

Original Research

Variation of Particulate Matter and Its Correlation with Other Air Pollutants in Xi'an, China

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Abstract

In recent years, the high concentration of air pollutants has seriously affected people's daily life. So, it is important and necessary to know the spreading PM_{2.5} concentration and its correlation with other pollutants. The data presented in this paper was received from 13 monitoring stations by a typical northern city of Xi'an in China for the whole year of 2017. The concentration distribution of PM_{2.5} and its variations with the season, month and day were analyzed. Also the average correlation between PM_{2.5} and CO, SO₂, NO₂, O₃ and PM₁₀ was studied. The results showed concentrating PM_{2.5} was consistent with the seasonal, monthly and daily trends. The concentration of PM_{2.5} showed a low in summer and autumn. While the concentration of PM_{2.5} was higher in spring and winter, and the highest concentration was in winter. The daily variation distribution of PM_{2.5} showed a double-peak variation characteristic. The concentration of PM_{2.5} reached a peak between 8:00-9:00 in the morning and 22:00-23:00 in the evening. Particles of Xi'an in atmospheric were mainly fine particles. There was a strong correlation between PM_{2.5} and CO, SO₂, NO₂, PM₁₀, but a negative correlation between PM_{2.5} and O₃. A multivariate linear regression model with the pollutant concentration of CO, SO₂, NO₂ and PM₁₀ was established. This study helps to understand the distribution of PM_{2.5} and its correlation with other pollutants of Xi'an, and further supplying important support for the targeted controlling approach of fog and haze.

Keywords: correlation, concentration distribution, other pollutants, PM_{2.5}, variation

Introduction

With improved living conditions, people gradually pay more and more attention to the problems which were caused by air pollution [1]. The concentrations of particulates and gassy pollutants in the atmosphere were all seriously exceeded. Such as PM_{2.5}, PM₁₀, sulfur

dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), and ozone (O₃) [2]. They would not only lead to a serious decline in atmospheric visibility, but also they would cause many problems to people's travel and transport at the same time [3]. PM_{2.5} was usually referred to as particulate with an average aerodynamic diameter of less than 2.5 μm, and they did not settle automatically [4]. PM_{2.5} was more likely to carry more viruses or bacteria with its small particle sizes and large specific surface area. It would bring different degrees of harm to human health, even death [5-7].

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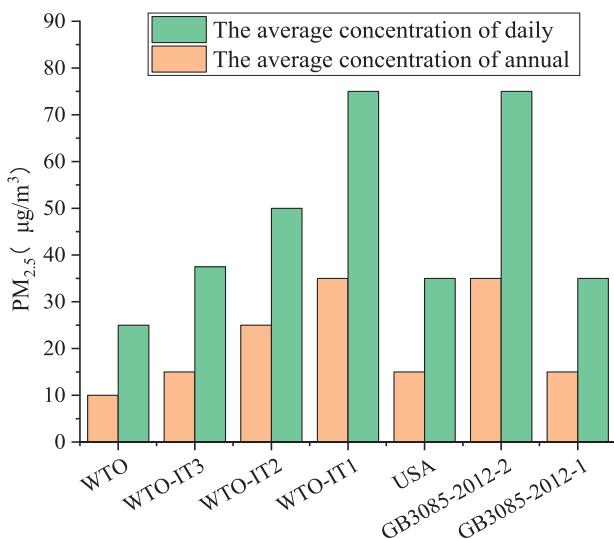


Fig. 1. Limit concentrations for $\text{PM}_{2.5}$ in each standard.

Therefore, all countries and related organizations had been adopted many policies and standards to reduce the concentration of atmospheric particulate matters now [8-12]. Most developed countries been updated and improved the relevant standards now. $\text{PM}_{2.5}$ was taken into the latest control target, and the limit concentrations for $\text{PM}_{2.5}$ were shown in Fig. 1.

Besides limited of the daily average concentration and annual average concentration for $\text{PM}_{2.5}$, WHO also showed three transition period target values, which would provide phased targets for countries or regions. The limit of daily average concentration of $\text{PM}_{2.5}$ in developed countries was consistent ($25\text{-}35 \mu\text{g}/\text{m}^3$), which was lower than the limit value of developing countries. The average daily concentration of $\text{PM}_{2.5}$ was as a recommended signal and it was not compulsory [13]. The daily average concentrations were 35 and 75 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$, 50 and 150 $\mu\text{g}/\text{m}^3$ for PM_{10} in Chinese standard, respectively [12].

The study of pollution characteristics and sources for $\text{PM}_{2.5}$ in atmosphere also gradually became the focus of researchers at different countries. Some results had been achieved, and the main focus were on composing particulate matters [14], the limits of the standards [15], regional studies [16], human health and the correlation between particulate matters and other pollutants [17]. In addition, more scholars were also focusing on the research and development of new air filter materials to control the concentration of particulate matter [18, 19]. Also some types of corresponding measures and research were carried out to solve the existing environmental pollution problems [20-25]. For example, plants could reduce many pollutants such as carbon monoxide, particles [20, 21], and they also could change the climate on the environment as well as urban area [22]. Furthermore, the plants could reduce the stress and negative feelings to improve the effectiveness of work [23-25].

However, there were few studies on the concentration distribution characteristics of $\text{PM}_{2.5}$ in different timescales and correlating other major pollutants in the atmosphere. The research on the current domestic was only part of the region. For example, Tianjin [26], Shanghai [27], Guangzhou [28], Xi'an [14]. But there were great distinctions in different regions of China, and the characteristics of pollutants would also change every year, which would lead to more complicated distribution and source of $\text{PM}_{2.5}$. There was why spreading $\text{PM}_{2.5}$ concentrations in different regions was different [29]. So, the typical regional research on the frequent smog in the central and western regions was even more lacking.

Xi'an was selected as an example in this paper, which was the typical city of northern China, and it is located at east longitude from $107.40^\circ\text{-}109.49^\circ$ and north latitude $33.42^\circ\text{-}34.45^\circ$. The data was received from 13 monitoring stations of Xi'an for the whole year of 2017. The aim of the study was to provide the detailed data on pollutant concentrations, and the concentration distribution of $\text{PM}_{2.5}$ and its correlation with other pollution were taken into analysis. It would help to explore the causes of $\text{PM}_{2.5}$ pollution and its main sources.

Methods

The data was collected from January 31, 2017 to December 31, 2017 in this paper, and they were gathered from the national urban air quality real-time publishing platform. Such as the average concentration values of O_3 , CO , SO_2 , NO_2 , PM_{10} and $\text{PM}_{2.5}$ were all collected from the weather forecast network (<http://www.tianqihoubao.com/aqi/xian>) every day. The hourly concentration values of six kinds of pollutants in 13 monitoring stations in Xi'an released by the weather network (<http://www.tianqi.com/air/xian.html>). According to the air quality index [12], the average value of each pollutant after the summary of each monitoring point was calculated. In addition, GRIMM1.109 portable aerosol particle size spectrometer was used to measure the concentration of particles in the atmosphere. Measuring range was $0.1\text{-}100.000 \mu\text{g}/\text{m}^3$. Counting range was 2000000 P/L, and 31 particle size channels were divided between $0.25\text{-}32 \mu\text{m}$. Repeatability was 5%. To ensure the truth of the data statistics, some of Chinese standards were referenced to make sure the data more effectively [12, 30, 31].

Fig. 2 showed the annual average concentrations of $\text{PM}_{2.5}$ in 31 tested cities in China was between 18.4 and 81.0 $\mu\text{g}/\text{m}^3$. The city with the smallest average concentration of $\text{PM}_{2.5}$ was Lasa, and the largest city was Shijiazhuang. The difference between them was 62.6 $\mu\text{g}/\text{m}^3$. The highest average daily concentration of $\text{PM}_{2.5}$ was Xi'an, while the lowest average daily concentration of $\text{PM}_{2.5}$ was Lasa, and the city with the daily average concentration of $\text{PM}_{2.5}$ meeting

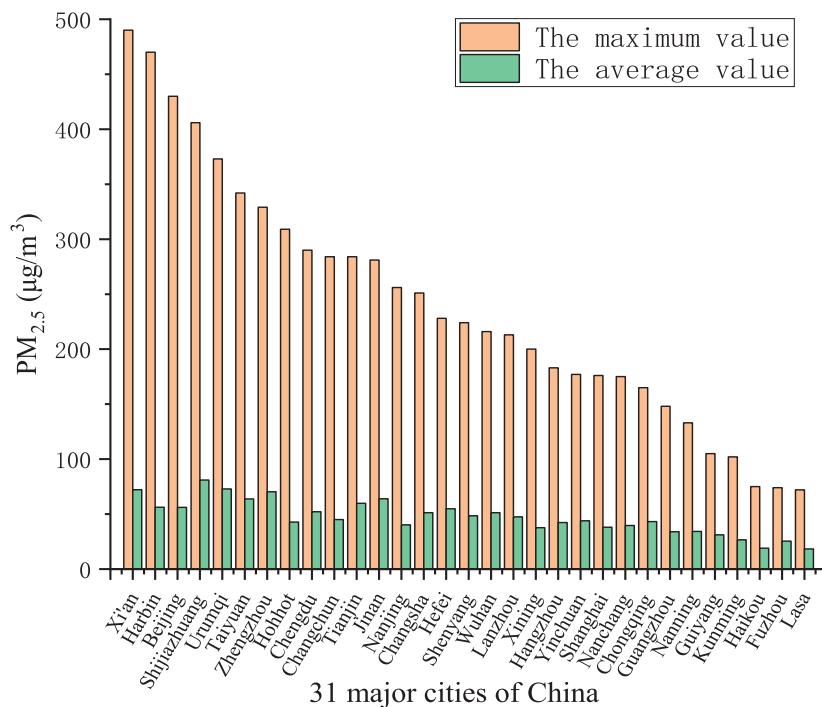


Fig. 2. Annual average concentration of PM_{2.5} in part cities of China.

the national secondary standard was only Lasa [12]. Therefore, the study of PM_{2.5} in atmosphere of Xi'an was more representative.

Results and Discussion

Quarterly Variation of PM_{2.5} Concentration

The data of five typical monitoring stations in Xi'an (Caotan, Fang Zhicheng, high voltage switch factory, Xiaozhai and Chang'an district) in 13 monitoring stations was selected in this paper. The statistics were divided into four seasons: spring, summer, autumn and winter. The spring was March to May, the summer was June to August, the autumn was September to November, and the winter was December to February [32]. The average concentration of PM_{2.5} in different seasons was shown in Fig. 3.

Fig. 3 showed the concentrations of PM_{2.5} in different seasons showed different trends. The concentrations of PM_{2.5} which were measured by different monitoring stations in the same season were roughly same. The concentrations of PM_{2.5} were low in summer (June-August) and autumn (September-November). The concentrations of PM_{2.5} were high in spring (March-May) and winter (December-February). The highest was in winter, and about 140 μg/m³~158 μg/m³. The lowest was in summer, and about 30.0 μg/m³~37.5 μg/m³. The seasonal average concentration was followed: winter>autumn>spring>summer. The concentrations of PM_{2.5} in winter was about 2.22~2.97 times higher than spring, about 3.74~5.27 times higher than summer,

about 2.11~2.56 times higher than autumn. It also showed the concentration of PM_{2.5} did not exceed the national secondary standard only Xiaozhai (29.6 μg/m³) and Chang'an District (30.2 μg/m³) in summer, while the other seasons were exceeded the secondary standard [12]. The reasons were affected by heating in winter, and large of particulate matters were produced by burning of fossil fuels. In addition, it was not conducive to spread of pollutants under the low air pressure in winter, while eroding rainwater also played a certain role in elimination in summer [32]. The season in winter had a greater impact on PM_{2.5}, while the season in summer had a much smaller impact on PM_{2.5}. It was consistent with the conclusions given in reference [26].

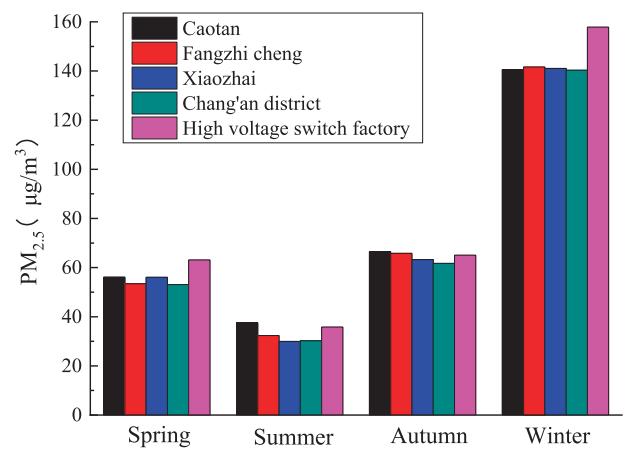


Fig. 3. Quarterly concentration characteristics of PM_{2.5}.

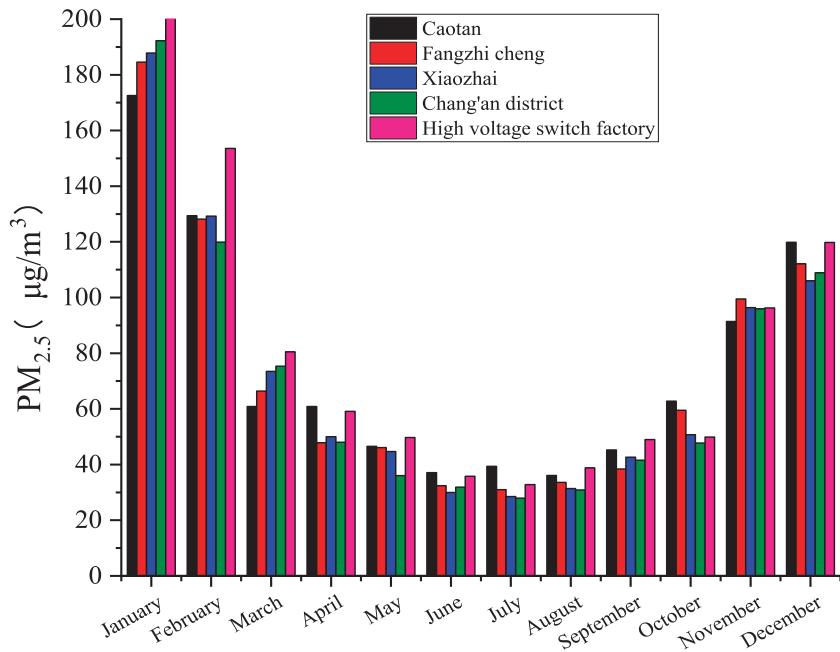


Fig. 4. Monthly concentration characteristics of PM_{2.5}.

Monthly Variation of PM_{2.5} Concentration

The average concentration of PM_{2.5} in five environmental monitoring stations was shown in Fig. 4.

Fig. 4 showed the annual trends of PM_{2.5} concentration which were given by the five regional monitoring stations were roughly the same, and they were not much different. The annual average values of PM_{2.5} in Caotan, Fangzhi Cheng, Xiaozhai, Chang'an district and High voltage switch factory were 68.8 μg/m³, 71.8 μg/m³, 71.5 μg/m³, 69.4 μg/m³ and 79.2 μg/m³, respectively. They were higher than the standard which was given the secondary standard limit (35 μg/m³) [12]. They were 1.97 times, 2.05 times, 2.04 times, 1.98 times and 2.26 times higher than the standard, respectively. The monthly distribution of PM_{2.5} showed a trend of U-shaped, and the average monthly concentration of PM_{2.5} was the highest in January, while the average monthly concentration of PM_{2.5} was the lowest in July. The average monthly concentration of PM_{2.5} was as followed: January>February>December>November>March>October>April>May>September>August>June>July. The main reason was the level of particulate matter increased because of the need for heating in winter [14]. They were not conducive to spread pollutants under the low temperature in winter [32].

Daily Variation of PM_{2.5} Concentration

The average daily concentration of PM_{2.5} was from 0:00 to 23:00 on February 1, 2017, and the variation of PM_{2.5} at different time of the day was shown in Fig. 5.

Fig. 5 showed the daily average concentration of PM_{2.5} in the five monitoring stations varied from 99 to

226 μg/m³. All of them were exceed the secondary limit [12]. The concentration distribution of PM_{2.5} was showed a double peak variation characteristic. Concentrating PM_{2.5} changed at different time of the day, and it showed that human activity had a significant effect on concentrations of PM_{2.5} [14]. PM_{2.5} concentration was the lowest at 0:00, the activities of human were low, while the outdoor environment was better. With the increase of people's activities in the morning, the sources of particulate matters also increased. The concentration of PM_{2.5} reached a peak between 8:00 and 9:00, while there were the high peak of people's travel at that time, and the pollutant emissions also reached the peak of the day. With the passage of time, the concentration of PM_{2.5} gradually decreased, which was

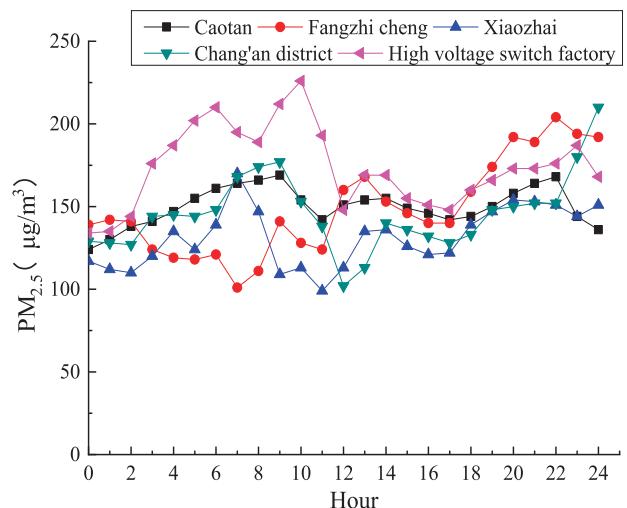


Fig. 5. Daily concentration characteristics of PM_{2.5}.

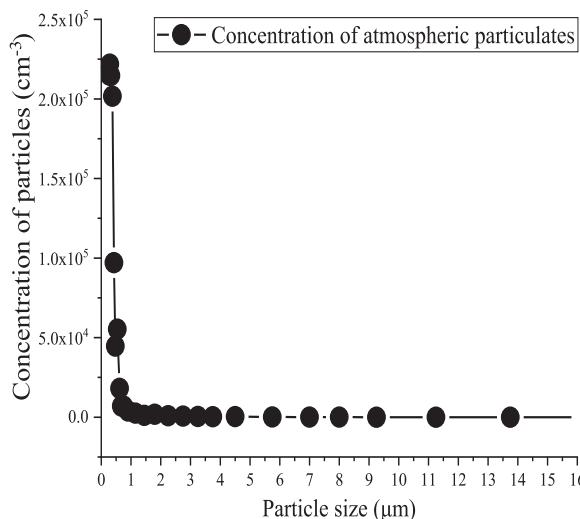


Fig. 6. Concentration distribution of particulate matters in atmospheric.

caused by strong solar radiation in the afternoon, high atmospheric temperature, and strong turbulent exchange and vertical diffusion between gas [14]. Concentrating PM_{2.5} reached peaks between 22:00 and 23:00, which was caused by people's everyday activities. The difference in hourly concentration variation which was given by different monitoring stations was related to the locations of monitoring stations and the make-up of the industrial chain [18].

Variation of Different Particle Sizes in Atmospheric

Fig. 6 showed the average of the test concentrations in 8 different months of the whole year in 2017 for analysis. Particle size of 0 to 0.54 μm accounted for 95.9%. Particle size of 0.54 to 1.0 μm accounted for 3.29%. With a particle size of 1.0 to 2.5 μm accounted for 0.591%. Particles above 2.5 μm accounted for 0.184%. Particle sizes of 0-2.5 μm accounted for most of the atmosphere during the testing, accounting for 99.8%. Particle sizes of 0-1.0 μm accounted for more than 99.2%. Particles of Xi'an in atmospheric were mainly fine particles. This conclusion was consistent with the literature [33], which were easy to enter the human respiratory tract and lungs, and they were seriously harmful to human health [4].

Correlation between PM_{2.5} and Other Major Pollutants

Xiao Zhai was located in the southern suburbs of Xi'an, and it has a large population and prosperous business [14]. Therefore, it was more representative as the selected point to study. The date was selected from January 1 to December 31 in 2017. The average correlation between PM_{2.5} and CO, SO₂, NO₂, O₃ and PM₁₀ was studied.

Fig. 7a) showed there was a consistent change of the trend between the daily average concentration value of PM_{2.5} and PM₁₀. The annual average value of PM_{2.5} was 71.5 μg/m³, while the annual average value of PM₁₀ was 137.8 μg/m³. The highest daily average concentration of PM₁₀ could reach 806 μg/m³, while the highest daily average concentration of PM_{2.5} could reach 561 μg/m³. This showed the decrease of PM₁₀ emissions was critical for reducing pollution with PM [1]. The correlation coefficient between PM_{2.5} and PM₁₀ was 0.917, which was considered to be highly relevant.

Fig. 7b) showed the annual average value of PM_{2.5} was 71.5 μg/m³, while the annual average value of CO was 1.43 mg/m³. The highest daily average concentration of CO could reach 5.5 mg/m³, while the highest daily average concentration of PM_{2.5} could reach 561 μg/m³. Related research showed that when the concentration of CO in the atmosphere was exceeded 35 ppm, it would cause serious harm to the human body where they were located [34]. The correlation coefficient between PM_{2.5} and CO was 0.871, which was considered to be highly relevant.

Fig. 7c) showed the annual average value of PM_{2.5} was 71.5 μg/m³, while the annual average value of NO₂ was 62.0 μg/m³. The highest daily average concentration of NO₂ could reach 155 μg/m³, while the highest daily average concentration of PM_{2.5} could reach 485 μg/m³. This was because consuming fossil fuel in winter was large so the air pollutions of outdoor were large [35]. The correlation coefficient between PM_{2.5} and NO₂ was 0.732, which was considered to be highly correlated.

Fig. 7d) showed the annual average value of PM_{2.5} was 71.5 μg/m³, while the annual average value of SO₂ was 17.4 μg/m³. The highest daily average concentration of SO₂ could reach 54.0 μg/m³, while the highest daily average concentration of PM_{2.5} could reach 108 μg/m³. Related research showed that SO₂ was the main gassy pollutant to form of PM_{2.5} [36]. The correlation coefficient between PM_{2.5} and SO₂ was 0.694, which was considered to be moderately correlated. The correlation between the concentration of PM_{2.5} and SO₂ was seasonally different. The correlation was better in spring and winter, while the correlation was less relevant in summer and autumn.

Fig. 7e) showed there was a different change of the trend between the daily average concentration value of PM_{2.5} and O₃. The annual average value of PM_{2.5} was 71.5 μg/m³, while the annual average value of O₃ was 51.7 μg/m³. The highest daily average concentration of O₃ could reach 163 μg/m³, while the highest daily average concentration of PM_{2.5} could reach 40.2 μg/m³. The average concentration of O₃ in summer was the highest. It was opposite to the change with the average concentration of PM_{2.5}. Related research showed that if ozone was increased in the troposphere, it would have a serious impact on the environment and human health [37]. The correlation coefficient between PM_{2.5} and O₃ was -0.449, which was considered to be a negative correlation.

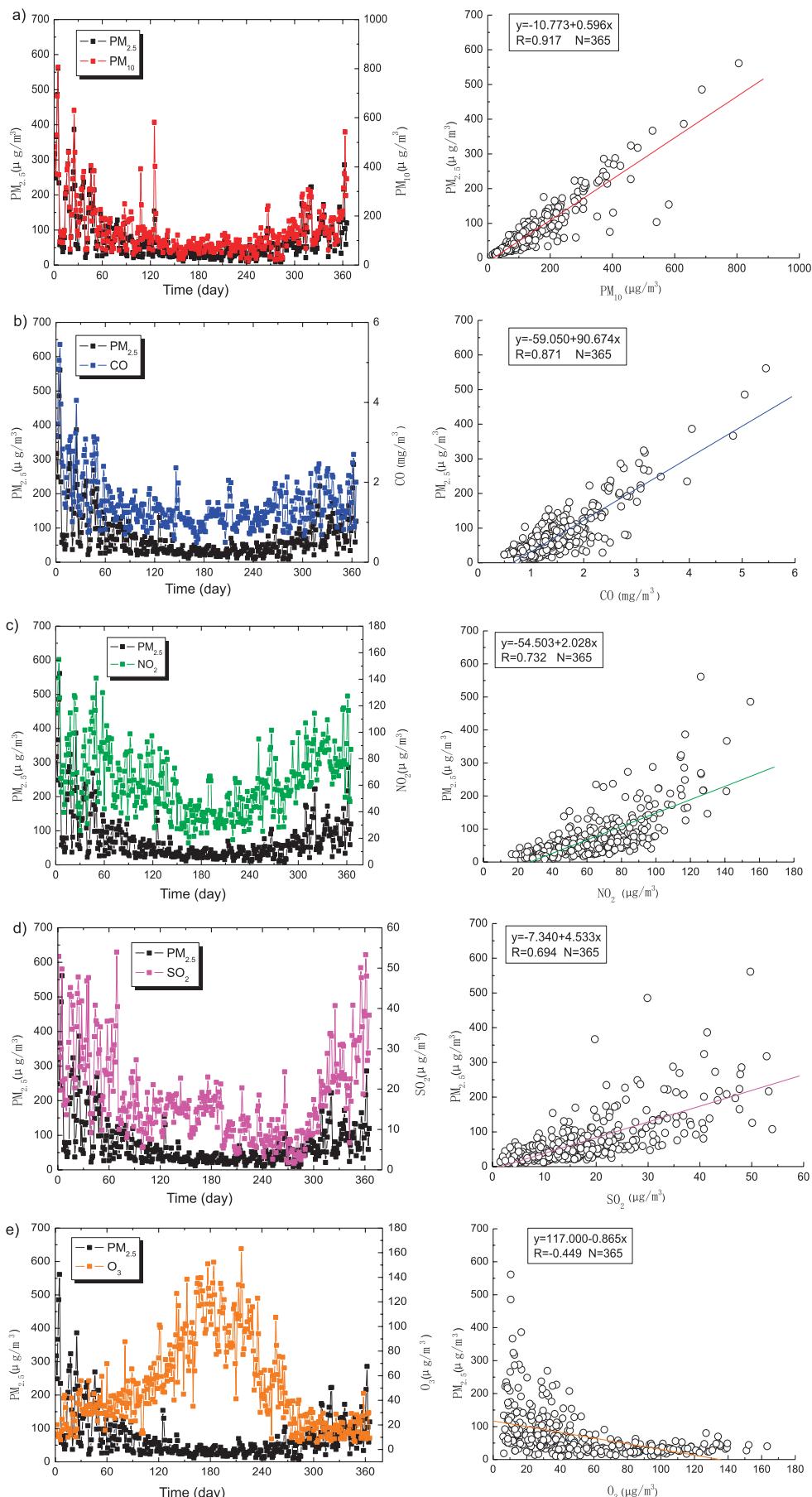


Fig. 7. Correlativity between $\text{PM}_{2.5}$ and other major pollutants: a) Correlativity between $\text{PM}_{2.5}$ and PM_{10} , b) Correlativity between $\text{PM}_{2.5}$ and CO, c) Correlativity between $\text{PM}_{2.5}$ and NO_2 , d) Correlativity between $\text{PM}_{2.5}$ and SO_2 , e) Correlativity between $\text{PM}_{2.5}$ and O_3 .

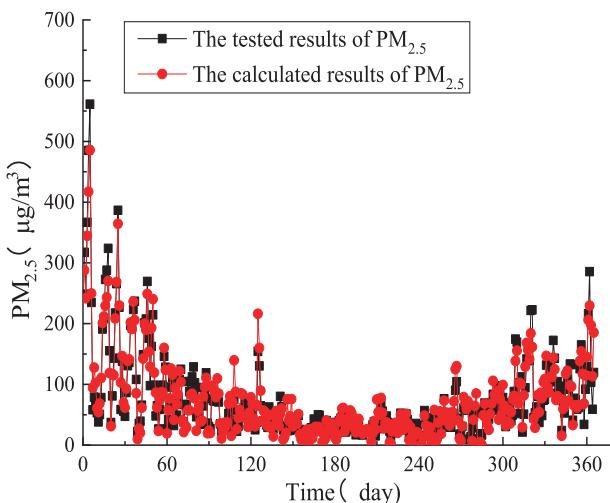


Fig. 8. Comparison of calculated and tested results of $\text{PM}_{2.5}$.

Multiple Linear Regression Equations for $\text{PM}_{2.5}$ and Other Pollutants

The correlation coefficients between $\text{PM}_{2.5}$ and each pollutant was as follows: $0.917 > 0.871 > 0.732 > 0.694$. The corresponding pollutants affecting the magnitude of $\text{PM}_{2.5}$ were: $\text{PM}_{10} > \text{CO} > \text{NO}_2 > \text{SO}_2$. Therefore, among them the most relevant pollutant was PM_{10} . A multiple linear regression model was established by the software Eviews as follows (1).

$$Y = \beta_0 + \beta_1 X_{\text{CO}} + \beta_2 X_{\text{NO}_2} + \beta_3 X_{\text{SO}_2} + \beta_4 X_{\text{PM}_{10}} \quad (1)$$

...where: Y , X_{CO} , X_{NO_2} , X_{SO_2} , and $X_{\text{PM}_{10}}$ were the average daily concentration values of $\text{PM}_{2.5}$, CO, NO_2 , SO_2 , and PM_{10} , respectively.

The final formula was as follows (2):

$$Y = 37.5X_{\text{CO}} + 0.107X_{\text{NO}_2} + 0.763X_{\text{SO}_2} + 0.348X_{\text{PM}_{10}} - 50.7 \quad (2)$$

The correlation coefficient R was 0.915, and the decision coefficient R^2 was 0.914. From the point of decision coefficient, the regression equation was obvious.

The daily average concentrations of CO, SO_2 , NO_2 and PM_{10} were substituted into the formula (2). Compared with the results between the tested and calculated of the $\text{PM}_{2.5}$ were shown in Fig. 8. It showed the prediction effect was good, and the overall trend was still consistent with the tested results. However, there was a large variation of $\text{PM}_{2.5}$ in spring. It was a certain deviation in the prediction effect, but the overall still had a good agreement. So it could be considered the daily average concentration of $\text{PM}_{2.5}$ which was obtained by the multiple linear regression equation (2) could be effectively predicted and monitored.

Conclusions

The data was based on five typical monitoring stations of Xi'an in China for the whole year of 2017 in this paper. The concentration distribution of $\text{PM}_{2.5}$ and its correlation with other air pollutants was analyzed, and the conclusions were as follows:

1. The concentration value of $\text{PM}_{2.5}$ was consistent with the seasonal, monthly and daily mean trends. It showed a low $\text{PM}_{2.5}$ concentration in summer (June-August) and autumn (September-November), while the concentrations of $\text{PM}_{2.5}$ were higher in spring (March-May) and winter (December-February), and the highest were in winter.

2. Variation distribution of $\text{PM}_{2.5}$ concentration showed a double-peak variation characteristic. The concentration of $\text{PM}_{2.5}$ reached a peak between 8:00-9:00 in the morning and 22:00-23:00 in the evening, and the particles of Xi'an were mainly fine particles.

3. There was a strong correlation between $\text{PM}_{2.5}$ and CO, SO_2 , NO_2 , PM_{10} ($\text{PM}_{2.5}/\text{CO}$ $r = 0.871$, $\text{PM}_{2.5}/\text{SO}_2$ $r = 0.694$, $\text{PM}_{2.5}/\text{NO}_2$ $r = 0.932$, $\text{PM}_{2.5}/\text{PM}_{10}$ $r = 0.917$). But a negative correlation between $\text{PM}_{2.5}$ and O_3 ($\text{PM}_{2.5}/\text{O}_3$ $r = -0.449$).

4. A multivariate linear regression model with the pollutant concentration of CO, SO_2 , NO_2 and PM_{10} as independent was established as follows: $Y = 37.5X_{\text{CO}} + 0.107X_{\text{NO}_2} + 0.763X_{\text{SO}_2} + 0.348X_{\text{PM}_{10}} - 50.7$. The present study was conducive to understanding the distribution of $\text{PM}_{2.5}$ and its correlation with other five pollutants of Xi'an. It would supply important support for the targeted controlling approach of fog and haze.

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Conflict of Interest

The authors declare no conflict of interest.

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