Temporal and Spatial Exposure of Gaseous Pollutants and Its Influence Factors in Shandong Province

Zhao Qiang, Zou Chunhui, Gao Qian, Zhang Shengnan and Li Xiumei
University of Jinan, School of Water Conservancy and Environment, Jinan, 250000, China
Li Xiumei, stu_lixm@ujn.edu.cn

Abstract. According to the monitoring data of SO2, NO2 and PM10 in Shandong Province from 2005 to 2016, and Daniel Tendency Verification was used to analyze the trends and influencing factors of urban air quality. The results show that: (1) The comprehensive pollution index of Shandong Province showed downtrend during 2010 to 2016 which indicated the ambient air quality was improving. The changes in the main atmospheric pollutants are obvious: SO2 and PM10 show a significant downward trend, and NO2 is relatively stable. (2) In recent years, pollutants in Shandong Province have obvious temporal and spatial changes, and the highest concentration of SO2 has appeared in Zibo City. The area with high concentration of NO2 gradually shifted to the central Shandong Province, while the high concentration of PM10 shifted from south to west. The monthly variation of SO2, NO2 and PM10 had the same tendency. The high concentration appeared in November, December and January and the low concentration occurred from June to September. PM10 had a small peak in the non-heating period (March to April) which was influenced by dust weather. (3) Some artificial control measures such as optimization of industrial and energy structure and regulations of atmospheric pollution sources played important roles in improving air quality in Shandong province. Topography, geomorphology, climate and other natural factors were significant external factors which had effects on the spatial and temporal distribution of air pollutants.

1. Introduction
With the rapid development of economy and acceleration of industrialization and urbanization, the increasing consumption of oil, coal, natural gas and other energy has produced a great deal of pollution and put tremendous pressure on regional ambient air quality[1]. Shandong province, located on the east coast of China, is a great province of China`s economy, industry and population. In recent years, the problems of environmental pollution have become more and more obvious, and the degree of air pollution has reached a higher level[2]. Domestic and foreign scholars have carried out a lot of research on air pollution. Eunhwa et al studied the characteristics of spatial and temporal distribution and the meteorological factors of pollutants such as SO2 and PM10 in Busan, South Korea[3]. Zhao Shaohua et al studied the application of satellite infrared remote sensing and radar remote sensing in environmental pollution monitoring, and provided new methods for air pollution monitoring[4]. What is lacking is that most studies are conducted only on a single city or some type of atmospheric pollutant, and there is less research on the regional scale.

Based on the environmental monitoring data in Shandong province during 2010-2016, this paper uses Daniel Tendency Verification and ArcGIS to analyse the regularity of spatial and temporal variation of SO2, NO2 and PM10 in the whole province, and further understand the distribution of air pollutants.
pollutants in Shandong province. Thus, it could provide accurate information for the atmospheric environmental management and effective basis for government decision-making in Shandong province.

2. Materials and methods

2.1. Characteristics of the study area
Shandong province, which is located in the mid-latitude coastal areas, eastern China, situated between east longitude 114° 36' ~ 122° 43' and latitude 34° 25' ~ 38° 23'. The topography of Shandong is complex: The terrain is higher in the center and lower around, the mountain and hill cut brokenly, and the plain is vast[5]. It has 155 thousand and 800 square kilometers of land and consist of 17 prefecture-level cities and 31 county-level cities. The geographical location of local cities is shown in Figure 1.

Fig.1. Geographical location of Shandong Province

2.2. Data sources
The interannual trend analysis of SO₂, NO₂ and PM₁₀ mean and pollution index was carried out with long-term fixed-point monitoring data on urban environmental air quality in Shandong from 2010 to 2016. The data used are from the Shandong statistical yearbook and the Shandong provincial Environmental Status Bulletin from 2010 to 2017, the data is reliable.

2.3. Research methods
The atmospheric environment quality was assessed by means of calculating the comprehensive air pollution index and the pollution load. The evaluation formulas are presented in (1) - (3).

\[ P = \sum P_j \]  
\[ P_j = C_j / S_j \]  
\[ f_j = P_j / P \]

In these formulas: \( P \) is comprehensive pollution index; \( P_j \) is the sub-index of the j-th air pollutant; \( C_j \) is seasonal mean value or annual average value of j-th air pollutant, μg/m³; \( S_j \) is the standard limited value of j-th air pollutant, μg/m³; \( f_j \) is the pollution load of j-th air pollutant.

The Daniel tendency test method, also known as Spearman coefficient of correlation method, is used to evaluate the statistical significance of the trends in air pollutants[6]. Daniel tendency test method requires the following formulas.

\[ R_s = 1 - (6 \sum_{i=1}^{n} d_i^2) / (N^3 - N) \]  
\[ d_i = X_i - Y_i \]

In these formulas: \( R_s \) is rank correction coefficient; \( N \) is the amount of data; \( X_i \) is the ordinal number of air pollutants; \( Y_i \) is the ordinal number of time.

The absolute value of the rank correlation coefficient (\( R_s \)) compares with the threshold value (\( W_p \)) in the statistical table of Spearman rank correlation coefficient. If \( R_s \) is negative, indicating that the
3. Results and discussion

3.1. Trend analysis of atmospheric pollution

3.1.1. Comprehensive index analysis. The comprehensive pollution index and pollution load was calculated according to the pollutant concentration in each year. Looking from the trend(Fig.2), the annual average values of SO\(_2\), NO\(_2\) and PM\(_{10}\) concentration showed a trend similar. The overall air pollution index in Shandong province showed a downward tendency, but it fluctuated in 2013. From the contribution rate of the overall atmospheric pollution (Fig. 3) during 2010-2016 years, the contribution rate of the PM\(_{10}\) is the greatest, and the pollution load is about 0.5, which is the primary pollutant in the air pollution.

![Fig. 2. Annual variation trend of pollutants in Shandong Province during 2010-2016](image)

![Fig. 3. Change of pollution load of each pollutant during 2010-2016](image)

3.1.2. Variation trend analysis of the major pollutant. The variation trend and degree of major air pollutants in Shandong province were calculated by Daniel tendency test method. According to the table 1, SO\(_2\) and PM\(_{10}\) showed a significant decline, while NO\(_2\) changes were more stable.

| Pollutant | Rs    | Result             |
|-----------|-------|--------------------|
| SO\(_2\)  | -1.96 | Significant decline|
| NO\(_2\)  | -0.43 | Smooth change      |
| PM\(_{10}\)| -1.50 | Significant decline|

3.1.3. Spatial and temporal trend analysis. 2010 and 2016 are the beginning and end of the study period, the time span is large, it can indicate the change of pollutant concentration more intuitively. So we take 2010 and 2016 as an example, pollutant concentration is spatially interpolated by ArcGIS 10.2
to draw the mean regional distribution contrast diagram of SO\textsubscript{2}, NO\textsubscript{2} and PM\textsubscript{10} in Shandong province. Through the above methods, we obtain result maps (Fig. 4 to Fig. 6).

In 2010, the concentration of SO\textsubscript{2} in the middle and south of Shandong is high, the city with the highest concentration is Zibo, and the concentration of SO\textsubscript{2} in most areas of the province is higher than the national secondary standard. Compared with 2010, the concentration of SO\textsubscript{2} is reduced generally in 2016, the concentration in central Shandong is also high, and the highest value still appeared in Zibo.

![Fig. 4. Comparison of spatial distribution of SO\textsubscript{2} in Shandong Province between 2010 and 2016](image)

The mean change trend of NO\textsubscript{2} years in 2010-2016 years is not significant. Compared with 2010, the high concentration area of NO\textsubscript{2} in 2016 shifted to the central part of Shandong, and the concentration value decreased as a whole. However, some areas still went beyond national secondary standard.

![Fig. 5. Comparison of spatial distribution of NO\textsubscript{2} in Shandong Province between 2010 and 2016](image)

In 2010, the concentration of PM\textsubscript{10} in the whole province surpassed national secondary standard, in which the concentration of Linyi was the highest and Weihai and Yantai were lower than other cities. In 2016, the high value of PM\textsubscript{10} concentration was transferred to the west of Shandong, and the highest value appeared in Liaocheng.

![Fig. 6. Comparison of spatial distribution of PM\textsubscript{10} in Shandong Province between 2010 and 2016](image)
From the spatial distribution characteristics of SO2, NO2 and PM10, the serious atmospheric pollution areas in Shandong are distributed in other areas except the coastal regions (such as Weihai and Yantai), which are related to the regional economic development level, industrial structure, population density and natural conditions.

3.1.4. Seasonal change trend analysis of pollutant concentration. Figure 7 discusses the monthly mean value change of air pollutants in Shandong province during 2010 to 2016. It can be seen that the monthly mean value change trend of SO2 and NO2 is basically same. The high concentration is mainly between November to January, and the low concentration is mainly between July to September. The change tendency of PM10 is basically the same as the two pollutants mentioned above, but it increased obviously in March and April, which was linked to the increase of sand and dust weather in March and April. The maximum appeared in December, and the minimum appeared in August. In conclusion, atmospheric pollution in Shandong was heavier between November to January and lighter between July to September.

3.2. Influencing factors analysis of environmental air quality change

3.2.1. Natural factors. Shandong province is situated in the southeast of North China Plain, the third step of China. The central and western part of it is the plain, and the middle and east is gentle hills and hilly areas. The overall view of the underlying surface is complicated and diverse. The topography of the underlying surface will affect the flow of the atmosphere, thus affecting the diffusion of air pollutants. Temperature, wind speed, precipitation and other factors are equally important external factors for seasonal variation of air pollutant concentration. The concentration changes of PM10 are related to dust weather. Dust storms frequently occur in spring (March to May) in the northern part of China[7]. During this process, the concentration of PM10 rises sharply and the visibility decreases.

3.2.2. Artificial factors. Figure 7 analyzes the change of vehicle ownership and annual average of NO2/SO2 from 2010 to 2016 in Shandong province. It can be observed in the chart that the amount of automobile ownership is rising year by year, and the average annual ratio of NO2/SO2 is also increasing year by year. It shows that air pollution characteristics of Shandong are gradually transition from coal smoke pollution to vehicle exhaust pollution, and the overall performance is compound pollution, which is similar to Urumqi and Xi'an[8].

![Fig. 7. Change of the ratio of NO2 to SO2 in Shandong Province during 2010-2016](image)

According to the plan of prevention and control of atmospheric pollution, Shandong has always upheld the idea of "regulating structure, promoting management and making greening", and vigorously adjusting the industrial structure. The development plan of total capacity control for the "two high" industries, such as iron and steel, electrolytic aluminum, cement, flat glass, coke and so on, has been formulated and implemented. The above industrial structure and the optimization of the energy structure have achieved certain results, for example, in 2016, the GDP of Shandong increased by 60.8% compared with 2010, while the total energy consumption increased by only 12.8%[9]. The
trend of pollutant concentration changes decreases and the concentration of atmospheric pollutants gradually decreases.

In order to vigorously promote pollution control, Shandong province controls outstanding environmental problems through promoting clean energy, cleaning up the "scattered pollution" enterprises and small coal-fired boilers, preventing vehicle exhaust pollution and other measures. At the same time, Shandong province is entirely implemented the "three dispatch and one notification" system. The implementation of various policies in Shandong Province has played a certain role in reducing SO2 and PM10 emissions. It will help to reduce the emission of pollutants and reduce the concentration of pollutants in the atmosphere so that the environmental pollution can be effectively controlled.

4. Conclusions
This paper analyzes the temporal and spatial characteristics of major pollutants SO2, NO2 and PM10 in Shandong Province. Based on the data collected from 2010 to 2016, we can conclude that:

(1) In the 2010-2016 year, the comprehensive pollution index of Shandong showed a downward trend, indicating that the environmental situation of Shandong province has improved. During the 2010 to 2016, SO2 and PM10 showed a significant downward trend, NO2 was relatively stable, and PM10 contributed most to the overall air pollution.

(2) On the spatial distribution, the high concentration area of SO2 appears in the central part of Shandong, including Zibo, Laiwu and other heavy industry regions, and the distribution of high NO2 and PM10 decreases. In central and southern Shandong, the concentration of SO2 was relatively high in 2010. In 2016, the whole concentration of SO2 decreased. The concentration in central Shandong was higher, and the highest value still appeared in Zibo City. The trend of the annual mean value of NO2 during 2010-2016 was not much different. Compared with 2010, the high value of NO2 concentration in 2016 shifted to the central Shandong. In 2010, the concentration of PM10 in Linyi City was the highest. In 2016, the high value of PM10 concentration transferred to the western Shandong Province, and the highest value appeared in Liaocheng.

(3) The overall change trend of SO2, NO2 and PM10 is basically the same. The high concentration is mainly in the 11-1, and the low concentration occurs in 7-9 months in summer and autumn. PM10 has a small peak in 3-4 months during the non heating period, which is affected by sand and dust weather.

(4) In Shandong, the optimization of industrial structure and the energy structure and the regulation of air pollution sources may play an important role in improving air quality. Natural factors such as topography, climate, wind and dust are the external causes of the temporal and spatial variations of air pollutant concentration.

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