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Impact of fine particulate matter 2.5 on hospitalization for upper respiratory tract infections in Lanzhou urban industrial area, China

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Abstract

Introduction and Objective. Abundant evidence has shown that an increase in the concentration of fine particulate matter 2.5 (PM2.5) leads to a simultaneous increase in the incidence of respiratory diseases. Xigu District is the main industrial district of Lanzhou, located in Lanzhou City in northwest China and central Gansu Province. Because of limited research and data in the region, the impact of PM2.5 on human health has not been systematically recognized. The aim of the study was to investigate the relationship between PM2.5 pollution and upper respiratory tract infections in urban industrial areas of Lanzhou City.

Materials and method. Data on outpatient visits, air pollutants, and meteorological indices were collected in the Xigu District of Lanzhou City from 1 January 2013 – 31 December 2019. A generalized additive model was used to evaluate the association between PM2.5 and outpatient visits for upper respiratory tract infections.

Results. The results show that PM2.5 had the greatest impact on outpatient visits for upper respiratory tract infections on 7 cumulative lag days. At cumulative lag days 1, 3, and 5, the effects gradually increased. In the subgroup analysis, the effect of PM2.5 on visits for upper respiratory tract infections was significantly influenced by gender. Men were more susceptible to PM2.5 pollution.

Conclusions. An increase in atmospheric PM2.5 concentration was associated with an increase in visits for upper respiratory tract infections with the lag effect. The obtained results can provide a reference for the development of prevention strategies to protect the population from the adverse effects of PM2.5 pollution.

Key words

PM2.5, Distributed lag non-linear model, upper respiratory infection (URI)

INTRODUCTION

With the continuous economic development in recent years, environmental pollution has become an inevitable phenomenon, and the increase in pollutant emission levels has resulted in a decline in air quality, thus affecting human health. According to the World Health Organization and the global health sector, particulate matter (PM10 and PM2.5) has a significant impact on health quality [1].

According to the China Ecological Environment Status Bulletin 2021, an air quality index greater than 100 was considered to exceed the standard; furthermore, 121 of 339 (35.7%) cities at or above the prefectural level in China did not meet the minimum standards for environmental air quality in 2021. The number of days with heavy pollution and above dominated by particulate matter 2.5 (PM2.5) and PM10 accounted for 39.7% and 34.7%, respectively, of the total. Atmospheric PM pollution is the current leading cause of smog in China. Atmospheric PM includes total suspended PM, inhalable PM, fine PM, and ultrafine PM. Among them, inhalable particulate matter (PM10) pertains to particles with aerodynamic diameters ≤ 10 μm that can enter the respiratory tract. Fine PM, also known as PM2.5, is a small particle that can easily be retained in the terminal bronchioles and alveoli and has aerodynamic diameters ≤ 2.5 μm. PM2.5 can cause damage to the human respiratory system by absorbing toxic metals, carcinogens, and pathogenic bacteria. PM deposited in the lung tissue can also cause lung injury by mediating inflammatory response and oxidative stress [2].

In recent years, the adverse effects of air pollution on human health have gained widespread attention. Previous studies have indicated that short-term exposure to ambient PM is associated with an increased incidence of upper respiratory tract infections and hospitalizations [3–7]. Epidemiological studies performed elsewhere have focused on all-cause mortality outcomes. In China, unlike in Western countries, the number of outpatient visits far exceeds the number of inpatients, which is more appropriate for indicating the acute health effects of PM pollution [8]. Therefore, it appears that morbidity may be a more appropriate index for the quantifying the impact of PM pollution on health rather than mortality. At present, studies on the effect of PM2.5 concentration on upper respiratory tract infections in China are mainly concentrated in Hefei, Tianshui, Wuhan, Beijing, Chongqing, and Lanzhou [3, 6, 9–12]. However, the composition of atmospheric PM varies from region to

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region and so does its health impact. Few previous studies have utilized outpatient data to evaluate the effects of PM2.5 on patients with upper respiratory tract infections, stratified by gender and age.

As the core industrial zone of Gansu Province and Lanzhou City and the largest petrochemical base in Western China, Xigu District is known as the 'cradle of the petrochemical industry'. Highly polluting industries, such as petroleum, metallurgy, and steel industries, are all distributed in urban areas, with heavy industrial structure, high energy consumption, long winter heating period, and coal burning as the main heating method, resulting in increased pollutant emissions during the heating period. In addition, Xigu District is located on the Loess Plateau where severe weather phenomena, such as sand and dust storms in winter and spring, occur frequently. The unique basin topography and special meteorological conditions make it difficult for pollutants to spread. In addition, the Tengger Desert, one of the three major sand sources in China, is only 200 km away from Lanzhou, and the Badan Jilin Desert is 500 km northwest of Lanzhou. These have a serious impact on the health of local residents [13]. Studies have indicated that the main sources of PM2.5 in Lanzhou are automobile exhaust, coal combustion, secondary inorganic salts, dust, and biomass combustion [14]. Industrial pollution sources in urban areas have large emissions but are affected by complex basin topography and adverse atmospheric boundary layer, which reduce the spread of pollutants and the formation of severe pollution weather. In addition, in spring, due to the influence of dust storms in the Hexi area, there is more dusty weather, which is easy to cause respiratory diseases.

The study mainly focuses on the effect of PM2.5 on upper respiratory tract infections. From 2013 – 2019, the average annual concentration of PM2.5 in Lanzhou exceeded the first level of China's ambient air quality standard (35 μg/m^3). PM2.5 concentration was maintained at 50–70 μg/m^3, which is 1.5 times higher than the national primary standard. With the increasing severity of air pollution and concerns about its impact on health, an increasing number of studies on atmospheric PM pollutants in Lanzhou City have been conducted [15, 16]. To the best of the authors' knowledge, no study has specifically evaluated the effect of PM2.5 concentration on upper respiratory tract infections in the Lanzhou urban industrial area.

This aim of this study was to investigate the relationship between PM2.5 pollution and outpatient visits for upper respiratory tract infections in Lanzhou urban industrial area, clarify the adverse effects of upper respiratory tract infections caused by PM pollution in Xigu District, and provide a basis for the development of prevention strategies.

MATERIALS AND METHOD

Study area. Xigu District (103°37′40.70″E, 36°05′18.43″N) is located at the west gate of Lanzhou, on the upper reaches of the Yellow River and on the east side of the Qinghai–Tibet Plateau. Its average altitude is 1,560 m. By the end of 2020, the permanent population of the district was 407,000 with a built-up area of 36 km². It has a typical temperate continental monsoon climate. Winter and spring are windy, sandy, and cold, with frequent cold air activity. The transition to summer and autumn is marked by rain, abundant sunshine, and high evaporation. Its average annual temperature is 8.5 °C–8.9 °C, and its temperature difference is large. The average annual precipitation is 324.8 mm, and its distribution of precipitation seasons is uneven, mainly concentrated from June to September. Average annual evaporation is 1,468 mm; average annual sunshine duration – 2,374 h. In winter, the wind speed is low, the frequency of calm wind is high, average wind speed is 1.0 m/s, and an easterly wind prevails throughout the year.

Data sources. The data of daily outpatient visits for upper respiratory tract infections in Xigu District from 1 January 2013 – 31 December 2019 were from the local People's Hospital of Xigu District. The information included the patient's home address, gender, age, date of outpatient visit, disease diagnosis, and visit ID. Non-local patients were excluded on the basis of their home addresses. Disease diagnoses were coded according to the International Classification of Diseases, 10th Edition (ICD-10) codes (J00-J99; upper respiratory tract infections; ICD-10: J00-J06 and J30-J39). Data on atmospheric pollutants released were from the national urban air quality real-time platform (http://106.37.208.233:20035/), and data on daily PM2.5 monitoring were chosen. Data integrity and consistency were in line with the requirements of the National Ambient Air Quality Monitoring code, without abnormally high or low values and missing values, but with high accuracy. Meteorological data were obtained from the Gansu Meteorological Bureau, including the mean temperature, wind speed, and relative humidity.

Statistical analysis. The proportion of daily outpatient visits for upper respiratory tract infections in the total population is small and roughly follows a Poisson distribution; therefore, the short-term effect of atmospheric PM2.5 on daily outpatient visits for upper respiratory tract infections was analyzed using a parametric generalized additive model (GAM), based on Poisson regression. The basic model formula is as follows:

$$\mathrm{Log}[E(Y_t)] = \alpha + \beta Z_t + ns(wind, df=3) + ns(RH_t, df=3) + ns(dear, df=7) + DOW + Holiday \quad (*)$$

where $E(Y_t)$ represents the expected outpatient visit on day t, α – the intercept, β – regression coefficient, Z_t – PM2.5 pollutant concentration on day t, ns – natural cubic spline, *wind* – wind speed, RH_t – average relative humidity on day t, *DOW* – the day of the week effect, and *Holiday* – the holiday effect. Both *DOW* and *Holiday* are used as dummy variables.

RESULTS

Descriptive statistics. Table 1 presents a statistical summary of fine PM concentrations and meteorological conditions during the study period. The average daily concentration of PM2.5 was 51.80 μg/m³; average daily temperature – 11.39 °C; relative humidity – 50.63%, and wind speed – 1.24 km/h.

Table 1 presents the descriptive statistics of daily upper respiratory tract infection inpatients in Xigu District, Lanzhou City, China, from 1 January 2013 – 31 December 2019. Among the 60,986 hospitalized patients with upper respiratory tract infections, 53.7% (n = 32,750) were male, and 54.04% (n = 32,960) were younger than 65 years.

Table 1. Descriptive statistics of PM2.5 pollution level, meteorological variables and the number of hospitalized patients with upper respiratory tract infection in Lanzhou industrial area, 2013–2019

Variable	Mean ±Standard Deviation	Mini-mum	Maxi-mum	Percentile		
				25%	50%	75%
Temperature (°C)	11.39 ± 9.85	−12.30	30.40	2.33	12.89	19.89
Relative Humidity	50.63 ± 15.31	11.71	96.09	39.19	51	61.62
Wind speed	1.24 ± 0.39	0.00	3.13	1	1.16	1.45
PM2.5 (μg/m^3)	51.80 ± 30.06	0.00	278	32	44	63.43
Category	Numbers	Percentages				
Gender						
Male	32,750	53.70084938				
Female	13,871	22.74456433				
Age						
<65 years	32,960	54.0451907				
≥65 years	28,008	45.92529433				
Total	60,986	100				

The estimated Spearman's correlation coefficients between air pollutants and meteorological factors are presented in Table 2. There is a significant positive correlation between PM and NO_2 and SO_2. PM2.5, PM10, NO_2, SO_2, and CO were negatively correlated with daily average temperature and average relative humidity ($p < 0.05$). There is a strong correlation between air pollutants and meteorological factors.

Table 2. Spearman's correlation coefficients between daily air pollutants and weather conditions in Xigu, 2013–2019

Pollutants	NO_2	PM10	PM2.5	CO	tem	RH
SO_2	0.400**	0.578**	0.667**	0.686**	−0.607**	−0.239**
NO_2		0.354**	0.356**	0.608**	−0.250**	−0.107**
PM10			0.849**	0.457**	−0.327**	−0.381**
PM2.5				0.589**	−0.463**	−0.139**
CO					−0.514**	0.031
tem						−0.024

**p < 0.01

After confounding factors were accounted for, GAM analysis was used to evaluate the effect of daily mean PM2.5 concentration on daily outpatient visits for upper respiratory tract infections in each group on the same day and different lagged days. The cumulative lag effect of PM2.5 is statistically significant in the whole cumulative lag period (lags 01–07).

Time-series analysis. The Ambient Air Quality Standards (Ministry of Ecology and Environment of the People's Republic of China 2012) of China specify the annual average concentration limits for various pollutants. The limit for PM2.5 is 35 μg/m^3. According to the comparison between the daily average concentration of fine PM and the national standard, the concentration of PM2.5 in the Lanzhou urban industrial area exceeded the standard, indicating that during the study period the haze pollution in this area was alarming.

Therefore, we are concerned about the short-term impact of PM2.5 on hospitalization for upper respiratory tract infections. Figures 1 show the time series plot of PM2.5 concentration and the number of inpatients in the urban industrial area of Lanzhou City from January 2013 to December 2019. It can be observed from the figures that there is an evident seasonal change in PM2.5 concentration: low in summer and high in winter. Hospitalizations followed the same trend. The number of hospitalizations increases during periods of high PM2.5 concentration.

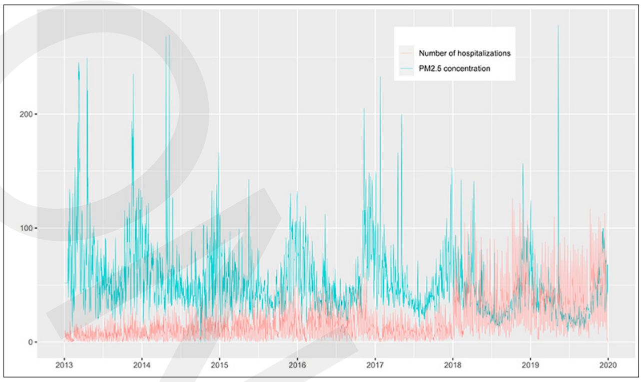

Figure 1. Time Series Plot of PM2.5 Concentration in Lanzhou Industrial Area and Hospitalizations for Upper Respiratory Tract Infections, 2013 – 2019

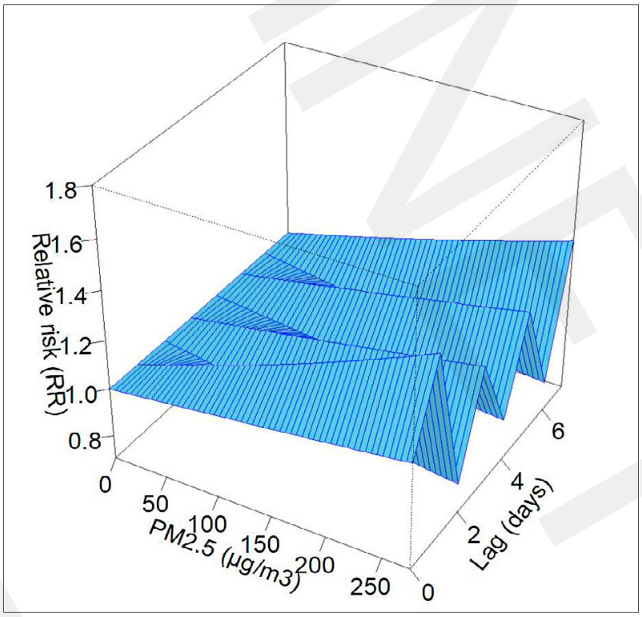

Figure 2. Relationship between hospitalization rate of upper respiratory tract infection and PM2.5 concentration in urban industrial area of Lanzhou City.

Figure 2 shows the cumulative effect of PM2.5 along lagged days and PM2.5 on the relative risk (RR) of upper respiratory tract infections. For PM2.5 concentration values, the RR of upper respiratory tract infections indicated a W pattern with the increase in lag time. The maximum RR for upper respiratory tract infection admission occurred at a PM2.5 concentration of 258 μg/m^3 with a delay of 1 day. The overall adverse effect of PM2.5 on the risk of upper respiratory tract infections was analyzed over 7 lag days by comparing it with the PM2.5 concentration 0, which had the lowest risk of hospitalization, to clearly explain the relationship between PM2.5 and the risk of hospitalization for upper respiratory tract infections (Figure 3). The results indicated that the RR value increased with the increase of PM2.5, exhibiting an upward trend. The curves portray how RR increases with higher fine PM (PM2.5) concentration. The red line represents the RR, and the gray area represents the upper and lower limits.

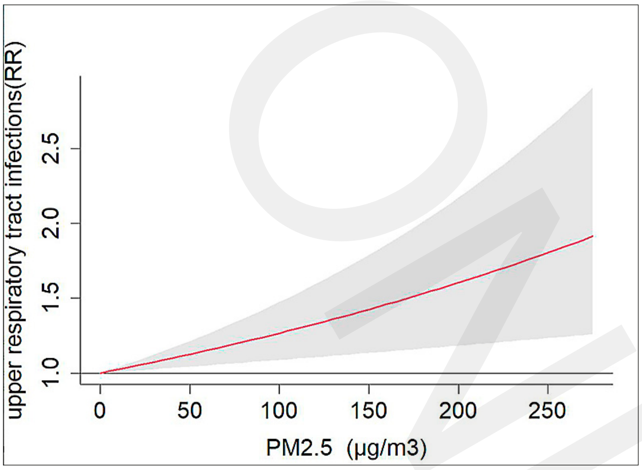

Figure 3. Changes in PM2.5 concentration and relative risk of upper respiratory tract infection

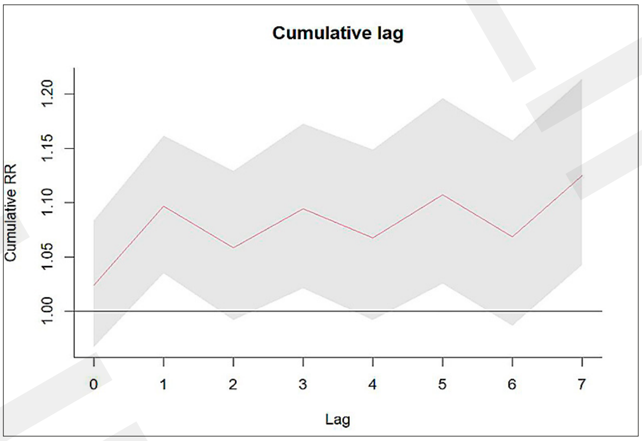

Figure 4. Cumulative effect of PM2.5 on the relative risk of upper respiratory tract infection at 0–7 days

Figure 4 depicts the estimated 0–7day cumulative effect of PM2.5 on the RR of upper respiratory tract infections. In general, all effects were significant at 7 days of cumulative lag. Significant fluctuations can be observed on days 1, 3, 5, and 7, which reached the peak at a cumulative lag of 7 days.

DISCUSSION

GAM was used in this study to evaluate the association between PM2.5 pollution and 60,986 outpatient cases of upper respiratory tract infections in Xigu District, Lanzhou, China. The results of the study indicated a significant correlation between increased PM2.5 concentration and an increased number of daily outpatient visits for upper respiratory tract infections. Previous studies have indicated that elevated PM2.5 concentrations can significantly increase the number of outpatient visits for upper respiratory tract infections [9, 17–21], which is consistent with the current findings.

Although it is not clear whether changes in PM2.5 concentration have a significant effect on upper respiratory tract infections, the results of this study indicate that PM2.5 appears to be the main cause of the increase in outpatient visits for upper respiratory tract infections. For the obtained results, several potential pathological mechanisms were hypothesized. Because PM2.5 is smaller, has a larger effective surface area, and has a higher absorption capacity for toxic air pollutants per unit mass [22], it can quickly enter the respiratory tract by inhalation and be deposited in the alveoli [23]. A small fraction of these deposits are more easily stored in the deeper parts of the lungs where they are in close contact with epithelial cells and macrophages [24], leading to enhanced airway responsiveness. In turn, this promotes increased oxidative stress and inflammation [19, 25].

It was discovered in this study that PM2.5 was statistically significant for the entire lag period and increased with the number of lag days, exhibiting a continuous effect of PM2.5 on upper respiratory tract infections, with the RR of PM2.5 reaching its peak at lag 07, and displaying an increasing trend at lags 03 and 05, consequently exhibiting an overall W pattern. Generally, a higher PM2.5 concentration indicates a stronger risk; however, in practice, the effect of this theory does not hold true due to factors such as the body's own defence mechanisms [26], or other reasons. The effect of PM2.5 on the human respiratory system is a short-term and transient effect, and an abnormal increase in PM2.5 concentration will lead to an increase in the number of outpatients. As PM2.5 undergoes metabolism within the human body, a portion of it is cleared by macrophages, while the remainder is deposited in the lungs.

The area where this study was conducted is the urban industrial area of Lanzhou City, where the annual average concentration of PM2.5 exceeds 51.8 µg/m^3 and the highest concentration can reach 275 µg/m^3, leading to a higher deposition of PM2.5 in the lungs than in ordinary cities. According to the principle of time-dependency, this additional increase in PM2.5 concentration does not contribute to an escalation of risk. Therefore, a dual-peaked trend emerges, characterized by an initial increase followed by a decrease. The effect on upper respiratory tract infections is also multiple, short-term, and instantaneous, as presented in the image, which forms a multi-peak shape.

Discrepancies between studies may exist for the following reasons [4, 6, 10, 12, 20]. First, the composition of PM pollution varies in different regions. The main components of PM2.5 in Lanzhou were carbonaceous aerosols, water-soluble ions, and a small amount of polycyclic aromatic hydrocarbons. Polycyclic aromatic hydrocarbons are toxic and carcinogeni, and can damage the respiratory system. Second, there were differences in the period of data collection, population distribution, medical resource capacity, and preventive measures among the studies. Therefore, the effects of PM2.5 pollution on health outcomes may differ [27].

Stratified analysis suggested gender differences in the association between PM2.5 pollution and upper respiratory tract infections. The effect of PM2.5 on upper respiratory tract infections was stronger in men than in women. The results were consistent with those of previous epidemiological studies on air pollution [9, 21]. The difference between men and women may be due to the following reasons: there are large differences in lifestyle and personal habits between men and women, men tend to be more active outdoors and have a higher frequency of smoking and alcohol consumption, and subsequent exposure to PM2.5 pollution. Circulating sex hormones may also be a factor in the conflicting results between men and women [28].

Compared with people above the age of 65 years, those younger than that age are more susceptible to the adverse effects of PM2.5 on the respiratory system. Among people younger than 65 years, PM2.5 is the most significant PM that causes upper respiratory tract infections. These findings are not consistent with those reported in previous studies [29–31]. However, the results of a study of pollutants in western China showed that younger people were more susceptible to air pollution than older people, which is consistent with the findings of the current study [32]. This difference may be related to the living conditions in Lanzhou City. Compared with people older than 65 years, those younger than 65 years need to work outside the home and are more likely to be exposed to high concentrations of PM2.5. As a result, they are more susceptible to the adverse health effects of air pollution.

To the best of the authors' knowledge, this is the first study to evaluate the association between PM2.5 pollution and outpatient visits for upper respiratory tract infections in Xigu. The results provide reference data for local public health authorities to plan and implement more effective PM pollution prevention strategies.

Limitations of the study. First, air pollution data collected from air quality monitoring stations were used to represent individual exposures. As a result, there may be some bias. Second, it was not possible to control several potential factors, such as personal habits, living circumstances, and chronic illnesses, all of which may bias the results. Third, pollutants often co-exist and interact with each other, it is therefore crucial to comprehensively assess the combined effects of multiple pollutants on upper respiratory tract infections. Only the effect of PM2.5 on upper respiratory tract infections was considered in this study.

CONCLUSIONS

The obtained results suggested a significant correlation between the increase in PM2.5 concentration and the increase in the number of daily outpatient visits for upper respiratory tract infections, with a lag effect. In the subgroup analysis, the effect of ambient PM on outpatient visits for upper respiratory tract infections was significantly changed by gender and age, with men found to be more susceptible to PM2.5 pollution. These findings may be critical for developing preventive strategies to protect people from the adverse effects of PM pollution. Relevant public health authorities should implement measures to reduce pollutant emissions, such as reducing fossil fuel combustion, limiting the number of vehicles on the road, and promoting the use of public transport.

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