A GIS-based spatial correlation analysis for ambient air pollution and AECOPD hospitalizations in Jinhua, China

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Abstract

**Background:** Acute exacerbations of COPD (AECOPD) are important events during disease procedure. AECOPD have negative effect on patients’ quality of life, symptoms and lung function, and result in high socioeconomic costs. Though previous studies have demonstrated the significant association between outdoor air pollution and AECOPD hospitalizations, less is known about the spatial relationship utilized a spatial analyzing technique- Geographical Information System (GIS).

**Objective:** Using GIS to investigate the spatial association between ambient air pollution and AECOPD hospitalizations in Jinhua City, 2019.

**Methods:** 1563 AECOPD hospitalization cases in Jinhua, 2019 were enrolled in our analysis. Monthly concentrations of six monitored six pollutants (SO₂, PM10, PM2.5, NO₂, CO, O₃) during January 2019 – December 2019 were provided by Environmental Protection Agency of Jinhua City. Everyone was geocoded in ArcGIS10.5 software. The spatial distribution of six pollutants and the temporal-spatial specific air pollutants exposure level for everyone was estimated by ordinary Kriging model. Spatial autocorrelation (Global Moran’s I) was employed to explore the spatial association between ambient air pollutants and AECOPD hospitalizations. A generalized linear model (GLM) using a Poisson distribution with log-link function was used to construct a core model.

**Results:** The concentrations of SO₂, PM10, PM2.5, NO₂, CO, O₃ and AECOPD hospitalization cases showed statistical significant spatially clustered at residence. The Z-score of SO₂, PM10, PM2.5, NO₂, CO, O₃ at residence is 31.88, 42.95, 45.90, 32.29, 52.18, and 34.59, respectively. After adjusting for potential confounders in the model, the SO₂, NO₂ and O₃ concentrations at residence showed statistical significance increase of hospitalizations due to AECOPD.

**Conclusions:** Ambient air pollution is correlated with AECOPD hospitalizations spatially. The SO₂, NO₂ and O₃ concentrations at residence was significantly associated with an increase of hospitalizations due to AECOPD in Jinhua, 2019.

**Background**

Chronic obstructive pulmonary disease (COPD) is a life-threatening condition characterized by persistent respiratory symptoms that interfere with normal breathing [1]. Patients with COPD may...
experience an acute worsening of respiratory symptoms that results in additional therapy; this event is defined as a COPD exacerbation (AECOPD) [2]. AECOPD bring negative effect on patients’ quality of life, symptoms and lung function, and result in high socioeconomic costs [3]. Up to 25% of AECOPD events require hospitalization [4]. In China the median cost of inpatient care for AECOPD was CN ¥11,598, with medication costs contributing to 36–88% of costs, depending on the tier level of the hospital [5]. Exacerbations of COPD can be triggered by various factors. Increasing evidence support that ambient air pollution is an environmental triggering factor for AECOPD [6]. Since China’s economic reforms plan, large emissions from energy consumption are concentrated in the megacity clusters, such as Beijing-Tianjin-Hebei (BTH), the Pearl River delta (PRD), and the Yangtze River delta (YRD) regions. Jinhua city is located in the YRD region of East China, in the middle of Zhejiang province [7]. The health effects of inhalable particulate matter (aerodynamic diameter < 10 μm, PM 10), (aerodynamic diameter < 2.5 μm, PM 2.5), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), and ozone (O₃) on COPD are well established [8-11]. Geographical information system (GIS) refers to computer-based programs to collect, store, retrieve, and statistically manipulate geographic or location-based information [12]. Better interpretation of the patterns, trends and relationships between disease and demography, environment, space and time could be obtained through GIS. Therefore, GIS has important application in medical and health area, especially in the application of etiological research [13, 14]. Wang et al. investigated the spatial association between ambient air pollution and AECOPD hospitalizations using GIS [15]. One limitation is lack of information of PM2.5, which was not regularly monitored in the study period due to limited monitoring technique in the year of 2009. China's rapid industrialization and urbanization has led to poor air quality. There is a substantial changes in air pollution across China within the last decades [16]. To our knowledge, few studies employed GIS technique to assess spatio-temporal specific exposure to air pollutants in the spatial association analysis between admissions for AECOPD and air pollution. There is no similar study in YRD region of East China. We aim to assess the spatial association
between ambient air pollution exposure and AECOPD hospitalizations in Jinhua City through GIS.

Methods

Study area & study period

We set the study in Jinhua City, 2019. Jinhua (alternately romanized as Kinhwa), is a prefecture-level city in central Zhejiang province in eastern China. It is located in the north-western part of Zhejiang province at 29°.079176 northern latitude and 119°.647423 east of Greenwich.

Target Population

All cases enrolled in our study were interspersed in Jinhua City. Written informed consent was obtained prior to data collection. The study and consent procedure were approved by the Ethics Committee of Jinhua Municipal Central Hospital.

COPD hospitalization cases met with the following inclusion criteria were included in our study: (1) Hospitalization due to acute exacerbations of COPD, identified by International Statistical Classification of Diseases, 10th Revision (ICD-10) codes, J40-J44; (2) Resided and worked in study area (Jinhua City) during study period (Jan 2019 – Dec 2019); (3) Adults patients (age > 18 years).

Exclusion criteria: (1) Patients who did not reside or work in Jinhua City during 2019. (2) In order to avoid the impact of occupational exposure to air pollutants, patients who worked at high-polluting environment were excluded.

Exposure Assessment

Subjects were geocoded using home residence and working site respectively in a Geographical Information System. We applied addresses geocoding techniques using ArcGIS 10.5 software. Each subject was shown on a map as a precise mark in correspondence with his/her home residence or working site respectively. For each marking site, concentrations of air pollutants were estimated using ordinary Kriging method to assess spatiotemporal-specific air pollution exposure. The monthly average concentrations of air pollutants from January, 2019 to December, 2019 were provided by Environmental Protection Agency of Jinhua City. The air pollution concentrations of SO₂, PM10, PM2.5, NO₂, CO, O₃ were monitored in 13 monitoring stations interspersed in different subdistricts of Jinhua City.

Statistical analysis
Global Moran’s I statistic was used for spatial autocorrelation analysis in ArcGIS 10.5. Moran’s I, p value and Z score were calculated to test the spatially clustered tendency between concentrations of air pollutants and AECOPD hospitalization cases. Confidence level of 99% was selected. Values of P < 0.01 were considered statistically significant.

A generalized linear model (GLM) using a Poisson distribution with log-link function was used to construct a core model. Monthly numbers of AECOPD admissions were selected as dependent variable. Age, gender, season of hospitalization, smoking status and air pollutants concentrations at residence and workplace were selected as dependent variables. After controlling for the confounding effects of seasonality, age, gender and smoking status, monthly concentrations of (O\textsubscript{2}, PM10, PM2.5, NO\textsubscript{2}, CO, O\textsubscript{3}) at residence for each individual were added to the core model to determine the increase of COPD admissions for a 10 µg/m\textsuperscript{3} increase in each of these air pollutants. An interaction effect between gender (male or female) and smoking status (ex-smoker or non-smoker or current smoker) were analyzed in the model. Values of P < 0.05 were considered statistically significant. All the analysis was performed with SPSS 25.0 software.

Results
Demographic information
Altogether 1563 admissions for acute exacerbations of COPD during January 1, 2019 – December 31, 2019 were enrolled in our study. The basic demographic information of enrolled patients (such as age, gender, smoking status, allergy history and comorbidities) were shown in Table 1. The average age of AECOPD patients was 74.1 ± 9.1 years, and the most of them were male (n = 1277, 81.7%). The most patients (77.5%) were non-smokers. Former and current smokers-patients counted as 162 cases (10.4%) and 189 cases (12.1%), respectively. 1277 (81.7%) cases had no history of penicillin allergy, and only 286 (18.3%) cases had an allergy history. The common comorbidities among the study patients were counted hypertension (650, 41.4%), heart failure (518, 33.1%), ischemic heart disease (292, 18.7%), cerebrovascular disease (229, 14.7%), diabetes (177, 11.3%), atrial fibrillation (149, 9.5%), chronic cor pulmonale (117, 7.5%) and lung cancer (53, 3.4%).
Table 1  
Characteristics of the whole subjects enrolled in the study.

| Variables                  | Items             | AECOPD hospitalization cases (n = 1563) |
|----------------------------|-------------------|----------------------------------------|
| Age (mean ± SD)            | -                 | 74.1 ± 9.1                             |
| Gender (n, %)              | Male              | 1277                                   | 81.7%                                  |
|                            | Female            | 286                                    | 18.3%                                  |
| Smoking status             | Non-smoker        | 1212                                   | 77.5%                                  |
|                            | Ex-smoker         | 162                                    | 10.4%                                  |
|                            | Current-smoker    | 189                                    | 12.1%                                  |
| Allergy history            | Yes               | 286                                    | 18.3%                                  |
|                            | No                | 1277                                   | 81.7%                                  |
| Comorbidities              | Chronic cor pulmonale | 117                               | 7.5%                                  |
|                            | Ischemic heart disease | 292                               | 18.7%                                  |
|                            | Heart failure     | 518                                    | 33.1%                                  |
|                            | Hypertension      | 650                                    | 41.6%                                  |
|                            | Atrial fibrillation | 149                               | 9.5%                                   |
|                            | Lung cancer       | 53                                     | 3.4%                                   |
|                            | Diabetes          | 177                                    | 11.3%                                  |
|                            | Cerebrovascular disease | 229                               | 14.7%                                  |

Spatial Distribution Of Aecopd Admissions

The acute exacerbations accelerate the rate of decline of lung function correlated with significant mortality, particularly in those requiring hospitalizations [17]. Analyses on association between air pollution and hospital admissions are performed on 1563 AECOPD cases at 2019. As shown in Fig. 1, the distribution of AECOPD admissions (green points) was uneven, as cases were concentrated in the northwest of Jinhua, but sparse in the rest of the city. Kriging interpolation can be used to determine the distribution of AECOPD admissions to air pollutions. Higher concentrations of SO₂ (Fig. 1A), NO₂ (Fig. 1D), CO (Fig. 1E) and O₃ (Fig. 1F) were generally observed at sites located in the northwest region of Jinhua probably due to the presence of a large number of industries there. In terms of the spatial distributions of particulate matter, PM10 (Fig. 1B) and PM2.5 (Fig. 1C) both were higher in the middle region of Jinhua, which are closely linked with a large population and polluting activities in the region, such as a large number of cars and industrial enterprises. Table 2 summarizes the data on monthly numbers of hospitalizations for AECOPD and values of the six selected environmental risk factors.
### Table 2
Summary statistics of monthly hospitalization counts and air pollution in Jinhua, China, 2019.

| Variable     | Mean | Min | P25 | Median | P75 | Max |
|--------------|------|-----|-----|--------|-----|-----|
| SO₂ (µg/m³) | 7.2  | 3.0 | 5.0 | 7.0    | 8.0 | 13.0|
| CO (µg/m³)  | 0.7  | 0.5 | 0.6 | 0.7    | 0.7 | 1.0 |
| PM₁₀ (µg/m³) | 30.9  | 14.0 | 26.0 | 30.0   | 34.3 | 57.0|
| PM₂.₅ (µg/m³) | 30.1  | 14.0 | 26.0 | 30.0   | 34.3 | 57.0|
| O₃ (µg/m³)  | 84.5 | 36.0 | 54.0 | 94.5   | 105.0 | 142.0|
| NO₂ (µg/m³) | 28.0 | 10.0 | 20.8 | 27.0   | 35.3 | 48.0|
| AECOPD      | 130  | 89  | 99  | 129    | 159 | 176 |

### Spatial Correlation At Residence
At residence, concentrations of SO₂, PM₁₀, PM₂.₅, NO₂, CO, O₃ and AECOPD hospitalization cases showed statistically significant spatially clustered (Table 3). The Moran’s I of SO₂, PM₁₀, PM₂.₅, NO₂, CO, O₃ at residence is 0.64, 0.86, 0.92, 0.64, 1.04, and 0.69, respectively. The Z-score of SO₂, PM₁₀, PM₂.₅, NO₂, CO and O₃ at residence is 31.88, 42.95, 45.90, 32.29, 52.18, and 34.59, respectively. Of the six air pollutants, O₃ is of greatest spatial correlation with AECOPD hospitalization.

### Table 3
Spatial autocorrelation analysis between air pollutants at residence and AECOPD hospitalization cases.

| Air pollutants | Moran’s I | Z score | P value |
|----------------|-----------|---------|---------|
| SO₂            | 0.64      | 31.88   | 0.00*   |
| CO             | 0.86      | 42.95   | 0.00*   |
| PM₁₀           | 0.92      | 45.90   | 0.00*   |
| PM₂.₅          | 0.64      | 32.29   | 0.00*   |
| O₃             | 1.04      | 52.18   | 0.00*   |
| NO₂            | 0.69      | 34.59   | 0.00*   |

*Data with statistical significance.

### Predicting Model
A generalized linear model (GLM) using a Poisson distribution with log-link function was used to construct a core model. Results of the core model were shown in Table 4. After adjusting for potential confounders in the model, only the SO₂, NO₂ and O₃ concentrations at residence showed statistical significance, with an increase of hospitalizations for acute exacerbations of COPD.
Table 4
Parameter estimates for a generalized linear model.

| Parameter | B    | Std. Error | 95% Wald Confidence Interval | Hypothesis Test |
|-----------|------|------------|-----------------------------|-----------------|
|           |      |            | Lower                       | Upper           | Wald Chi-Square | df   | Sig.   |
| (Intercept)| 4.844| 0.479      | 3.905                       | 5.783           | 102.261         | 1.000| 0.000  |
| SO₂       | 0.236| 0.058      | 0.121                       | 0.350           | 16.338          | 1.000| 0.000* |
| CO        | -0.215| 0.695      | -1.577                      | 1.147           | 0.096           | 1.000| 0.757  |
| PM10      | 0.000| 0.012      | -0.025                      | 0.024           | 0.000           | 1.000| 0.987  |
| PM2.5     | 0.025| 0.024      | -0.021                      | 0.071           | 1.122           | 1.000| 0.290  |
| O₃        | -0.008| 0.002      | -0.013                      | -0.003          | 10.672          | 1.000| 0.001* |
| NO₂       | -0.046| 0.016      | -0.076                      | -0.016          | 8.883           | 1.000| 0.003* |

Dependent Variable: monthly AECOPD hospitalizations events
Model: (Intercept), SO₂, PM10, PM2.5, NO₂, CO, O₃
*Data with statistical significance.

Discussion

In recent years, air pollution has become a worldwide environmental issue, and China is facing the greatest challenge from deteriorating air quality. It is of great importance and urgency to find out the definite impact of air pollution. Our study assessed the spatial correlation of ambient air pollution related exposure on AECOPD admissions in Jinhua City, China, 2019, and the results indicate that ambient air pollution is correlated with AECOPD hospitalizations spatially. At residence, SO₂ is of the greatest spatial correlation with AECOPD hospitalization. After adjusting for potential confounders in the model, SO₂, NO₂ and O₃ concentrations at residence showed statistical significance. Our research proved the spatial correlation between ambient air pollution and AECOPD hospitalizations in Jinhua (located in the most polluted YRD region in China), which provided novel evidence and new direction for triggering factors and prevention of AECOPD.

Though previously descriptive retrospective study have reported the associations between ambient air pollution and COPD hospitalizations [18], and less knowledge was known on the spatial correlation between ambient air pollution and AECOPD hospitalization cases. More evidence is needed to demonstrate the solid association between ambient air pollution and AECOPD hospitalizations. In the association study between O₃ and COPD admissions, several previous studies have demonstrated the association. In APHEA project conducted in Europe, O₃ was associated with daily admissions for COPD, the relative risks (RR) for a 50 mg/m³ increase in daily mean concentrations of O₃ was 1.04 (1.02,
In the research conducted in Hong Kong, associations between $O_3$ and COPD hospitalizations were convinced both in single-pollutant model and multipollutant model [20]. Sauerzapf’s study on a rural county of England showed that 10 µg/m3 increase in CO was associated with a 2% increase in the odds of admission, but no associations were observed with $O_3$ or particulates [21]. Current studies support the role of $SO_2$ and $NO_2$ in COPD hospitalizations. Similar conditions exist in the association analysis between $SO_2$ and COPD hospitalizations. In the research conducted in Hong Kong, associations between $SO_2$ and COPD hospitalizations were convinced both in single-pollutant model and multi-pollutant model [20]. In Mohammad’s study, they using Air Q model (2011–2012 year) have shown that $SO_2$, $O_3$ and $NO_2$ have a significant impact on COPD hospitalization [22]. In APHEA project, $NO_2$ was associated with daily admissions for COPD, the relative risks for a 50 mg/m3 increase in daily mean concentrations of NO2 was 1.02 (1.00, 1.05) [19]. Sauerzapf et al. showed that each 10 mg/m$^3$ increase in $NO_2$ was associated with a 22% increase in the odds of COPD admission [21]. The role of PM10 in COPD hospitalizations was inconclusive. In a research conducted in Hong Kong, PM10 was associated with COPD hospitalizations in single pollutant model, with RR = 1.024 for admissions per 10 mg/m$^3$ increase, but it is not statistically significant in multi-pollutant model [20]. A meta-analysis of 31 studies (2000–2011 year) showed that a 10 µg/m$^3$ increase in PM10 was associated with a 2.7% (95%CI = 1.9%-3.6%) increase in COPD hospitalizations with an odds ratio (OR) of 1.027 (95%CI: 1.019–1.036) [23]. A combined analysis by Li et al. indicated that short-term exposure to a 10-µg/m$^3$ increment of ambient PM2.5 is associated with increased COPD hospitalizations and mortality [24]. In 2019, a population-based study involved 3941 nonsmoking Taiwanese adults (2008–2015 year) demonstrated that exposure to PM2.5 in the highest quartile ($> 38.98$ µg/m$^3$) was significantly associated with COPD (OR, 1.29; CI 1.01–1.65) after multivariate adjustments. Our results for the first time proved the spatial correlation between ambient PM2.5 and AECOPD hospitalization, which added new evidence to the association (especially spatial association) between ambient air pollution and AECOPD hospitalization. As a spatial data processing
tool, GIS showed novel and great potential on air pollutants exposure assessment and spatial analysis in AECOPD research.

One limitation is the cross-sectional nature of the study, which could not demonstrate the causal relationship between ambient air pollution and AECOPD hospitalization. As the monitoring technique developing, further study could be done to better illustrate the association between ambient air pollution and admissions due to AECOPD in East China. Prospective cohort study was also needed to illustrate the causal relationship in the future.

Conclusion
Ambient air pollution is spatially correlated with AECOPD hospitalizations. At residence, SO2 is of greatest spatial correlation with AECOPD hospitalization. After adjusting for potential confounders in the model, SO2, O3 and NO2 concentrations at residence showed a statistically significant relation with the increase of hospitalizations for acute exacerbations of COPD. As a spatial data processing tool, GIS has novel and great potential on air pollutants exposure assessment and spatial analysis in AECOPD research.

Abbreviations
AECOPD, Acute exacerbations of Chronic Obstructive Pulmonary Disease; CO, Carbon monoxide; GIS, Geographical information system; NO2, Nitrogen dioxide; O3 Ozone; PM2.5, Particular matter with aerodynamic diameter less than 2.5 μm; PM10, Particular matter with aerodynamic diameter less than 10 μm; SO2, Sulfur dioxide.

Declarations
Authors’ contributions
All authors contributed substantially to the study design. ZML and YLH conceived and designed the experiments. WJD and WDZ collected and analyzed the data. HYH and MYZ wrote the first draft of the manuscript. All authors critically reviewed and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study protocol was approved by the institutional review board and ethics committee of Jinhua municipal central hospital and was conducted according to the principles of the Declaration of Helsinki. The need to obtain informed consent was waived due to the retrospective nature of the study.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Figures
Figure 1

Distribution of air pollution concentration and AECOPD hospitalization. SO2 (A), PM10 (B), PM2.5 (C), NO2 (D), CO (E), O3 (F) concentration distribution and admission data of April, 2019 in Jinhua, China. Air pollution levels were analyzed using monitoring data and Kriging method, distribution of residence of AECOPD hospitalization. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 2

Distribution of AECOPD hospitalization cluster in Jinhua. Spatial patterns of AECOPD hospitalization cluster including 1025 cases in two sub-districts of Jinhua. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.