Analysis on the Temporal and Spatial Characteristics of Air Quality in the Main Urban Area of Jinan City

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Abstract. According to the monitoring data of air pollutants in Jinan City and Jinan Statistical Yearbook from 2005 to 2016, the space-time variation characteristics of mean concentration were analyzed. Although the overall air pollution in Jinan City was relatively serious, there was a generally lowering tendency in recent years. Firstly, the average concentration of SO$_2$ increased from 2005 to 2016, and then decreased, with the maximum concentration of 93ug/m$^3$ appearing in 2013. The average concentration of PM$_{10}$ showed a slow decline during 2005-2012. At the turning point in 2013, the average concentration increased suddenly, reaching a maximum of 191ug/m$^3$. As far as NO$_2$ is concerned, its annual change trend is analogous to that of SO$_2$. The average monthly concentration presented a serious seasonal variation, with severe pollution in winter and light pollution in summer. Secondly, on the part of the spatial distribution, the concentration of pollutants in the central and northern parts of the main urban area of Jinan was higher, while that in the south was lower. Last but not least, correlation analysis shows that there is a significant negative correlation between SO$_2$, PM$_{10}$, NO$_2$ and temperature. The maximum correlation coefficient is -0.868, and the correlation is strong. PM$_{10}$ is positively correlated with atmospheric pressure, with a correlation coefficient of 0.701, which is negatively correlated with relative humidity and precipitation.

1. Introduction
With the rapid development of China's economy, the air quality is under enormous pressure [1]. Atmospheric particles especially inhalable particles and fine particles play a significant role in the quality of atmospheric environment [2-3]. Air pollution not only leads to increasingly serious environmental pollution in cities, but also further exacerbates the harm to human health and ecological balance [4]. Nowadays, air quality is increasingly a focal point of concern for citizens. Since 2000, many scholars have taken up research into PM$_{10}$ pollution status, health assessment, source analysis, transboundary pollution [5-7] and other achievements, but most of researches focus on the single pollution factor in the air. There are few studies on multiple air pollution factors. This article quantitatively analyzed the air quality in the main urban area of Jinan City through the scaling exponents and air pollution index. Only by understanding the current status of environmental quality and clearly identifying the influences, can we propose a creative solution on environmental governance.

2. Study area overview and data sources
Jinan City is located in the middle of Shandong Province, between 36° 01′~37° 32’ N and 116° 11′~117° 44’ E[8]. The space structure of Jinan is “one city and two districts”, representing the
main urban area and the western and eastern urban areas respectively. The main urban area is located in east of Yufu River, west of the highway east ring, and between the Yellow River and the southern mountainous area [9]. It is determined as the four districts of Huaiyin, Lixia, Tianqiao and Shizhong. The air quality indicators for this study were inhalable particles (PM$_{10}$), sulfur dioxide (SO$_2$), and nitrogen dioxide (NO$_2$). The monitoring points for these three indicators were located in the main urban area of Jinan City (Figure 1). The data of pollutant concentration and meteorological for 2005-2016 were gained from the China Meteorological Data Network and Statistics Bureau of Jinan City.

![Figure 1. The distribution map of the monitoring points in the main city of Jinan](image)

### 3. Research Methods

Pearson correlation is used in correlation analysis. Its value range is -1 to 1, and the greater the absolute value, the stronger the correlation, conversely, the closer the correlation coefficient is to 0, the weaker the correlation. Consequently, it is applicable to the correlation analysis of meteorological data and has a significant correlation. The specific formula is as follows:

$$\rho_{XY} = \frac{\text{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E((X - \mu_X)(Y - \mu_Y))}{\sigma_X \sigma_Y} = \frac{E(XY) - E(X)E(Y)}{\sqrt{E(X^2) - E(X)^2} \sqrt{E(Y^2) - E(Y)^2}}$$  \hspace{1cm} (1)

Where $E$ is the mathematical expectation; COV represents covariance; $X$ and $Y$ are the corresponding elements, and this paper is the concentration of atmospheric pollutants and meteorological data respectively.

### 4. Analysis of Time Distribution Characteristics of Air Pollutants

#### 4.1. Analysis of inter-annual variability in major pollutants

By analyzing the concentration of pollutants, an interannual variations of the main urban area of Jinan City was obtained (Figure 2). From 2005 to 2016, the SO$_2$ concentration increased first and then decreased. The concentration presented an increasing trend before 2013, and showed a decreasing trend after 2013. In 2016, the minimum concentration reached 38ug/m$^3$. The largest increase occurred in 2013, reaching the maximum concentration of 93ug/m$^3$ within 11 years.

On the whole, the PM$_{10}$ concentration showed a slow downward trend from 2005 to 2012, reaching a minimum annual average concentration of 104ug/m$^3$. However, in 2013, the annual average concentration suddenly increased to a maximum of 191ug/m$^3$, and then decreased gradually in 2014-2016.

The analysis of NO$_2$ showed that the average annual concentrations had no pronounced changes, and the tendency of change was similar to that of SO$_2$. The minimum and maximum concentrations appeared in 2006 and 2013 separately.
In general, the annual PM$_{10}$ pollution level was relatively high, both exceeding the national secondary standard of 100ug/m$^3$, especially in 2013, the concentration reached 191ug/m$^3$. The concentration of SO$_2$ in the period from 2005 to 2016 was generally volatile, showing a trend of increasing first and then decreasing. NO$_2$ pollution in 2005-2016 has no obvious variations. Through analysis, PM$_{10}$ was the main pollutant in Jinan City, and NO$_2$ pollution was lighter.

4.2. Analysis of inter-monthly variation of major pollutants

Results from monthly analysis revealed that concentration of SO$_2$ peaked in January, exceeding the national secondary standard of 60 $\mu$g/m$^3$ (Figure 3). By contrast, the trend of SO$_2$ from January to July was gradually decreased. After August, SO$_2$ pollution began to gradually increase. The pollution of SO$_2$ was relatively serious during the heating period, while the summer pollution with light precipitation was light.

From the perspective of various indicators, the pollution of PM$_{10}$ was relatively serious. In November of each year to April of the following year, the pollution was relatively severe, and in the 5-10 months of each year, the pollution was lighter. The extremes of concentration occurred in January and August. According to the change data of NO$_2$ in the period from 2005 to 2016, it can be seen that NO$_2$ pollution was relatively light, and the trend of change was the same as that of SO$_2$.
5. **Spatial distribution characteristics of atmospheric pollutants in Jinan**

This paper opts the air quality of the last three years as the object, using the ARCGIS software from the inverse distance weighting method for the concentration of SO$_2$ (ug/m$^3$), PM10 (ug/m$^3$), and NO$_2$ (ug/m$^3$) to analyze spatial interpolation and spatial distribution research of Jinan urban area atmospheric pollutants. The pollution of SO$_2$ showed an increasing distribution from south to north (Figure 4). A maximum area was formed in the north with a concentration of more than 120ug/m$^3$, which was closely related to the topography. The SO$_2$ concentration decreased overall in 2014-2016, and the change in the central urban area of Jinan City was more obvious.

In spatial analysis, PM$_{10}$ had serious pollution in the northwest and relatively low pollution in the southeast. There was a maximal center in the middle and the difference between the maximum values was 1.7 times. This spatial differentiation might be the consequence of both wind direction and topographic effects (Figure 5). Interannual changes showed that the concentration of PM$_{10}$ decreased year by year, the area where the maximum occurred shifts from the middle to the north, and the pollution in the west has improved.

![Figure 4. The spatial distribution of SO$_2$ in the main city of Jinan for 2014-2016 years](image)

![Figure 5. The spatial distribution of PM$_{10}$ in the main city of Jinan for 2014-2016 years](image)

![Figure 6. The spatial distribution of NO$_2$ in the main city of Jinan for 2014-2016 years](image)

The concentration of NO$_2$ exceeded the secondary standard of ambient air quality of 40ug/m$^3$. Within three years, the concentrations were not much different, but the transfer occurred in areas with severe pollution. In 2014, it appeared in the central part of the study area, and in 2015 it changed to the northeast, and 2016 turned to the north (Figure 6). The appearance of this situation might be related to industrial production.
In general, the pollution in the southern part of Jinan City was light, while the pollution in the north and central parts was serious. From 2014 to 2016, the concentration of pollutants has been significantly reduced, and the environmental quality has improved.

6. Correlation Analysis of Air Pollutants and Meteorological Factors in Main Urban Area of Jinan City

Through Pearson correlation coefficient analysis, the correlation between atmospheric pollutants and meteorological factors in the main urban area of Jinan City was obtained. The results are shown in Table 1. The table shows that SO$_2$ and NO$_2$ have a significant correlation (p<0.01 or p<0.05) with the average temperature, the maximum temperature, and the minimum temperature, with the largest correlation coefficient being -0.748. However, there is a significant correlation between PM$_{10}$ and air pressure, average temperature, maximum temperature, minimum temperature, relative humidity, and maximum precipitation (p<0.01 or p<0.05). The largest correlation coefficient was -0.868.

Table 1. Analysis of atmospheric pollutants and meteorological factors in the main city of Jinan

|           | Atmospheric pressure | Average temperature | Maximum temperature | Minimum temperature | Relative humidity | Maximum precipitation |
|-----------|----------------------|---------------------|---------------------|---------------------|------------------|-----------------------|
| PM$_{10}$ | 0.701*               | -0.867**            | -0.866**            | -0.868**            | -0.605*          | -0.738**              |
| SO$_2$    | 0.612                | -0.748**            | -0.743**            | -0.748**            | -0.468           | -0.569                |
| NO$_2$    | 0.622                | -0.721**            | -0.716**            | -0.721**            | -0.430           | -0.545                |

*: p<0.05  **: p<0.01

Average temperature, maximum temperature, minimum temperature and three pollutants are negative correlation, and the correlation of PM$_{10}$ is strongest, maintaining near 0.86, shows that with the increase of the temperature, the concentration of PM$_{10}$ presents downward trend. The relationship between NO$_2$ and SO$_2$ is also negatively correlated with temperature, and the correlation coefficient is near -0.7. Temperature is the dominant meteorological factor on affecting air pollutants. The concentration of PM$_{10}$ is positively correlated with air pressure and negatively correlated with precipitation and relative humidity. The relation between PM$_{10}$ and relative humidity is consistent with the conclusion of Tan [12], while NO$_2$ and SO$_2$ have no significant correlation with these meteorological factors.

7. Conclusions

This paper analyzed the temporal and spatial characteristics of major pollutants SO$_2$, NO$_2$ and PM$_{10}$ in the main urban area of Jinan City. Based on the data collected from 2005 to 2016, we can conclude that:

(1) PM$_{10}$ pollution was relatively serious throughout the year and was the main pollutant in Jinan City.

(2) In 2005-2016, the average concentration of SO$_2$ in the main urban area of Jinan City increased first and then decreased, with the maximum concentration of 93ug/m$^3$ occurring in 2013. The average concentration of PM$_{10}$ showed a slow downward trend in 2005-2012. In 2012, it reached an annual average concentration of 104ug/m$^3$, which suddenly increased after 2013, reaching a maximum of 191ug/m$^3$. The average annual concentration of NO$_2$ was similar, and the inter-annual variation was similar to that of SO$_2$.

(3) The monthly variation of atmospheric pollutant concentration in the main urban area of Jinan city has obvious seasonal characteristics. In winter, the pollution was the most serious, especially in January, the most serious pollution was in the summer, and the pollution was lighter in summer.

(4) In recent years, air pollutants in Jinan had obvious spatial and temporal variation characteristics. The concentrations of pollutants in the south were relatively low, while the concentrations in the central and northern parts were relatively high. The concentration in 2014-2016 years had been reduced to varying degrees.
(5) SO$_2$, PM$_{10}$ and NO$_2$ have a significant negative correlation with the highest temperature, minimum temperature and average temperature, and the maximum correlation coefficient was -0.868. PM$_{10}$ was positively correlated with air pressure, with a correlation coefficient of 0.701, but negatively correlated with relative humidity and precipitation.

Acknowledgments
This study was financially supported by the Natural Science Foundation of China (NO.41471160)

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