Association Between Air Pollutants and Hospitalization with Chronic Obstructive Pulmonary Disease in Ganzhou, China

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Research

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Abstract

**Background.** The evidence of the harm of air pollutants to respiratory health in inland cities in southern China is relatively limited. Therefore, it is necessary to explore the relationship between air pollutants and the number of hospitalized patients with chronic obstructive pulmonary disease (COPD) in this area.

**Method.** The number of inpatients with COPD, air quality data and meteorological data in the First Affiliated Hospital of Gannan Medical University in Ganzhou City from 2016 to 2020 were collected. Generalized additive models were used to analyze the lagged effects of air pollutants and their health effects on the number of hospitalizations for COPD.

**Results.** Among a variety of pollutants, the air pollutants PM$_{2.5}$, PM$_{10}$, NO$_2$ and O$_3$ in Ganzhou City have a significant impact on the number of hospitalized patients with COPD. Using PM$_{2.5}$ as an example, the single day lag effect and cumulative lag effect reached their maximum at lag 6 day and lag 12 day, respectively, at which time the number of hospitalizations due to COPD increased by 2.82% and 6.60%, respectively. After adjusting for other pollutants, it was found that the impact of PM$_{2.5}$ on the number of hospitalizations of COPD patients did not change much. Compared with the cold season, the changes of PM$_{2.5}$, PM$_{10}$ and O$_3$ in warm season have a greater impact on the number of inpatients with COPD.

**Conclusions.** The increased concentrations of PM$_{2.5}$, PM$_{10}$, NO$_2$ and O$_3$ in Ganzhou may increase the risk of COPD patients, which is one of the reasons for the increase in the number of COPD hospitalizations.

**Background**

Exposure to atmospheric particulates has been confirmed to be closely related to the incidence rate and mortality of respiratory diseases$^{[1-4]}$. Many kinds of atmospheric pollutants, represented by PM$_{2.5}$, have become a non negligible problem to harm human environmental health. They can carry many kinds of hazardous substances into the depth of human lungs$^{[5]}$.

Chronic obstructive pulmonary disease (COPD), a progressive and incurable lung disease, was the top 4 leading cause of years of life lost (YLL) and the top 3 leading cause of disable-adjusted life years (DALYs) in China in 2017$^{[6]}$. For developing countries such as China, the major risk factor for causing COPD is exposure to atmospheric environmental pollutants this risk factor contributes to 58.1% of the COPD burden$^{[7]}$. Many scholars have previously confirmed that air pollutants are closely related to the number of outpatients and inpatients of chronic obstructive pulmonary disease through large-scale cohort studies$^{[8-10]}$.

Ganzhou City, old region of revolution, is the largest and most populous city in Jiangxi Province, China. In recent years, with economic development, the increasing popularity of transport and the influx of township and town populations, the challenge of the residential environment in urban areas is increasing, there are not small differences in the components and concentrations of air pollutants in different
regions\textsuperscript{[11]}, and studies on the population health effects of air pollution in local areas are still limited. This study used daily monitoring data of air pollutants, hospitalization data of general hospitals and meteorological data in Ganzhou City from 2016 to 2020 to quantitatively evaluate the acute effects of major air pollutants in the air on the number of COPD hospitalizations using time series analysis.

**Methods**

Health data collection

We collected the data of patients with COPD in the First Affiliated Hospital of Gannan Medical University from January 1, 2016 to December 31, 2020. The data of hospitalized case includes medical record number, gender, date of birth, international statistical classification of diseases (ICD) code of discharge diagnosis and other information. Patients with chronic obstructive pulmonary disease whose ICD code (ICD code: J44) was the main disease diagnosed in discharge according to ICD-10 were included as the research objects in this study. The study was approved by the Ethics Committee of Gannan Medical University.

Environmental Data Collection

We collected daily concentrations of air pollutants from Ganzhou Environmental Monitoring Center from January 1, 2016 to December 31, 2020, including fine particulate matter (PM$_{2.5}$), inhalable particles (PM$_{10}$), sulfur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), ozone (O$_3$) and carbon monoxide (CO). The average daily concentration of six air pollutants in five monitoring stations was calculated to represent the daily exposure concentration of Ganzhou residents\textsuperscript{[12]}. In addition, we obtained daily meteorological data, including daily mean temperature and relative humidity, from Ganzhou Meteorological Bureau.

**Statistical analysis**

SPSS 22.0 software was used for statistical analysis. Descriptive analysis was used for the average daily concentration of the six air pollutants and the number of patients with COPD in the hospital every day, and rank correlation analysis was used for the mass concentration of a variety of common air pollutants and meteorological data. Similar to previous studies\textsuperscript{[13–16]}, this study should use the generalized additive model (GAM) with Poisson distribution to analyze the relationship between the number of COPD hospitalizations and the concentration of air pollutants. In the model, natural cubic spline (NS) was used to adjust the long-term trend, seasonal trend and meteorological factors of time variable, and day of the week effect (DOW) was added into the model in the form of classified variable to control. The choice of degrees of freedom is based on the Akaike's Information Criterion (AIC). The GAM model is established as follows:

$$\log[E(Y_i)]=\alpha + \beta X_i + \text{ns(time, df)} + \text{ns(Temp, df)} + \text{ns(RH, df)} + \text{DOW}$$
In the formula, $E(Y_i)$ is the expected number of hospitalizations on the $i$th day, the unit is the number of people; Alpha is the intercept; $\beta$ is the regression coefficient; $X_i$ is the concentration of pollutants on the $i$th day, in $\mu g/m^3$ (CO in $mg/m^3$); $ns$ is natural cubic spline function; time is a time variable, the unit is days; Temp is air temperature in degrees Celsius; RH is relative humidity in percentage; $df$ is the degree of freedom corresponding to each variable; DOW is the weekday variable.

Air pollutants have a lag effect on population health combined with the length of lag time for the health effects of pollutants in previous studies\cite{2}\cite{17}, this study analyzes single day lag effects ($lag_0$-$lag_{15}$) and multiday lag effects ($lag_{00}$-$lag_{015}$) over a 15 day period. The results of this paper are expressed by the excess risk (ER) and 95% confidence interval (CI) of the increase of hospitalization volume. The maximum effect value within 15 days of single day lag is taken as the exposure risk estimation value of the impact of the pollutant on the inpatient, When the one-day lag effect is the largest, other single pollutants are introduced into the model in turn to establish a two pollutant model to evaluate the health effects caused by the individual and combination of multiple pollutants.

**Results**

Table 1 shows descriptive statistics on the number of people with COPD, air pollutants and meteorological conditions. During our five-year study, 4980 patients with COPD were hospitalized, with an average of 2.73 patients per day. The male patients accounted for a large proportion (81.61%), most of them (70.4%) of the inpatients were elderly (over 65 years old). During the study period, the daily average concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, O$_3$ and CO in Ganzhou City were 37.47$\mu g/m^3$ (ranging from 16.27 to 58.76$\mu g/m^3$), 60.06$\mu g/m^3$ (ranging from 26.24 to 83.88$\mu g/m^3$), 18.74$\mu g/m^3$ (ranging from 7.48 to 30.00$\mu g/m^3$), 23.51$\mu g/m^3$ (ranging from 9.91 to 37.11$\mu g/m^3$), 70.00$\mu g/m^3$ (ranging from 37.38 to 102.62$\mu g/m^3$) and 1.24$mg/m^3$ (range is 0.92 to 1.56$mg/m^3$). The daily mean concentrations of both PM$_{2.5}$ and PM$_{10}$ have exceeded the Chinese ambient air quality first-order concentration standards (the PM$_{2.5}$ daily mean first-order concentration limit is 35$\mu g/m^3$; PM$_{10}$ average daily concentration limit is 50$\mu g/m^3$). The daily average temperature was 19.72°C (ranging from 11.65 to 27.79°C), and the relative humidity was 74.35% (ranging from 62.17 to 86.53%).
Table 1
Summary statistics for air pollutants concentrations and meteorological variables

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Minimum</th>
<th>P(25)</th>
<th>Median</th>
<th>P(75)</th>
<th>Maximum</th>
</tr>
</thead>
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<tr>
<td>COPD</td>
<td>2.73 ± 2.04</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>PM$_{2.5}$ (µg/m$^3$)</td>
<td>37.47 ± 21.20</td>
<td>6</td>
<td>23</td>
<td>33</td>
<td>47</td>
<td>197</td>
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<tr>
<td>PM$_{10}$ (µg/m$^3$)</td>
<td>60.06 ± 33.82</td>
<td>11</td>
<td>36</td>
<td>52</td>
<td>76</td>
<td>258</td>
</tr>
<tr>
<td>SO$_2$ (µg/m$^3$)</td>
<td>18.74 ± 11.26</td>
<td>2</td>
<td>11</td>
<td>16</td>
<td>23</td>
<td>73</td>
</tr>
<tr>
<td>NO$_2$ (µg/m$^3$)</td>
<td>23.51 ± 13.60</td>
<td>4</td>
<td>14</td>
<td>20</td>
<td>28</td>
<td>94</td>
</tr>
<tr>
<td>O$_3$ (µg/m$^3$)</td>
<td>70.00 ± 32.62</td>
<td>4</td>
<td>46</td>
<td>67</td>
<td>91</td>
<td>194</td>
</tr>
<tr>
<td>CO (mg/m$^3$)</td>
<td>1.24 ± 0.32</td>
<td>0.60</td>
<td>1.00</td>
<td>1.20</td>
<td>1.44</td>
<td>2.90</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>19.72 ± 8.07</td>
<td>0</td>
<td>13</td>
<td>21</td>
<td>27</td>
<td>32</td>
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<tr>
<td>Relative humidity (%)</td>
<td>74.35 ± 12.18</td>
<td>35</td>
<td>65</td>
<td>74</td>
<td>84</td>
<td>99</td>
</tr>
</tbody>
</table>

Notes: SD: standard deviation; P: percentile; COPD: Chronic Obstructive Pulmonary Disease; PM$_{2.5}$: fine particulate matter; PM$_{10}$: inhalable particles; SO$_2$: sulfur dioxide; NO$_2$: nitrogen dioxide; O$_3$: ozone; CO: carbon monoxide

Table 2 presents the Spearman correlation coefficients for air pollutant concentrations and meteorological variables. All the correlation coefficients between air pollutants and meteorological factors in this study were statistically significant (P < 0.05). Using particulate matter as an example, PM$_{2.5}$ was highly positively correlated with PM$_{10}$ (r = 0.960), moderately correlated with SO$_2$ (r = 0.687) and NO$_2$ (r = 0.618), weakly correlated with O$_3$ (r = 0.259) and CO (r = 0.445), and negatively correlated with air temperature (r = -0.211) and relative humidity (r = -0.228). PM$_{10}$ showed moderate positive correlations with SO$_2$ (r = 0.706), NO$_2$ (r = 0.656), weak correlations with O$_3$ (r = 0.330) and CO (r = 0.387), and negative correlations with temperature (r = -0.127) and relative humidity (r = -0.359).
Table 2
Correlation analysis of air pollutants and meteorological factors

<table>
<thead>
<tr>
<th></th>
<th>PM$_{2.5}$</th>
<th>PM$_{10}$</th>
<th>SO$_2$</th>
<th>NO$_2$</th>
<th>O$_3$</th>
<th>CO</th>
<th>Temperature</th>
<th>Relative humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>PM$_{10}$</td>
<td>0.960</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO$_2$</td>
<td>0.687</td>
<td>0.706</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_2$</td>
<td>0.618</td>
<td>0.656</td>
<td>0.510</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_3$</td>
<td>0.259</td>
<td>0.330</td>
<td>0.221</td>
<td>-0.093</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CO</td>
<td>0.445</td>
<td>0.387</td>
<td>0.292</td>
<td>0.401</td>
<td>-0.182</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>-0.211</td>
<td>-0.127</td>
<td>0.066</td>
<td>-0.394</td>
<td>0.369</td>
<td>-0.321</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Relative humidity</td>
<td>-0.228</td>
<td>-0.359</td>
<td>-0.294</td>
<td>-0.075</td>
<td>-0.645</td>
<td>0.210</td>
<td>-0.315</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes: all correlation coefficients are statistically significant (p<0.05). PM$_{2.5}$: fine particulate matter; PM$_{10}$: inhalable particles; SO$_2$: sulfur dioxide; NO$_2$: nitrogen dioxide; O$_3$: ozone; CO: carbon monoxide.

The single day lag effect analysis by single pollution generalized additive model showed (Fig. 1) that the effects of PM$_{2.5}$ and PM$_{10}$ on the number of COPD hospitalization reached the maximum at lag 6 day, with ER and 95% CI of 2.82 (1.00, 4.67) and 1.31 (0.26, 2.36), respectively. The effect of NO$_2$ on the hospital volume of COPD reached its maximum at lag 9 day, with an ER and 95% CI of 3.56 (1.17, 6.19), respectively. The effect of O$_3$ on the hospital volume of COPD reached its maximum at lag 1 day, with an ER and 95% CI of 1.45 (0.17, 2.74), respectively.

The single pollution cumulative lag effect analysis showed (Fig. 2), the cumulative effect of PM$_{2.5}$ and PM$_{10}$ on the hospital volume of COPD began to appear continuously at lag 6 day (the cumulative lag effect of PM$_{10}$ appeared briefly at lag 2 day), and presented a short-term progressive increase trend and reached the cumulative effect maximum at lag 12 day and 10 day, respectively. Their maximum excess risk and 95% CI were 6.60 (2.34, 11.04) and 3.51 (1.28, 5.79), respectively. The cumulative effect of SO$_2$ on the number of hospitalizations for slow conducting lung disease appeared at a lag of 10 days, and it had an excess risk and 95% CI of 8.34 (0.08, 17.28). The cumulative effect of NO$_2$ on the number of COPD hospitalizations reached its maximum at lag 11 day, and its excess risk and 95% CI were 7.06 (0.45, 14.10), respectively. The cumulative effect of O$_3$ on COPD hospital volume both appeared at lag 2 day and reached its maximum at lag 13 day, when it reached its maximum value, its excess risk and 95% CI was 2.94 (0.57, 5.36).
The two pollution model showed (Fig. 3) that the effects of PM$_{2.5}$ on the hospital volume of COPD were found to be slightly higher after adjusting for SO$_2$, NO$_2$, O$_3$, and CO, respectively, than the results of the single pollution model, which found no statistical significance after adjusting for PM$_{10}$; after adjusting for NO$_2$, O$_2$ as well as CO, it was found that PM$_{10}$ had a slightly higher effect on the hospital volume of COPD than its single pollution model effect level; compared with the single pollutant models, the effects of SO$_2$ on slow resistance lung hospitalization were statistically significant after adjusting for NO$_2$, O$_3$, as well as CO; after adjusting for other pollutants separately, NO$_2$ was found to have a higher impact on the number of chronic obstructive pulmonary hospitalizations than the results from the single pollutant model; found that the effect of O$_3$ on the hospital volume of COPD remained statistically significant after adjusting for NO$_2$, O$_3$ as well as CO; the two pollution model of CO showed that after adjusting for other pollutants, the effect of CO on the hospital volume of COPD was similar to the estimation results of its single pollution model, and no more statistically significant values were found.

We subsequently performed subgroup analyses (Fig. 4). We found that among the effects of pollutants in different seasons, the cumulative lag effect of the concentration changes of PM$_{2.5}$, PM$_{10}$ and O$_3$ in warm season was statistically significant. Compared with the cold season, every 10µg/m$^3$ change of PM$_{2.5}$ in the warm season will lead to an increase of 13.95%(5.74%~22.81%) in the hospitalization of COPD after a cumulative lag of 7 days; For every 10µg/m$^3$ change of PM$_{10}$ in warm season, the hospitalization of COPD will increase by 8.45%(3.77%~13.34%) after 7 days of cumulative lag; For every 1mg/m$^3$ change of O$_3$ in warm season, the hospitalization of COPD will increase by 1.48%(4.10%~6.79%) after 5 days of cumulative lag. In general, compared with the cold season, the changes of PM$_{2.5}$, PM$_{10}$ and O$_3$ concentrations in the warm season have a greater impact on COPD hospitalization.

**Discussion**

In this study, we investigated the short-term effects of multiple common air pollutants on the number of hospitalizations for COPD among residents of Ganzhou City, Jiangxi Province, China, from January 1, 2016 to October 31, 2020. Our results showed a strong positive association between short-term air pollutant exposure and hospital admissions for COPD.

Many previous studies have pointed out the inevitable link between short-term acute exposure to PM$_{2.5}$ and the number of hospitalizations for chronic obstructive pulmonary disease$^{[18–21]}$. In a single pollutant single day lag model, our study found that each 10µg/m$^3$ increase in PM$_{2.5}$ concentration (lag 6 day) was associated with a 2.82% increase in hospitalization for chronic obstructive pulmonary disease, which is consistent with previous findings. A time-series analysis$^{[22]}$ in Beijing estimated that a 0.67% increase in daily hospital admissions for COPD patients was associated with each 10µg/m$^3$ increase in inhalable PM$_{2.5}$. Studies by Zhang et al$^{[23]}$ and Heinrich et al$^{[24]}$ found that each 10µg/m$^3$ increase in PM$_{2.5}$ can cause a 2.17% and 2.5% increase in COPD hospitalizations, respectively. Li et al$^{[25]}$ estimated that the
incremental change in COPD hospitalization associated with a 10 µg/m³ increase in PM\textsubscript{2.5} (lag 0–7 days) was 3.1% (95% confidence interval: 1.6% – 4.6%).

Effect estimates based solely on single day pollutant exposure are likely to underestimate the true health effects of air pollutants on hospital admissions for respiratory diseases\cite{26}. Therefore in single pollutant models, we pay more attention to the results of cumulative lag effects. Our study observed that the largest effect of PM\textsubscript{2.5} on COPD patient visits occurred in the distribution lag period of 0–7 days, within a lag week. This finding is slightly different from the results of previous studies. Hwang et al\cite{18} studied a single pollutant model within five days of lag and found that the effect of PM\textsubscript{2.5} on hospital volume for COPD reached its maximum at cumulative lag 0–5 days. A time-series study of all large hospitals in Beijing analyzed the effect of atmospheric PM\textsubscript{2.5} on the number of COPD hospitalizations and found that the cumulative lag effect of PM\textsubscript{2.5} on COPD hospital volume increased day by day starting at cumulative lag 0–1 days, reached a maximum at cumulative lag 0–6 days, and decreased thereafter (cumulative lag 0–6 days)\cite{27}. We continued to extend the observation period relative to prior studies and found that the health effects of cumulative PM\textsubscript{2.5} exposure on COPD increased cyclically with longer distribution lags, reaching effect maxima at distribution lags of 0–12 days.

The question of whether adjusted two pollutant models better describe the association of pollutants with the number of hospitalizations for COPD than single pollutants has been debated. A single day lag effect maximum (lag 6 day) for PM\textsubscript{2.5} was selected in the PM\textsubscript{2.5} two pollutant model of this study. The results showed that the association of PM\textsubscript{2.5} with the number of chronic obstructive pulmonary disease hospitalizations was elevated after adjustment for NO\textsubscript{2} compared with single pollutant models; The association of PM\textsubscript{2.5} with the number of hospitalizations for chronic obstructive pulmonary disease changed little after adjustment for SO\textsubscript{2}, O\textsubscript{3}, and CO; PM\textsubscript{2.5} did not present statistical association with the number of chronic obstructive pulmonary disease hospitalizations after adjustment for PM\textsubscript{10}. Some studies have found that after SO\textsubscript{2}, NO\textsubscript{2} and CO adjustment, the relationship between PM\textsubscript{2.5} and COPD outpatient and inpatient quantity is weakened or not significant\cite{28–29}. A study in southwestern Taiwan suggested that PM\textsubscript{2.5} exposure was more significantly correlated with hospital stay in patients with COPD exacerbation after adjusting for O\textsubscript{3} and NO\textsubscript{2} \cite{20}.

When we compare the risk estimates of warm season and cold season, we find that the impact of warm season is greater. Our results are similar to those of most previous studies\cite{22,30}. According to our analysis, in recent years, the public has enhanced their awareness of protection. When encountering severe fog and haze, they reduce going out and outdoor sports. Even if they have to go out, they will wear masks. Even indoors, they will use air purification devices to improve the indoor air quality. Air pollution is more serious in the cold season. On the contrary, in the warm season, most people spend more time outdoors, and the windows are often kept open and ventilated. Therefore, ordinary residents are more likely to be directly exposed to air pollution in warm and humid seasons. There was a disagreement in the study by Nascimento et al\cite{31}, who found that those born during winter tended to have higher years of life
lost due to respiratory diseases compared to those born during other seasons. It is worth mentioning that the pollution situation was obviously worse in winter. Therefore winter tends to be a season with a high incidence of respiratory diseases. But the analysis of our study is that, assuming the same situation of air pollution during the cold season as during the warm season, the effect of the modification of the air pollutant concentration during the warm season on COPD hospitalization is more significant.

There are still some problems in our research. First of all, the air pollutant exposure data we collected are all obtained from five fixed air monitoring points in the urban area, and only a few fixed points of environmental exposure dose are measured. It is difficult to quantify the specific biological effective dose of human exposure. This error may lead our research to misjudge the impact of air pollutants. Secondly, our data source is only from a general hospital in Ganzhou City, in which the daily number of COPD patients is relatively small, which is not suitable for multi classification subgroup analysis, which may lead us to ignore some important links between air pollutants and COPD. This may lead us to ignore some important links between air pollutants and COPD. In the future, large-scale clinical multicenter studies will be needed to verify these results. Thirdly, we only balanced other pollutants, time trend, temperature, relative humidity and weekend effect in the model, while other influencing factors such as legal holidays, pandemic influenza and other variables have not been included in the model, which can not truly reflect the relationship between air pollutants and the number of inpatients with COPD.

**Conclusions**

In conclusion, this study further demonstrates that short-term acute exposure to air pollutants may increase the hospitalization risk of COPD in Ganzhou City, Jiangxi Province, China. On the basis of previous studies, we further provide data support on the lag effect of single or multiple pollutants. This study confirmed that reducing the concentration of air pollutants is an effective preventive measure to reduce the incidence of COPD, the number of inpatients and the corresponding medical economic burden.

**Abbreviations**

COPD: Chronic Obstructive Pulmonary Disease; GAM: Generalized Additive Model; NS: natural cubic spline; AIC: the Akaike's Information Criterion; df: degree of freedom; ER: excess risk; ICD: international statistical classification of diseases; PM\textsubscript{2.5}: fine particulate matter; PM\textsubscript{10}: inhalable particles; SO\textsubscript{2}: sulfur dioxide; NO\textsubscript{2}: nitrogen dioxide; O\textsubscript{3}: ozone; CO: carbon monoxide; YLL: years of life lost; DALYs: disable-adjusted life years; DOW: day of the week effect; CI: confidence interval

**Declarations**

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Gannan Medical University

Consent for publication
Not applicable

Availability of data and materials

The data sources used in this study are included in this paper.

Competing interests

No competing interests

Funding

This study was supported by the doctoral startup project of Gannan Medical College (QD201901) and the science and technology research project of Jiangxi Provincial Department of Education (GJJ190786)

Authors’ contributions

XZ carries out literature retrieval, and determines the research direction and data analysis according to the existing literature. CL participated in the data collection of the article and assisted in the statistical analysis. CZ and YG explained the data results, discussed them in combination with the existing articles, and wrote the first draft of the article. XZ is the principal and corresponding author of the subject. It is mainly responsible for contacting the hospital to provide the data required for this study, and putting forward modification opinions on the first draft of the article. Finally, all authors read and approved the final manuscript.

Acknowledgements

Not applicable

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Figures
Figure 1

single-day lag model Notes: excess risk changes with 95% CIs in COPD admission visits with per 10 μg/m3 increase in PM2.5 (A), PM10 (B), SO2 (C), NO2 (D), O3 (E), and CO (F) levels by single-day lag model. For CO, excess risk change corresponded to per 10 mg/m3 increase of CO levels. ER: excess risk; CI: confidence interval; PM2.5: fine particulate matter; PM10: inhalable particles; SO2: sulfur dioxide; NO2: nitrogen dioxide; O3: ozone; CO: carbon monoxide.
Figure 2

Multiday lag model Notes: excess risk changes with 95% CIs in COPD admission visits with per 10 μg/m³ increase in PM2.5 (A), PM10 (B), SO2 (C), NO2 (D), O3 (E), and CO (F) levels by multiday lag model. For CO, excess risk change corresponded to per 1 mg/m³ increase of CO levels. ER: excess risk; CI: confidence interval; PM2.5: fine particulate matter; PM10: inhalable particles; SO2: sulfur dioxide; NO2: nitrogen dioxide; O3: ozone; CO: carbon monoxide.
the two pollutant model Notes: the excess risk of COPD changes with the increase of 10 μg/m3 of different pollutants. (A) PM2.5(lag6), (B) PM10(lag6), (C) SO2(lag10), (D) NO2(lag9), (E) O3(lag1), (F) CO(lag0). For CO, excess risk change corresponded to per 1 mg/m3 increase of CO levels. ER: excess risk; CI: confidence interval; PM2.5: fine particulate matter; PM10: inhalable particles; SO2: sulfur dioxide; NO2: nitrogen dioxide; O3: ozone; CO: carbon monoxide.
Figure 4

Comparison of excess risk (ER) in different seasons Notes: excess risk (ER) with 95% CIs in multiday lag model for COPD admission visits with per 10 μg/m3 increase in PM2.5 (A), PM10 (B), SO2 (C), NO2 (D), O3 (E), and CO (F) levels in the warm season (in red color) and cold season (in blue color). For CO, percentage change in the relative risks corresponded to per 1 mg/m3 increase of CO levels. ER: excess
risk; CI: confidence interval; PM2.5: fine particulate matter; PM10: inhalable particles; SO2: sulfur dioxide; NO2: nitrogen dioxide; O3: ozone; CO: carbon monoxide.