmed those of previous results in the European countries (Middleton et al. 2008; Neophytou et al. 2013; Perez et al. 2008; Perez et al. 2012) and Asia (Ueda

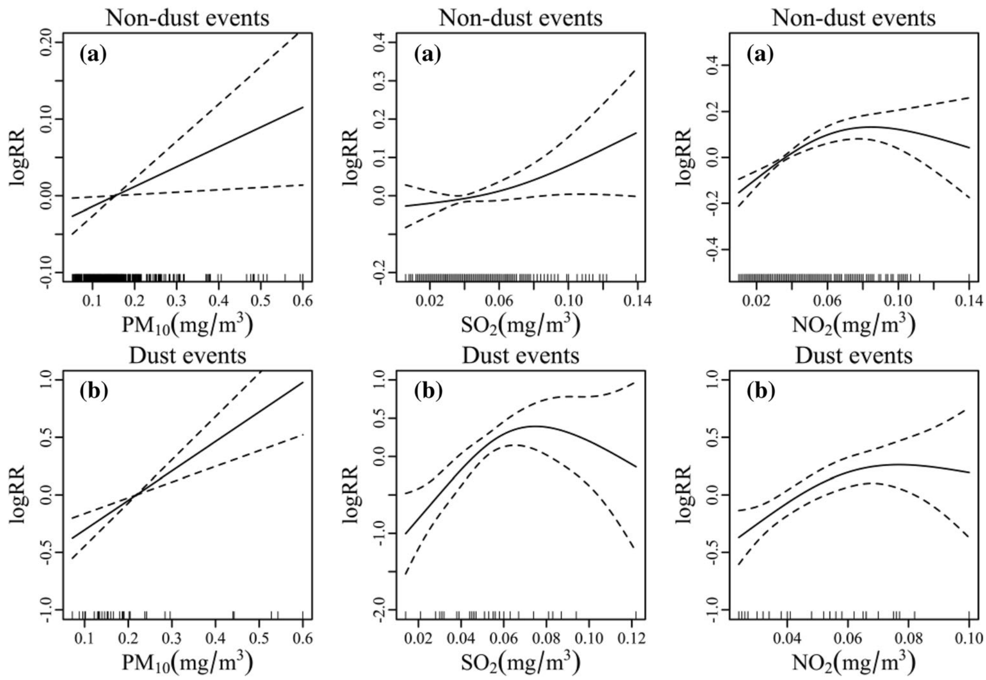

Fig. 2 Smoothing plots of air pollutant concentrations against cardiovascular admissions risk under non-dust days (**a**) and dust days (**b**) for PM_{10} (*left*), SO_2 (*center*), and NO_2 (*right*). *X*-axis is the pollutant concentration (mg/m^3). The *solid lines* indicate the log RR of cardiovascular admissions, and the *dotted lines* represent 95% confidence intervals. Single-day lags (L2 for PM_{10}, SO_2, and NO_2) were used on non-dust days. Single-day lags (L2 for PM_{10} and SO_2, L1 for NO_2) were used on dust days. All models were controlled for time trend, DOW, holiday and weather conditions

et al. 2012; Ebrahimi et al. 2014; Meng et al. 2007) on dust-exacerbated cardiovascular diseases in hospital admissions.

Our study results further suggested that increased daily cardiovascular admissions are associated with SO_2 daily level. Previous study conducted in Beijing suggested that per 10 μg/m^3 increase of SO_2 resulted in a 0.76% increase in the total hospital emergency admissions and a 1.56% in cardiovascular (Zheng et al. 2013). Other studies suggested associations between SO_2 and hypertension (Guo et al. 2010), ischemic heart disease (Chiu et al. 2013), and heart failure (Shah et al. 2013). NO_2 has been also associated with cardiovascular admissions. This finding is in agreement with previous studies (Zheng et al. 2013; Guo et al. 2009). A study reported an ER of 1.27% for NO_2 in residents of Shanghai (Kan et al. 2008). Many other studies performed in Europe (Larrieu et al. 2007; Chiusolo et al. 2011; Stafoggia et al. 2014), and Asia (Chen et al. 2010; Chen et al. 2012) also proved the short-term effect of NO_2 on increased hospital admissions and mortality.

Numerous studies have suggested the mechanisms whereby air pollution may accelerate the occurrence of cardiovascular diseases. PM inhaled and deposited in the lung could lead to an inflammatory response and then resulted in increment of blood coagulating and thrombus formation (Brook et al. 2003). Inhaled PM also incited the imbalance between sympathetic and parasympathetic autonomic nervous system (Franklin et al. 2015; Department of Health 2006). Very fine particles might enter the blood stream and penetrate directly into cardiovascular tissue (Brook 2008; Routledge et al. 2003). Previous studies also suggested that PM specific components, rather than mass may be related more with health effects, although it is still uncertain (Nagar et al. 2014; Ghio and Delvin 2001). The elements of TSPs during dust events in Lanzhou were reported including heavy metal elements such as Cd, V, Mn, Ba, Ni, Hg, Pb, As, Co, Cu, Zn, and other elements such as Ga, Sc, Ti, K, F, S, C, and O (Ta et al. 2004; Zang et al. 2017). The heavy metals can be bound to PM and adversely affect human health (Peng et al. 2017).

The greater adverse effects of air pollution in the present study are probably because of the unique topography of valley basin and the poor atmospheric diffusion conditions. The basin is narrow but long in the northwest to southeast and surrounded by mountain. The typical characteristics of the atmospheric boundary layer are high frequency of static wind and strong temperature inversion (Wang et al. 2009). Furthermore, located on the Asian dust transport path, Lanzhou is very frequently swept through by dust storms from upwind region in spring, with large quantities of incoming particles. In addition, coal fired heating is still the main heating mode in winter, and coal provides about 71% of the total energy in Lanzhou (Zhang et al. 2000). These factors

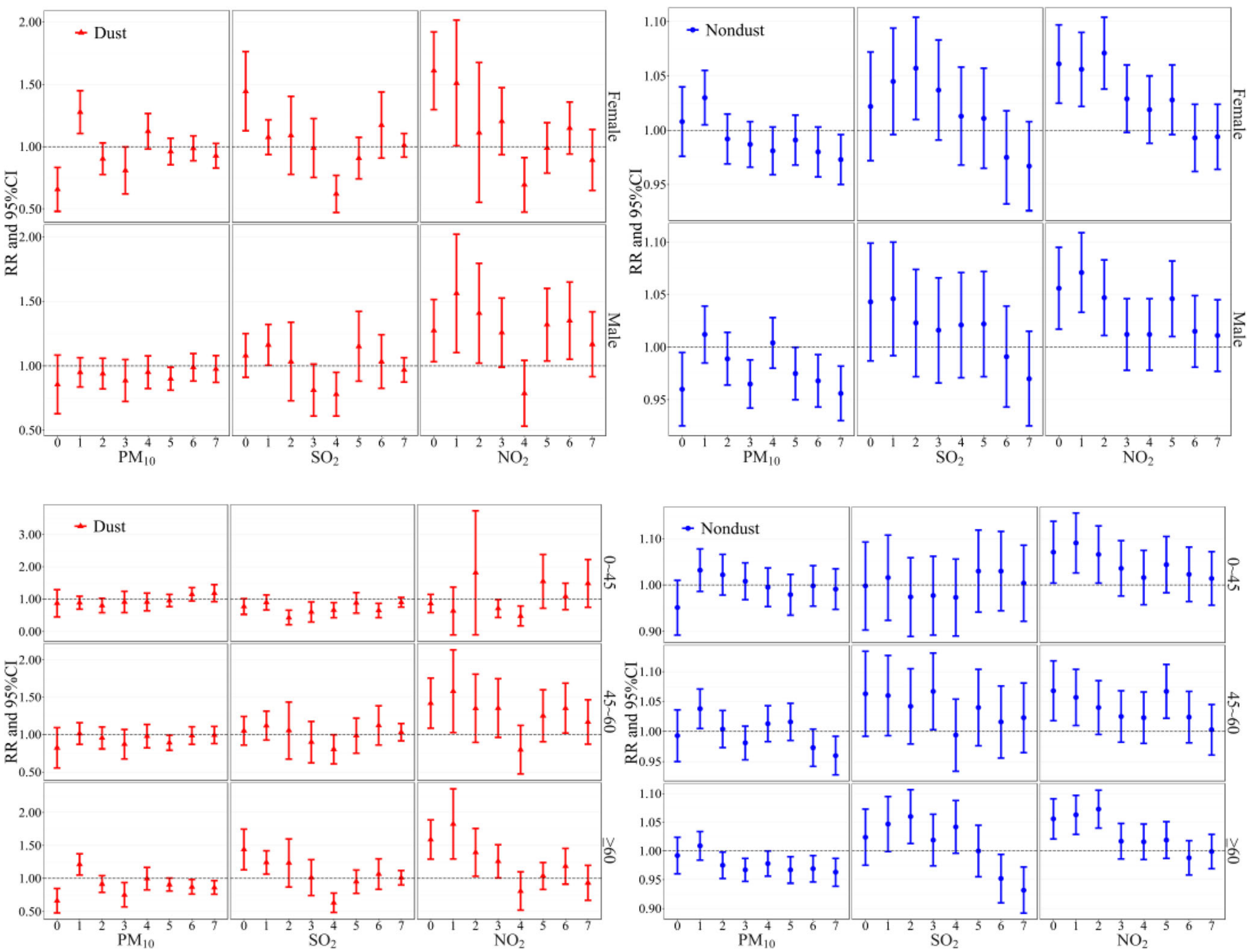

Fig. 3 RRs (95% CIs) for per 10 μg/m^3 in pollutants on different groups (*top*: sex; *below*: age) of cardiovascular admissions in Lanzhou from March 1st to May 31st during 2007 to 2011

make Lanzhou become one of the most severely polluted cities in China, even in the world.

Table 4 RRs (95% CIs) for per 10 μg/m^3 increase in pollutants on cardiovascular admissions in multiple models from March 1st to May 31st during 2007 to 2011*

Pollutants	Dust days RR (95% CI)	Non-dust days RR (95% CI)
PM_{10}	0.872 (0.793, 0.958)**	0.965 (0.947–0.982)**
$+SO_2 + NO_2$	1.009 (0.930–1.093)	0.966 (0.949–0.984)**
SO_2	0.704 (0.603, 0.821)**	1.045(1.01, 1.082)*
$+PM_{10} + NO_2$	0.711 (0.574–0.896)**	1.006 (0.968–1.044)
NO_2	1.401 (1.226, 1.600)**	1.059 (1.035–1.084)**
$+PM_{10} + SO_2$	1.323 (1.153–1.518)**	1.056 (1.030–1.083)**

*Single-day lags (L7 for PM_{10}, L1 for SO_2, and L2 NO_2) were used on non-dust days. Single-day lags (L6 for PM_{10}, L4 for SO_2, and L0 for NO_2) were used on dust days. All models were controlled for time trend, DOW, holiday, and weather conditions. **$P < 0.01$, *$P < 0.05$

In summary, our study strengthened the evidence of effects of air pollution on health and dust-exacerbated cardiovascular admissions in spring in Lanzhou, China. But some limitations in our study also should be taken into account. Hospital admissions and pollutants' data were collected only from three hospitals and four monitoring stations in Lanzhou, thus, selection bias may exist. However, these biases could not be quantified due to a lack of the personal exposure information. Further study was needed to investigate the effects of air pollution on health using entire period data, considering the effect modification by season and personal characteristics.

Conclusions

We found an evidence of an association between air pollutants levels and hospital admissions for cardiovascular diseases in Lanzhou, China. The effects of air pollutants were particularly strong on dust days. There are both gender and age differences in the effects of air pollutants on RR values of cardiovascular diseases. Results also showed delayed effects of air pollutants on different specific groups. The insights obtained in this study may help us to understand the association between ambient air pollution and cardiovascular diseases and may have implications for local environmental and social policies.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

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