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# The Effects of Outdoor Air Pollutants on the Costs of Stroke Hospitalizations in China

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**Abstract:** Stroke, the most frequent cause of severe disability and the second cause of death among adults in the world, brings tremendous mental and economic burden to patients and their families. Emerging evidence indicates that the air pollution mixture contributes to strokes. Knowing the relationship between the air pollution and the hospital costs of stroke can help us predict the costs due to air pollution, provide grounds for the allocation of medical insurance funds, and provide better working arrangements for CDC. However, few studies have examined this connection. We used time series analysis with a generalized additive model to estimate the associations between ambient air pollutions and hospital costs between the period of 2015–2017. We were surprised to find that although same-day air pollutions were positively associated with stroke mortality hospital costs were found to have a negatively association. Suggestive evidence of an association between fine particles and the costs of stroke were found: more serious air pollution increases the risk of stroke, but has a dampening effect on hospital costs. This study is the first step in optimizing medical resources, which is essential for policy making, service planning, and cost-effectiveness analysis of new therapeutic strategies.

**Key words:** stroke, cost, air pollution

## INTRODUCTION

Stroke is the most frequent cause of severe disability and the second cause of death among adults in the world, There were 5.8 million deaths in 2016 due to the stroke and it remained the leading causes of death globally over the last 16 years<sup>1</sup> and the rate of stroke occurrence continues to increase this years<sup>1-2</sup>. In the United States, beyond the morbidity, mortality, and human suffering is the staggering financial and economic cost of this disease<sup>3</sup>, Stroke is the leading cause of disability and it brings tremendous mental and economic burden to patients、 their families and the government medical insurance funds<sup>4-10</sup>. There are many factors of stroke, such as high blood pressure, high BMI ,cigarette smoking<sup>11</sup>,diabetes,age,gender,low birth weight<sup>12</sup>,genetic factors<sup>13</sup>,and air pollutions<sup>14-15</sup>. It is impossible for us to change objective factors such as gender, age, low birth weight, etc., while high BMI, smoking, and high blood pressure all require long time of behavioral control, which are very difficult. Therefore, air pollution is the easiest factor we can control in the short term. As human beings have been facing huge air pollution problems and health challenges over the last five decades<sup>16-17</sup>, and increasing number of studies have focused on the relationship between air pollution and stroke, Evidences has shown that strokes have a close relationship with air pollution, and numerous studies have shown that particulate matter in the air have a certain correlation with strokes<sup>18-21</sup>. The disabling nature of strokes causes them to have a higher cost after discharge than other diseases, and it is lifelong. Due to the huge economic burden brought by stroke to society and families, researchers have done some studies on the cost of strokes. It is generally believed that the factors that affect the cost of strokes are type of stroke, living condition 、 age of onset and so on、 living condition、 age of onset and so on<sup>22</sup>. However, no studies on the relationship between air pollution, which is a controllable factor, and strokes exists. Therefore, it is of great significance to fill this gap.

In addition to general hospital expenses, stroke costs include acute-care costs incurred in the 2 years following a first stroke, long-term ambulatory care, and nursing home costs of aggregate lifetime costs of stroke . The total cost to an individual stroke patient over their lifetime is hard to evaluate, most studies use the hospital cost or the Medicare claims data as the direct cost measure for this kind of study. In this paper, the study group was a group of patients who were initially diagnosed with stroke on admission. We measure cost as the cost of the patient from admission to the

hospital and include all costs, including surgery costs, examination costs, treatment costs, drug costs and other costs incurred in the hospital.

The health harm from air pollution leads to increased healthcare expenditures as well as labor productivity losses, which have large social costs and cause immense economic pressure. Given that China accounts for one-fifth of the world's population and suffers from severe air pollution, a comprehensive study of the indicators accounting for the health costs in relation to air pollution will benefit evidence-based and health-related environmental policy-making. A growing study has consistently shown a positive association between exposure to air pollution and increased health costs. Jing et al.(2018) revealed that a 1% increase in yearly exposure to PM<sub>2.5</sub> corresponds to a 2.942% increase in household healthcare expenditure. These quantitative studies only focused on the influence of the whole social medical cost of air pollution, and the overall cost may reflect the characteristics of certain kinds of diseases costs, differences in etiology, and surgical difficulty among certain kinds of diseases may be inconsistent with the overall cost. Due to the age, gender, living environment and education level, the cost may be differences among individuals. Therefore, analyzing stroke independently, which is a devastating disease associated with significant economic costs, is necessary to analyze the impact of environmental pollution on this particular kind of disease costs. Knowing the relationship between air pollution and hospital costs of stroke can help us predict the costs due to air pollution, provide grounds for the allocation of medical insurance funds, and provide better working arrangements for CDC. This research can fill a gap in theoretical knowledge in this field.

Through the quantitative analysis of real data, we selected controllable air pollution as the entry point among the numerous inducing factors of stroke, we used time series analysis with a generalized additive model to estimate the associations between ambient air pollutions and stroke hospital costs between the period of 2015–2017. This study is the first step in optimizing medical resources, which is essential for policy making, service planning, and cost-effectiveness analysis of new therapeutic strategies.

## EXPERIMENT SETTING

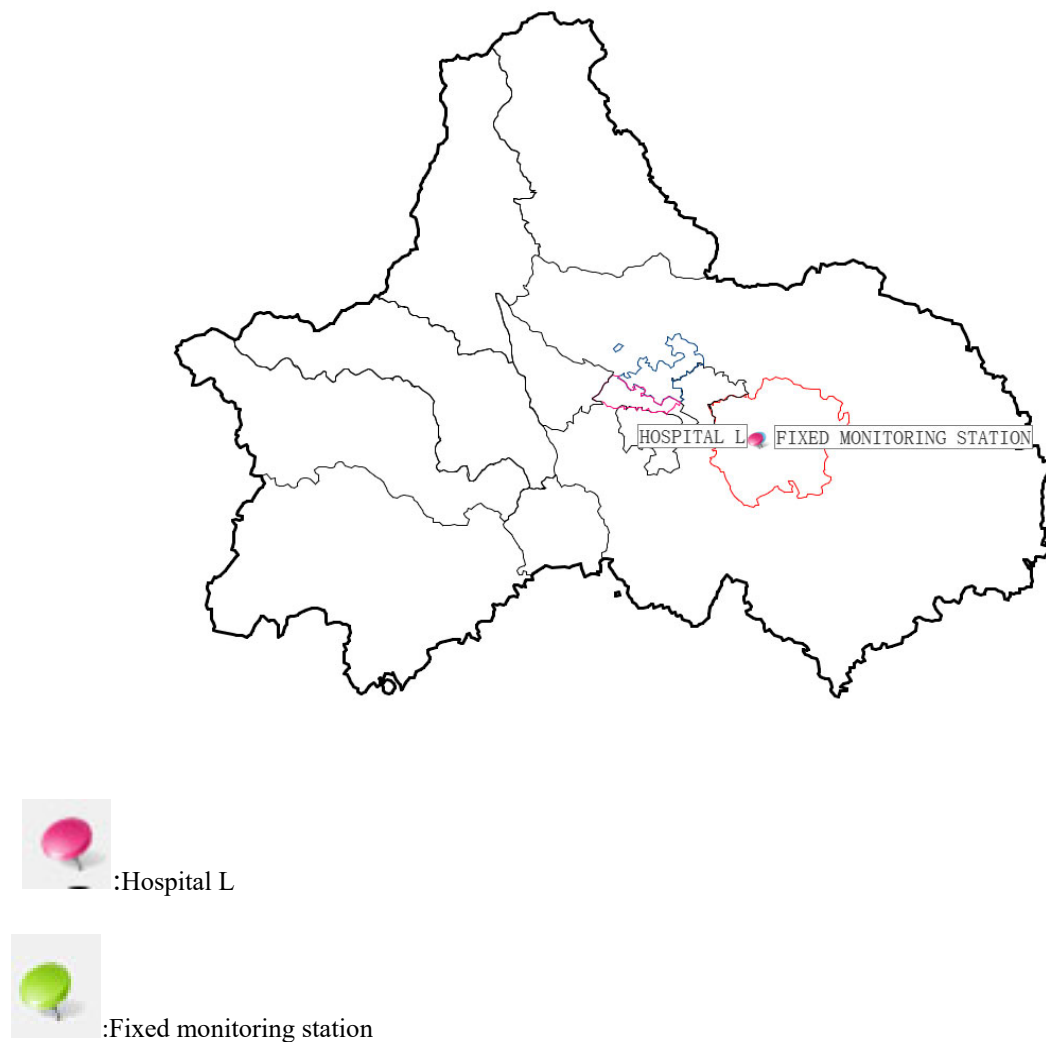
City C, the evaluation of complex strength is NO1 in the southwest of China, It's subtropical monsoon humid climate is different from previous studies. It has the second largest number of private cars in China, important because automobile exhaust is one of the causes of air pollution. This all makes City C very special for this study. Stroke requires timely treatment, so when patients call for an ambulance, they should take the seek medical treatment nearby. We chose hospital L as our research object, as a fixed monitoring station is 1.2km away from the hospital and environmental data reflects the exposure level can well match the hospital patients admission data (Fig.1).

The red dots is hospital L, the blue dots is the monitoring stations, and the red areas are service areas of hospital L, which can be matched with the data of monitoring stations

### Data

Daily counts of hospital admissions for stroke, including all cerebrovascular diseases (ICD-10:60-64) as the principal diagnosis from year 2015-2017 were obtained from hospital L, which has a 556.98 square kilometer service area and serves population of 872,300 people. Considering the stroke risk markers and risk factors, we also computed the cost of stroke by gender, by two age groups(age≤65,age>65) and by season for subgroup analysis, all of the data was from the Hospital Management Information System (HMIS). We only consider the direct cost in this paper. Ethics approval and consent from individual subjects were not required by our institute as we used only aggregated data and not any individualized data in this study.

Air pollution data between January 1th 2015 and December 31th 2017 was obtained from the State Environmental Protection Administration of the fixed monitoring station which is 1.2 km from the hospital. We calculated daily concentration of sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), ozone (O<sub>3</sub>), carbon monoxide (CO), particle matter 10 (PM<sub>10</sub>), and particle matter2.5 (PM<sub>2.5</sub>) from the monitoring station. The temperature and humidity data are drawn from the National Meteorological Information Center of China.



**Figure 1: L Hospital is in the Patient Coverage Area of C City**

### Statistical Modeling

This is a retrospective study, since the relationship between cost and air pollution variables is non-linear, we chose Generalized Additive Poisson Models (GAM) to analyze the relationship between stroke cost and air pollution by using R project with packages “mgcv”. Time series analysis of the relationship between air pollution and health has attracted a lot of attention and we set up our model based on previous studies. Before setting up the GAM model, we used t step regression to select variables by taking into account meteorological factors, social factors and patient factors comprehensively through the existing data. Traditionally, length of stay has been one of the factors influencing costs. It is a big innovation to select length of stay as the research variable of patient factors. We have done a lot of work to verify the feasibility of including length of stay in the model, including multicollinearity test. The GAM model was established in two steps. The first step was the blank model, that is, air pollution variables were not added. The second step was to add air pollutants respectively. A minimum variable was selected to enter the model according to AIC (akaike information criterion, AIC). After the test of the degree of freedom(df) for the time trend, we set up our model as follows:

$$\log(E(Y)) = \alpha + S(Temp_{1-5}, df = 7) + S(Hum, df = 3) + \beta_1 * Holiday \\ + \beta_2 * Length \text{ of stay}$$

Here  $E(Y)$  stands for the expected costs for stroke patients,  $\alpha$  is the model intercept,  $S(\cdot)$  is the smoothing spline function for nonlinear variables, Temp represents the temperature, Hum represents the humidity,  $\beta_1$  and  $\beta_2$  are the regression coefficients. The choice of df is based on previous studies and our sensitivity analysis, according to our results, we made 7 df the temperature and 3 df the humidity.

We separately tested SO<sub>2</sub>、NO<sub>2</sub>、PM<sub>2.5</sub>、PM<sub>10</sub>、O<sub>3</sub> for the same day and up to 14 days prior to the outcome(single-lag effect from lag0-lag14). In the subgroup comparison of gender, age and season, we used the RR value to analyze the degree of association of this factor with the cost. All tests were conducted in the statistical environment R.

In our study, we also considered the impact of the combined action of various pollutants on the cost, in which the pollutants were included in the same lag period at the same time(lag0-10). For example, in order to analyze the effects of O<sub>3</sub> and PM<sub>2.5</sub>, we set up model as below:

$$Model = GAM \left( \begin{array}{l} \text{cost} \sim O_3 + PM_{2.5} + S(Temp_{1-5}, df = 7) + S(Hum, df = 3) \\ + \beta_1 * \text{Holiday} + \beta_2 * \text{Length of stay} \end{array} \right)$$

## RESULTS

### Data description

According to our statistical analysis, a total of 8,076 cerebrovascular admission data were collected in this area during the study period. Data cleansing excluded children ( $\leq 18$  years old), external trauma, work and life outside the scope of the monitoring station etc. After removing outliers, a total of 1,663 cases were selected as the overall sample for the study. Among them, males accounted for 51.29% and females 48.71%. The age over and including 65 comprises 72.82% and 27.18% are those under 65 years old. The warm season accounts for 54.15% of the cases and the cool season for 45.84%. The average cost is 10750.24 RMB, with the highest cost being 171838.4RMB, and the lowest cost at 280.68RMB. The details are shown in Table 1. Average daily air concentrations of SO<sub>2</sub>, NO, CO, O<sub>3</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> are 12.36、50.75、1.10、95.85、59 and 93.71 (unit : ug/m<sup>3</sup>) respectively.

**Table 1: Subgroup Details**

Subgroup	variable	Mean.SD.	Median.25.75th.percentile.	Total
Total	cost	1053.75 (2001.06)	991.97 (991.97-673.82)	18195440.98
Gender	male	1193.63 (2472.52)	1056.52 (1056.52-701.01)	10594332.36
	female	905.80 (1300.35)	926.28 (926.28-661.60)	7601108.62
Age	old( $\geq 65$ )	956.16 (1227.43)	976.10 (976.10-669.05)	11377182.35
	young( $< 65$ )	1270.06 (1758.79)	1026.79 (1026.79-683.08)	6818258.624
Dtype	infarction	806.61 (918.51)	920.08 (920.08-646.61)	10613038.73
	hemorrhage	1844.99 (3529.94)	1400.49 (1400.49-800.22)	7582402.243
Result	death	2094.35 (3249.81)	2092 (2092-953.03)	1059000.282
	else	1022.36 (1934.93)	980.30 (980.30-670.66)	17136440.69

Note: This table is a comparison of the average, median, and total cost of the partial grouping.

## Spearman risk correlation analysis

The Spearman Coefficient is used to measure the dependence and correlation between data. We tested the Spearman Correlation between the pollutants, as shown in Table 3. It is clear that there is a positive correlation between SO<sub>2</sub>, NO<sub>2</sub>, CO, PM<sub>2.5</sub>, PM<sub>10</sub>. O<sub>3</sub> is significantly different from the others, its concentration is negatively correlated with other pollutants. This is an important result for the next discussion.

**Table 3: Spearman Correlation Analysis**

	SO <sub>2</sub>	NO <sub>2</sub>	CO	O <sub>3</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>
SO <sub>2</sub>	1	0.6547	0.4331	0.0017	0.5042	0.5396
NO <sub>2</sub>	0.6547	1	0.6833	-0.2688	0.7448	0.7191
CO	0.4331	0.6833	1	-0.3461	0.6828	0.6753
O <sub>3</sub>	0.0017	-0.2688	-0.3461	1	-0.3092	-0.2869
PM <sub>2.5</sub>	0.5042	0.7448	0.6828	-0.3092	1	0.9488
PM <sub>10</sub>	0.5396	0.7191	0.6753	-0.2869	0.9488	1

## Regression results

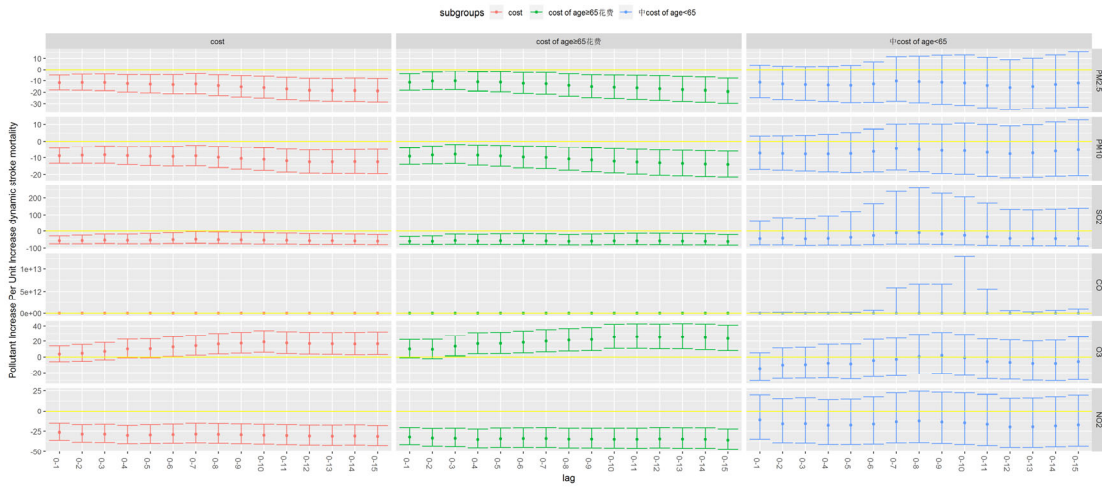
### Single-Pollutant models

In the single model, adjusted ER (95% CI) of cost and SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> IQR increases for lag periods (lag0–lag14), as shown in Fig.1. Among the lag day analyses, the lag10 day was found to have the most model fit.

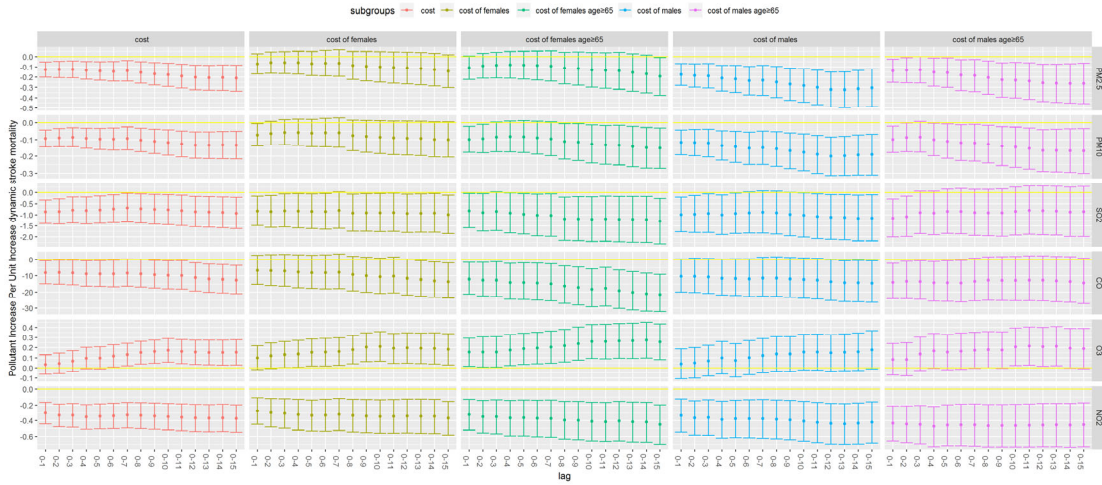
The results showed that PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub> and NO<sub>2</sub> were significantly negatively associated with total cost, with the best model at lag10 day (10-day moving average), and the corresponding ER for per IQR increase was 0.16%(95% confidence interval (95% CI)0.27%, 0.05%), 0.11% (95% CI0.18%, 0.03%), 0.74% (95% CI 0.14%, 0.07%) and 0.34% (95% CI 0.05%, 0.17%), respectively (P < 0.05). CO was significantly associated with total non-accidental mortality only at lag1, lag 4, lag 5, lag 12, lag 13, lag 14 day, the corresponding ER for per IQR increase was 7.82% (95% CI15.2%, 0.44%) (P < 0.05) at lag10 for example. The results of O<sub>3</sub> were significantly inconsistent with those of other pollutants. There was no statistical significance from the lag1 to lag6, but it was statistically significant since lag7 showed a positive correlation, reaching the maximum value at lag10, the corresponding ER per IQR increase was 0.16% (95% CI0.04%, 0.27%) (P < 0.05).

As shown in Fig.2, interestingly, except O<sub>3</sub>, the air pollutants in the subgroup of age showed statistical significance for the age $\geq$ 65 from lag1 to lag 14, O<sub>3</sub> showed the statistical significance from lag 3 to lag14, but no statistical significance for age<65 groups. In addition to the positive correlation of ozone at each significant time, there was a significant negative correlation between cost and other pollutants. We take lag10 to analysis, PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, CO, O<sub>3</sub> and NO<sub>2</sub>, the corresponding ER for per IQR increase was -0.14%(95% CI-0.22%, -0.05%), -0.1% (95%CI-0.16%, -0.04%), -1.01% (95%CI-0.17%, -0.32%), -1.01% (95%CI-0.17%, -0.32%), -14.63% (95%CI-23.14%, -6.11%), 0.11% (95%CI0.05%, 0.17%), -0.42% (95%CI-0.58%, -0.26%).

We also tested the gender as a subgroup, the details can be seen in Fig. 2, Only SO<sub>2</sub>, NO<sub>2</sub> and PM<sub>10</sub> on the first day had a significant negative correlation with women, and the rest of the pollutants had no significant correlation with women's costs. However, PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub> and part of SO<sub>2</sub> lag days have significant negative correlation with male's costs while O<sub>3</sub>, CO showed no significant correlation. Based on the above analysis, we made a further comparison between elderly males and elderly females. Although each pollutant has a significant correlation with the cost of strokes in the elderly, the results of elderly males and elderly females are different, O<sub>3</sub> has a positive correlation with the cost of elderly males and females, while NO<sub>2</sub> and CO have a negative correlation. PM<sub>2.5</sub> and PM<sub>10</sub> has a significant negative correlation with elderly males in each lag period, while only part of the lag period has a significant negative correlation with elderly women's cost. Sulfur dioxide showed a significant negative correlation with women in all lag periods, while men only showed a negative correlation with some lag periods.



**Figure 2: Excess Risk (ER) with 95% CI per IQR Increase of Daily Mean Concentration of SO<sub>2</sub>, NO<sub>2</sub>, CO, PM<sub>2.5</sub>, PM<sub>10</sub>, O<sub>3</sub> with Different Lag Days – the Overall Sample**



**Figure 3: Excess Risk (ER) with 95% CI per IQR Increase of Daily Mean Concentration of SO<sub>2</sub>, NO<sub>2</sub>, CO, PM<sub>2.5</sub>, PM<sub>10</sub>, O<sub>3</sub> with Different Lag Days – Subgroup(Age, Gender)**

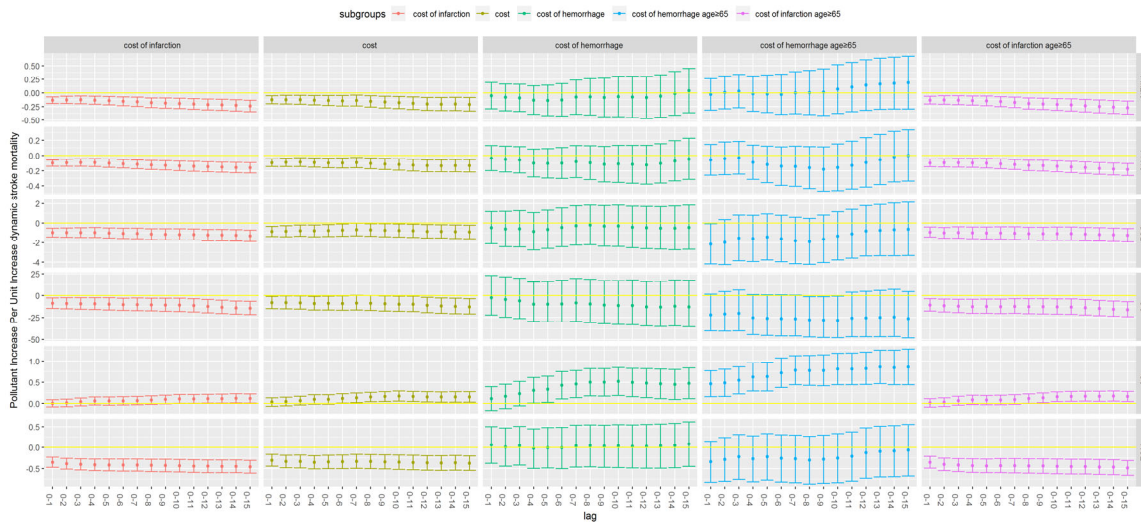
We also tested the disease subgroup hemorrhage and infarction. Though significant negative correlations are found for infarction, no significant correlation was found for hemorrhage. We tested a lot of subgroups such as seasons,



results, type of medical insurance, and selected meaningful parts as shown in the figure below:



**Figure 4: Excess Risk(ER) with 95% CI per IQR Increase of Daily Mean Concentration of SO2, NO2, CO, PM2.5, PM10, O3 with Different Lag Days - Cold Weather, Warm Weather**



**Figure 5: Excess Risk (ER) with 95% CI per IQR Increase of Daily Mean Concentration of SO2, NO2, CO, PM2.5, PM10, O3 with Different Lag Days - Different Disease Type Age >=65**

The two-pollutant adjusted models showed clear differences, the results of lag10 in two-pollutant adjust models were shown in Table 4. We analyzed various combinations, O3 and NO2 are interesting impact factors, for the whole group, PM2.5/O3、PM10/O3、O3/NO2、CO/NO2、SO2/NO2 showed a significant correlation, in the subgroups, only the elderly group can be seen to have a significant correlation with SO2/NO2、CO/O3、NO2/O3. The results also showed that when SO2、NO2、O3 was used as an adjusted variable, other pollutant concentrations tended to show the significant correlation with stroke hospitalization costs.



**Table 4: ER of Total Cost for IQR Increase of PM2.5, PM10, SO2, O3, CO, NO2 after Adjusting for Other Pollutions in Lag10 Day**

Variable		IQR increases
PM2.5	Adj. for PM10	-0.0007(-0.0039,0.0025)
	Adj. for SO2	-0.0014(-0.0029,0.0001)
	Adj. for CO	-0.0014(-0.0029,0.0001)
	Adj. for O3	-0.0014(-0.0025,-0.0002)*
	Adj. for NO2	0.0001(-0.0015,0.0017)
PM10	Adj. for PM2.5	-0.0006(-0.0028,0.0015)
	Adj. for SO2	-0.0011(-0.0022,0.0001)
	Adj. for CO	-0.0012(-0.0023,-0.0001)*
	Adj. for O3	-0.0008(-0.0016,0)*
	Adj. for NO2	0.0002(-0.0009,0.0014)
SO2	Adj. for PM2.5	-0.0018(-0.0108,0.0071)
	Adj. for PM10	-0.0001(-0.0103,0.0102)
	Adj. for CO	-0.0061(-0.0166,0.0044)
	Adj. for O3	-0.0055(-0.0123,0.0013)
	Adj. for NO2	0.0127(0.0007,0.0247)*
CO	Adj. for PM2.5	-0.0012(-0.1257,0.1233)
	Adj. for PM10	0.0207(-0.1155,0.157)
	Adj. for SO2	-0.0237(-0.1687,0.1214)
	Adj. for O3	-0.0539(-0.15,0.0421)
	Adj. for NO2	0.157(0.0079,0.306)*
O3	Adj. for PM2.5	0.0014(0.0002,0.0026)*
	Adj. for PM10	0.0013(0.0001,0.0024)*
	Adj. for SO2	0.0014(0.0002,0.0026)*
	Adj. for CO	0.0014(0.0002,0.0026)*
	Adj. for NO2	0.0013(0.0001,0.0024)*

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NO2	Adj. for PM2.5	-0.0036(-0.0061,-0.0012)*
	Adj. for PM10	-0.0039(-0.0065,-0.0012)*
	Adj. for O3	-0.0031(-0.0048,-0.0014)*
	Adj. for SO2	-0.006(-0.009,-0.003)*
	Adj. for CO	-0.0056(-0.0083,-0.0029)*

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We also compared the two-pollutant models in subgroups. Below is an analysis table for one of these subgroups, with more results to be seen in the subsequent appendix:

**Table 5: Compare of ER in Gender Subgroup or IQR Increase of PM2.5, PM10, SO2, O3, CO, NO2 after Adjusting for Other Pollutions in Lag10 Day**

Variable		IQR increases (male)	IQR increases (female)
PM2.5	Adj. for PM10	-0.0032(-0.0079,0.0015)	0.0026(-0.0015,0.0066)
	Adj. for SO2	-0.0029(-0.0051,0.0008)*	0.0004(-0.0015,0.0023)
	Adj. for CO	-0.0031(-0.0053,-0.001)*	0.0001(-0.0018,0.002)
	Adj. for O3	-0.0024(-0.004,-0.0008)*	-0.0002(-0.0017,0.0013)
	Adj. for NO2	-0.0017(-0.0041,0.0006)	0.002(0,0.004)
PM10	Adj. for PM2.5	0.0005(-0.0027,0.0036)	-0.0024(-0.0051,0.0003)
	Adj. for SO2	-0.002(-0.0037,-0.0003)*	0(-0.0014,0.0014)
	Adj. for CO	-0.0021(-0.0036,0.0005)*	-0.0003(-0.0017,0.0011)
	Adj. for O3	-0.0015(-0.0026,0.0003)*	-0.0004(-0.0014,0.0006)
	Adj. for NO2	-0.0008(-0.0025,0.001)	0.0011(-0.0004,0.0025)
SO2	Adj. for PM2.5	0.0037(-0.0099,0.0172)	-0.0108(-0.022,0.0003)
	Adj. for PM10	0.0052(-0.0103,0.0207)	-0.0092(-0.022,0.0035)
	Adj. for CO	-0.0072(-0.023,0.0085)	-0.009(-0.0221,0.0042)
	Adj. for O3	-0.0077(-0.0178,0.0024)	-0.0068(-0.0154,0.0018)
	Adj. for NO2	0.0119(-0.0064,0.0301)	0.0075(-0.0073,0.0222)
CO	Adj. for PM2.5	.0735(-0.1113,0.2583)	-0.1062(-0.2633,0.0509)
	Adj. for PM10	0.087(-0.1149,0.2888)	-0.0697(-0.2417,0.1023)
	Adj. for SO2	-0.0299(-0.2482,0.1885)	-0.0056(-0.1862,0.1751)
	Adj. for O3	-0.0884(-0.2299,0.053)	-0.0485(-0.1706,0.0736)
	Adj. for NO2	0.1417(-0.0813,0.3646)	0.137(-0.0492,0.3232)
O3	Adj. for PM2.5	0.0005(-0.0012,0.0023)	0.0022(0.0007,0.0037)*
	Adj. for PM10	0.0005(-0.0013,0.0022)	0.0021(0.0006,0.0036)*
	Adj. for SO2	0.0009(-0.0009,0.0026)	0.002(0.0005,0.0034)*
	Adj. for CO	0.0009(-0.0009,0.0026)	0.002(0.0005,0.0035)*
	Adj. for NO2	0.0007(-0.001,0.0024)	.0018(0.0003,0.0032)*
NO2	Adj. for PM2.5	-0.0017(-0.0054,0.002)	-0.0058(-0.0088,0.0028)*
	Adj. for PM10	-0.0023(-0.0064,0.0017)	-0.0054(-0.0086,0.0021)*
	Adj. for O3	-0.0034(-0.0059,0.0009)*	-0.0029(-0.005,-0.0008)*
	Adj. for SO2	-0.0062(-0.0107,0.0016)*	-0.005(-0.0087,-0.0014)*
	Adj. for CO	-0.0057(-0.0097,0.0016)*	-0.0054(-0.0088,0.0021)*

\*P&lt;0.05

## DISCUSSION

Time series study is a quantitative evaluation method applied to the study of the health effects of acute exposure to air pollution, which was first applied to the environmental epidemiology study of air pollution by Schwartz. A large number of studies have used this model for different diseases to find links between air pollutants and daily morbidity and mortality. Previous studies have demonstrated the selection of variables in this model, such as temperature, humidity, and so on. The selection method of degree of freedom refers to previous studies and the design. We make adjustments to this study based on our literature review.

Daniela A et al.(2013) use a negative binomial regression model for the time series study, and found when the PM<sub>2.5</sub> concentration increases by 10 mg/m<sup>3</sup>, the risk of emergency hospital admissions for cerebrovascular causes increases by 1.29% (95% CI: 0.55, 2.03)<sup>36</sup>. Jeffrey J.Wing et al.(2010) have found an association between higher levels of PM<sub>2.5</sub> and O<sub>3</sub> and higher rates of ischemic stroke<sup>37</sup>, but a study in Taipei found that carbon monoxide alone in air pollutants had an impact on stroke risk<sup>38</sup>, the inconsistency of the results may be due to geographical location<sup>39-40</sup>. Some studies have also focused on the effects of carbon monoxide and ozone in the air on the incidence of stroke<sup>41-42</sup>.

According to our results, we divided the patients into the death group and the alive group. The experimental results showed that the concentration of air pollutants had no correlation with the cost of the dead patients, while for the alive patients, except O<sub>3</sub>, the concentration of other pollutants had a significant influence on the costs of the alive patients, and all showed negative correlation. After subdividing stroke diseases into cerebral hemorrhage and cerebral infarction, it was found that there was no significant difference for those with hemorrhage, but infarction was significantly correlated with all pollutants except O<sub>3</sub>.

Air pollution should be recognized as a silent killer inducing stroke whose mortality rates remain elevated by its role as a new modifiable neurovascular risk factor. Different people react differently to O<sub>3</sub>. There are significant differences in the susceptibility of Chinese adults to ozone-related stroke, and a small proportion of the population may be seriously affected by O<sub>3</sub>. Through spearman analysis of various pollutants, we found that the correlation coefficients of O<sub>3</sub> are inconsistent with other pollutants, which may explain why O<sub>3</sub> has a negative effect on costs, while other pollutants have a positive correlation with costs.

People's behavior is affected by air pollution levels, which can cause changes or cancellations of trips. Studies show air pollution levels induce different behaviors such as reducing time spent outdoors, use of masks, and increased air cleaner use to protect against high outdoor air pollution. Since February 29th 2012, the Chinese government has required all regions to publish PM data to the public and PM has been getting more and more attention. Therefore, when the pollution is large, the increase in people's self-protection consciousness may make the individual's exposure value much lower than the environmental exposure value. There are many causes of stroke, such as high blood pressure, high BMI, cigarette smoking, and diabetes. Although many studies have proved a positive correlation between air pollution and stroke admission, no literature has proved that air pollution is the main influencing factor, and there is no evidence that air pollution affects the severity of strokes. Hospitalization costs were correlated with age, difficulty of surgery, comorbidity, etc. Although air pollution may increase the incidence of stroke, it may also cause milder cases. This may explain why pollutants such as PM are negatively correlated with stroke costs, which is also consistent with spearman's analysis results. If our guess is correct, residents' awareness of self-protection can be enhanced through the early warning of air pollution, which may reduce the admission of stroke caused by air pollution, thus reducing the costs to society as a whole.

In the gender subgroup studies, we found that female's costs was affected by SO<sub>2</sub> and NO<sub>2</sub>, while male's costs was significantly correlated with all pollutants except CO and O<sub>3</sub>. Most Chinese men have the behavior of smoking, and Chinese men who smoke more than 10 cigarettes a day and have been smoking for more than 10 years have CO levels in their bodies that exceed the normal value. Due to the influence of smoking behavior, the CO content in the air is lower than the long-term exposure value. This explains why men are less affected by CO, while women's costs are significantly affected by CO. There was no significant relationship between female's costs and PM value, while the influence on men was significant. This may be because women are more sensitive to the air quality index and know how to protect themselves, such as adopting masks and reducing time outside.

In the grouped studies, we found males were more likely than females, and people over 65 years old were more likely than younger adults to be affected by air pollution in their spending. The research shows that age is the most important risk for stroke, and men are more likely to suffer from strokes than women. These are consistent with our results. A significant correlation was found among the subgroups (such as gender, season) of people over 65 years old.

In the age subgroup studies, the elderly are particularly affected by air pollution, with almost all pollutants having a significant impact on their spending. There was no significant correlation between air pollution concentration and stroke costs in young people (age < 65). In the data description stage, we found that 79.57% of the elderly were admitted to hospital due to cerebral infarction, and 20.43% were admitted to hospital due to cerebral hemorrhage. Medical studies have shown that particulate matter in the air can cause cerebral infarction, but no link has been found between air pollution and cerebral hemorrhage. In the study grouped by disease type, we also found that most air pollution had a significant relationship with the cost of infarction stroke, but no significant relationship with hemorrhagic stroke. The physical weakness of the elderly makes them vulnerable to air pollution, while hospital admissions among young people are often caused by other causes.

In the cold season, only on a very few lag days could a significant negative correlation in PM analyses be found, but the relationship between pollutant concentrations and costs is more pronounced in warmer seasons. It may be that the cold season itself is a season of high disease incidence so that the costs are affected by other factors.

In the result (death and non-death) sub group, all air pollution had no significant effect on the cost of dying patients, while in the non-death patients, all pollutants except O<sub>3</sub> had a significant effect. This further confirms our hypothesis that air pollution has only a slight effect on stroke. As we continued to divide the elderly group into gender and disease type, we found a significant correlation, particularly in the elderly infarction expenditure group, which had a greater impact than the other groups.

Although a large number of studies have found that air pollution increases medical costs, the findings of this study may be decreasing for individual stroke patients. Also, there are a few limitations in this study: firstly, we only took the total cost as the research object and did not carry on the analysis to the expenditure constitution result. Also, with only two years of data available, the amount of data is limited. We only considered the area covered by one monitoring station. Moreover, this study did not take into account the patient's own factors, such as age, history of disease, comorbidity, etc., which all affect the cost. Thus, more research needs to be done.

## CONCLUSION

Our study gives us an interesting conclusion, we found a correlation between air pollution and stroke medical costs, especially in age ≥ 65, warm season and hemorrhage subgroups. Although a large number of research has proven that air pollution is positively correlated with the incidence of stroke, most pollutants, except O<sub>3</sub>, are significantly negatively correlated with the medical cost of a stroke. Moreover, environmental problems are huge challenges facing developing countries. We need to dig deeper into the impact of environmental pollution on healthcare. More diseases are worth studying.

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