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Research Article

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# Seasonal Variation Characteristics and Forecasting Model of $PM_{2.5}$ in Changsha, Central City in China

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## Abstract

This paper describe the seasonal variation characteristics of $PM_{2.5}$, $PM_{2.5}/PM_{10}$ and established the multivariable linear regression model of $PM_{2.5}$ based on the observation during the period of January 1, 2014 to December 31, 2014 in central city of China. It is found that the mean concentration of $PM_{2.5}$ has obvious seasonal variation characteristics, the lowest value in summer and the higher value in winter and autumn. The daily average mass concentration of $PM_{2.5}$ in January is 161.93 μg/m³ and the over standard rate is 90 percent which is the annual maximum; the annual minimum in august. The ratio of $PM_{2.5}$ and $PM_{10}$ is high ratio of autumn and winter, up to 2.9, the spring and summer is relatively stable trend, the ratio between 0.6 to 0.9. The two multivariable linear regression model of $PM_{2.5}$: $[PM_{2.5}]=-39.241+0.394 \times [PM_{10}]+44.253 \times [CO]+0.4 \times [BPM_{2.5}]$ and $[PM_{2.5}]=-43.979+0.462 \times [PM_{10}]+70.083 \times [CO]$. The former is suitable for short-term prediction, high accuracy, the latter is suitable for long-term forecast. Certain probability model can predict the trend of the $PM_{2.5}$ to explore the pros and cons of air quality. But there are still many deficiencies, need to further improve.

**Keywords:** $PM_{2.5}$ seasonal variation; Air pollution calculation; Multivariable linear regression model; China

## Introduction

In recent years, many regions in China suffered heavy haze as well as reduced visibility with air pollution. In January, 2013, several large range of haze happened many times involving lots of aspects in China. The data from Beijing Environment Protection Bureau showed that the $PM_{2.5}$ concentration detected by part of monitoring stations in Beijing was more than 700 μg/m³ [1]. Not only the high frequency and wide bound haze could do harm to human health, but also bring a few negative effects. This phenomenon, especially the monitor about $PM_{2.5}$ which was the 'cuoprit' of haze and the pollution has caused the whole society's hitherto unknown attention. $PM_{2.5}$ is called by fine particulate matter with a diameter less than 1/20 of human hair. However, $PM_{2.5}$ may have a greater impact on human health and the environment compared with other large particulate matter like $PM_{10}$. Because of its small size, light weight and larger surface area than both $PM_{10}$ and $PM_{100}$, $PM_{2.5}$ was more easily to absorb more harmful materials such as more bacteria, viruses and several kinds of pollutants.

China has launched parts of monitoring studies, but the research was mostly concentrated in the Beijing-Tianjin-wing, the Yangtze River Delta and Pearl River Delta region. The information of air quality from environment protection departments in China display that more than 300 prefecture-level city are under heavy pollution, as well as the central city of Changsha. But the air quality investigation about Changsha which also faces grim air pollution is rarely reported. Therefore, it's urgent to research the pollution characteristics of $PM_{2.5}$ and forecasting model.

Through studying the characteristics of $PM_{2.5}$ pollution, the seasonal variation characteristics of $PM_{2.5}$ in Changsha area was studied, which further clarify the pollution characteristics during different periods of $PM_{2.5}$ pollution and its important source. At the same time, the establishment of statistical regression model on $PM_{2.5}$ can fit the concentration of Changsha region, assess the trend of air quality according to the monitoring indicators and investigate the correlation between basic air monitoring index and time series, thereby contributing to predict trend of $PM_{2.5}$ in a certain probability and explore the air quality. This could provide theoretical basis for the government to develop environmental policies and pollution control measures [2].

After the first air quality standard of $PM_{2.5}$ established in USA in 1997, lots of the studies on $PM_{2.5}$ emerged. Although our research in this area started later than in other countries, the research results of $PM_{2.5}$ in recent years is quite encouraging. The main scope of the study included $PM_{2.5}$ pollution characteristics, emission inventories, emission characteristic spectrum, $PM_{2.5}$ source apportionment and the influences of $PM_{2.5}$ on atmospheric visibility and human health.

The abroad study of $PM_{2.5}$ in terms of pollution characteristics showed one of the most important factors was influenced by interactions from many complex factors such as source emissions, chemical changes, weather conditions and geographical conditions and other complex factors $PM_{2.5}$ is one of the main factors affecting the $PM_{2.5}$ concentration. While the concentration of primary particulate matter in urban areas was higher than in rural areas around, the secondary particulate matter in urban distributed more uniform [3]. In certain areas, the concentration of $PM_{2.5}$ and its precursors of secondary particles were mainly affected by local and regional source emissions and meteorological conditions. Besides, the concentration of $PM_{2.5}$ may differ depending on the changing season. The ratio of $PM_{2.5}$ to $PM_{10}$ ratio is usually between 1/2~4/5 and may changed in different regions and seasons. And the ratio is higher in fall than in summer [4]. Domestic research was mainly investigated in the Beijing-Tianjin-wing, the Yangtze River Delta and Pearl River Delta region. In order to assess the trends of basic monitoring index of air quality, predict the rules of $PM_{2.5}$ at a certain probability and study the air quality, there are

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more and more research on the heavily polluted areas like Beijing by establishing a variety of models such as Gaussian diffusion model, Doha Mei integration, joint multi-fractal and statistical methods. Although most studies focused on the Beijing-Tianjin-wing, the Yangtze River Delta and Pearl River Delta region, the pollution situation of other second tier cities also attracted more and more attention of scholars.

## Materials and Methods

### Data sources

This study researched five groups of data about air pollutants contained $PM_{2.5}$, $PM_{10}$, CO, etc. from environmental monitor stations of Changsha Environmental Protection Agency Environmental (http://hbj.changsha.gov.cn), including followed nine state-controlled ambient air quality assessment points: Ma Poling, Hunan Normal University, Yuhua District, environmental protection station, Wu Jialing, train stations, high open area, through the open area, Tianxin and Hunan University of Chinese Medicine. The data were overall mean calculated by daily monitoring points per hour in everyday from January 1, 2014 to December 31, 2014.

### Methods

All data were input in excel and statistically analyzed in using SPSS 18.0.

**The basic conditions of $PM_{2.5}$ and the rules of seasonal variation:** All data were classified according to different season. Based on the the descriptive statistical analysis, the seasonal variation of $PM_{2.5}$ including average concentration of $PM_{2.5}$ in four seasons, exceedances of $PM_{2.5}$ in four seasons and maximum daily average concentration in each season.

**The relationship between $PM_{2.5}$ and $PM_{10}$:** Take comparative analysis and ratio analysis with $PM_{2.5}$ and $PM_{10}$. And research the ratio varieties according to different seasons.

**The establishment of $PM_{2.5}$ forecasting model:** The correlation analysis was carried out among $PM_{2.5}$, $PM_{10}$, CO, $NO_2$ and $SO_2$. Screen the data of air pollutants correlated with $PM_{2.5}$ to perform multiple linear regressions and establish regression models. In order to test the regression model and evaluated the prediction, some new data was chosen by analyzing and comparing estimated and true value.

## Results

### Seasonal variation characteristics of $PM_{2.5}$

All data were divided into 4 groups according to seasons as followed. Spring: March 1, 2014 - May 31, 2014; Summer: June 1, 2014 - August 31, 2014; Fall: September 2014 1st - November 30, 2014; Winter: January 1, 2014 - February 28, 2014 and December 1, 2014 -December 31, 2014. Our country's National Ambient Air Quality Standard (GB3095-2012) shows that 24 hour average concentration limit of $PM_{2.5}$ is 75 μg/m³. According to the results of the daily average concentration variation chart $PM_{2.5}$ concentrations in Changsha exhibited significant seasonal variation, which the concentration was dramatically higher in autumn and winter than in spring and summer ($t=-6.422$, $P=0.000<0.05$). Among them, there is a small variation in spring, summer two seasons, the season average concentration and excessive rate are 63.19 μg/m³, 54.88 μg/m³ and 28.6%, 20.0%. The change range of autumn and winter is obviously bigger, the season average concentration are 74.24 μg/m³, 105.49 μg/m³, and the excessive rate are 40.7%, 58.4%. It showed both the average concentrations and excessive rate in summer was the lowest in Changsha area in the whole 2014, while in winter got a highest excessive ratio. According to the results of the monthly average concentration variation chart a particularly serious pollution with an average concentration $PM_{2.5}$ which was up to 161.93 μg/m³, exceeding the highest annual rate of 90% up in January 2014. At the followed months, concentration $PM_{2.5}$ was then gradually decreased and a minimum value was obtained in August in summer. And then rose again in September and had a high excessive ratio of 67.7% in October.

### The correlation between $PM_{2.5}$ and $PM_{10}$

The chart of the monthly average concentration variety characteristics of $PM_{2.5}$ and $PM_{10}$ shows that the average concentration of $PM_{10}$ was apparently higher than $PM_{2.5}$ in the whole year except January and February. The concentration of $PM_{10}$ gradually increased from February and reached a peak value of 105.39 μg/m³, while the concentration of $PM_{2.5}$ was stable from February to June except a small decline in April. After that, the variety characteristics of $PM_{2.5}$ and $PM_{10}$ were similar which contemporarily reached lowest point in August, rose dramatically in October and then got to peak concentration in January ($PM_{10}$=161.93 μg/m³, $PM_{2.5}$=125.13 μg/m³).

The ratio of $PM_{2.5}$ to $PM_{10}$ was respectively showed in Figure 1. The value was stable with 0.6-0.9 in Changsha from March to October in 2014. However, the ratio was straight up to more than 1 in January, February, December and November. Even the ratio achieved to peak of 2.9. According to the season, the ratio was abnormally at the late fall and the whole winter, while remained relatively stable in spring and summer.

### The establishment of $PM_{2.5}$ forecasting model

The table of the result of Pearson correlation coefficient between $PM_{2.5}$, $PM_{10}$, CO, $NO_2$ and $SO_2$ shows that there existed statistical significance among each correlation coefficient with $P<0.001$, which indicated that there were positive correlation between $PM_{2.5}$, $PM_{10}$, CO, $NO_2$ and $SO_2$ in Changsha. $PM_{2.5}$ and CO had the highest correlation of 0.709, and $PM_{10}$ was 0.647 followed.

The values existed rather high correlation among each other, thus it could carry out further multivariate linear regression model to build relationships models. In addition, considering the influence of accumulation of background value from real-time pollutants last day, it should be increase a variable $BPM_{2.5}$ [5].

By using stepwise regression to get the multiple linear regression results between $PM_{2.5}$ and air pollution. The regression coefficient of determination was 0.792, significant test $F=269.854$ and $P<0.00$, which proved a distinct regression results with statistical significance. However, the t-test was 1.912 and $P=0.057>0.05$ in equation of $SO_2$. It meant $SO_2$ on the dependent variable ($PM_{2.5}$) was not statistically significant regression. The value R of $NO_2$ was -0.357, which was

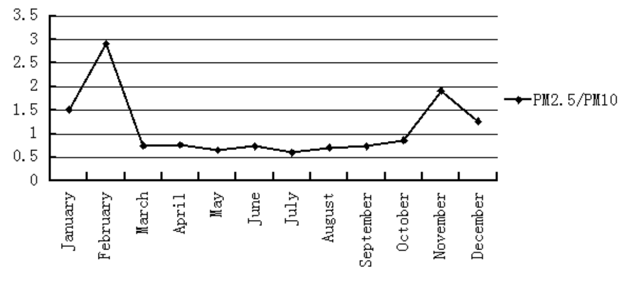


**Figure 1:** The ratio varieties between $PM_{2.5}$ and $PM_{10}$ in Changsha region in 2014.

contradicted with the correlation coefficient of 0.534 above. After further analysis, the correlation coefficient between NO and $SO_2$ was 0.842 exhibited a high correlation. Perhaps because there existed co-linearity between NO and $SO_2$. Meanwhile some research [6] had verified in many cases multicollinearity could lead to conflicting results between the positive or negative sign in regression coefficient of arguments and qualitative analysis. Therefore removed the results of $SO_2$ and re-regressed. The regression coefficient of $NO_2$ is still negative with t=-1.821 and P=0.070>0.05, which meant there was no statistical significance between $NO_2$ and dependent variable ($PM_{2.5}$). Because it was still collinearity with another argument as well as multicollinearity was existed in $NO_2$, $SO_2$ and CO with each other published by Wang [5], this study reselected 3 arguments: $PM_{10}$, $BPM_{2.5}$ and another one argument picked from $NO_2$, $SO_2$ and CO in order to get a new re-fit regression results as shown in Table 1.

It could be found in the Table 1 that T value was greater than $t_{0.05}$ and F value was greater than $F_{0.05}$ among the 3 models under the significance level of α=0.05, which showed a similar relevance as before. It indicated there was significant relevance with all variables in new regression model which also could reflect the linear correlation between $PM_{2.5}$ with other pollutants. Besides the values of $R^2$ and F in regression model of $PM_{2.5}$ with $PM_{10}$, $BPM_{2.5}$, and CO were the greatest, exhibiting an optimal model. Thus, the correlation model of $PM_{2.5}$ air pollutants could be expressed as equation 1.

$$[PM_{2.5}]=-39.241+0.394\times[PM_{10}]+44.253\times[CO]+0.4\times[BPM_{2.5}] \quad (1)$$

The true value and estimated value calculated by regression equation 3-1 were compared. Both the results were fitted very well except few greater values existed deviation. The correlation coefficient of true value and estimated value of $PM_{2.5}$ after analysis was 0.887, and the root mean square error (i.e., the difference between the estimated value and the original value of the square root of the mean square) of 22.00 μg/m³.

Calculated 28 days' data of $PM_{2.5}$, $PM_{10}$ and CO value from February 1, 2015 -2015 February 28 in Changsha by using regression model to verify and evaluate the regression results. Because the independent variables values of $BPM_{2.5}$ were different, two results were obtained as followed.

- Took the second day forecast $PM_{2.5}$ value to carry out short-term prediction. Selected the real value of argument $BPM_{2.5}$ to analyze and then compared the predicted value and the true value of $PM_{2.5}$ as shown in Figure 2.
- Progressed long-term prediction in using the model. All data were from the predicted value of $PM_{2.5}$ with previous day except the first day (Figure 3) to analyze. The results were similar with the other, but the error was slightly larger with a mean square root of 29.22 μg/m³.

According to the results, it could be drawn that although the model had advantages with relatively and high fitting in short-term prediction, it obviously did not proper to apply in long-term forecasts. For the accumulated error was formed by predicted value to next, the more prediction time, the greater error. Therefore it should be ignored the impact of $PM_{2.5}$ to the background values of $PM_{2.5}$ and re-selected the dependent variable to establish a new correlation model between $PM_{2.5}$ and air pollutants (The correlation coefficients between each pollutant were as same as the above).

The stepwise regression was applied in this analyze with dependent variables of $PM_{10}$, $NO_2$, $SO_2$ and CO. After screened the dependent variables in using SPSS soft, two dependent variables of $NO_2$ and $SO_2$ were removed and $PM_{10}$ and CO were dependent variables in the regression equation. When α=0.05, T value and F value were greater than $t_{0.05}$ and $F_{0.05}$ respectively with a consistent correlation as above. It demonstrated a significant regression efficiency of $PM_{10}$ and CO in the regression model. The final model equation was as followed.

$$[PM_{2.5}]=-43.979+0.462\times[PM_{10}]+70.083\times[CO] \quad (2)$$

This regression model revealed a good fitting with $PM_{2.5}$. But the correlation coefficient between estimated and original value of $PM_{2.5}$ was 0.826, and the root-mean-square error was 26.90 μg/m³. The comparison chart between estimated and original value of $PM_{2.5}$ in February, 2015 in Changsha was exhibited in Figure 4 with a similar fitting results as the above regression model with a root-mean-square error of 25.98 μg/m³.

## Discussion

### The seasonal variation characteristics of $PM_{2.5}$

The results in this research displayed the annual average concentration of $PM_{2.5}$ was 74.33 μg/m³ in Changsha region, which was 2.12 times as high as the national ambient air quality standard (GB3095-2012) of 35 μg/m³. And the exceeding percent was 36.8% during the whole year. The highest concentration of $PM_{2.5}$ was 306 μg/m³ ---- 4.08 times as high as the national ambient air quality standard. The concentration and excessive ratio in summer were lowest than in other seasons, while highest in winter with the excessive ratio of 58.4%.

| | Regression Coefficient | t | P | $R^2$ | F | P value(F) |
|---|---|---|---|---|---|---|
| (Constant) | -39.241 | -10.337 | 0.000 | 0.788 | 441.249 | 0.000 |
| $BPM_{2.5}$ | 0.400 | 13.307 | 0.000 | | | |
| $PM_{10}$ | 0.394 | 14.591 | 0.000 | | | |
| CO | 44.253 | 11.479 | 0.000 | | | |
| (Constant) | -13.808 | -3.719 | 0.000 | 0.714 | 297.221 | 0.000 |
| $BPM_{2.5}$ | 0.552 | 17.615 | 0.000 | | | |
| $PM_{10}$ | 0.417 | 11.988 | 0.000 | | | |
| $NO_2$ | 0.251 | 2.472 | 0.014 | | | |
| (Constant) | -13.503 | -4.003 | 0.000 | 0.720 | 305.459 | 0.000 |
| $BPM_{2.5}$ | 0.541 | 17.411 | 0.000 | | | |
| $PM_{10}$ | 0.396 | 11.358 | 0.000 | | | |
| $SO_2$ | 0.536 | 3.647 | 0.000 | | | |

**Table 1:** The regression results.

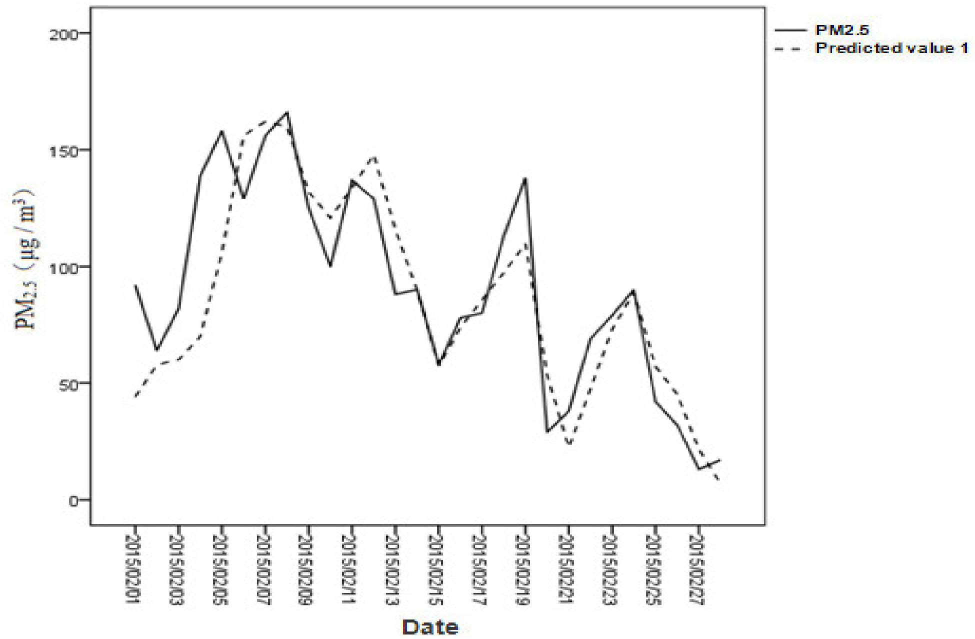


**Figure 2:** The verified profile of regression model of $PM_{2.5}$ in short-term method.

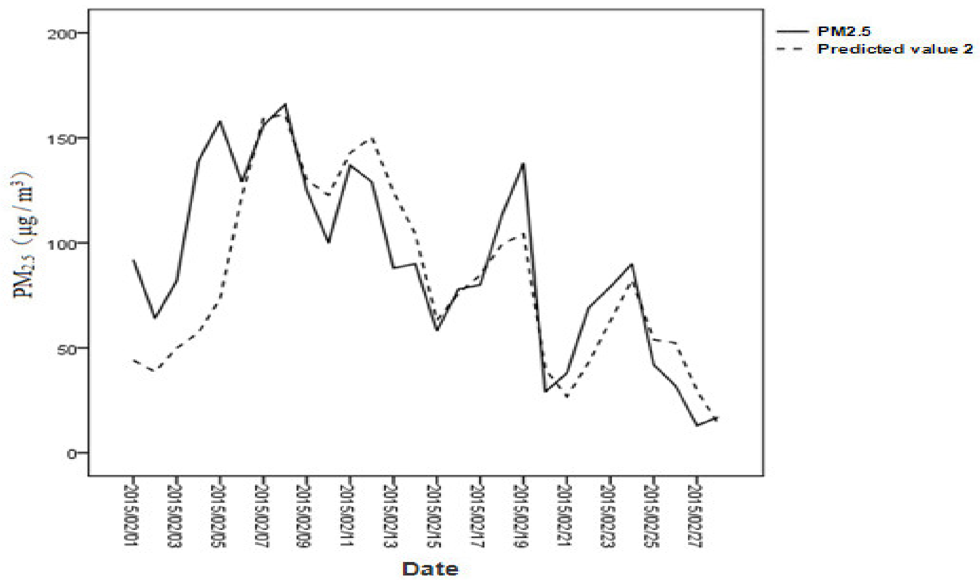


**Figure 3:** The verified profile of regression model of $PM_{2.5}$ in long-term method.

Among the whole year, the pollution was the heaviest rather heavy with an average concentration up to 161.93 μg/m³ and excessive ratio of 90% in January, 2014. During 31 days in January, the exceedance happened 27 days and the excessive ratio was more than 100 μg/m³ in 26 days. The concentration of $PM_{2.5}$ was decreased lately, reached to minimum in August and began to rise in September. The excessive ratio was 67.7% in October.

The seasonal characteristics with high concentration in winter and autumn but low in summer mainly could be attributed to the stable atmosphere in Changsha in autumn and winter. Under this condition the vertical air convection and advection were weak and prone to occurring inversion phenomenon that the air is colder near the surface of the earth while warmer in high altitude. And it's happened oftenly in Changsha. Du [7] and other studies had found that the concentration of pollution was negatively correlated with the isssnversion layer, while showed a positive correlation with the inversion frequency. In addition, the low rainfall and dry air also made the air pollution and gathered so as to spread difficultly. Meanwhile, Zhang [8] also inferred that the solar radiation was weak as well as the boundary layer was lower with frequent small wind calm weather in autumn and winter, increasing the pollutants and the secondary particulate matter's formation with a

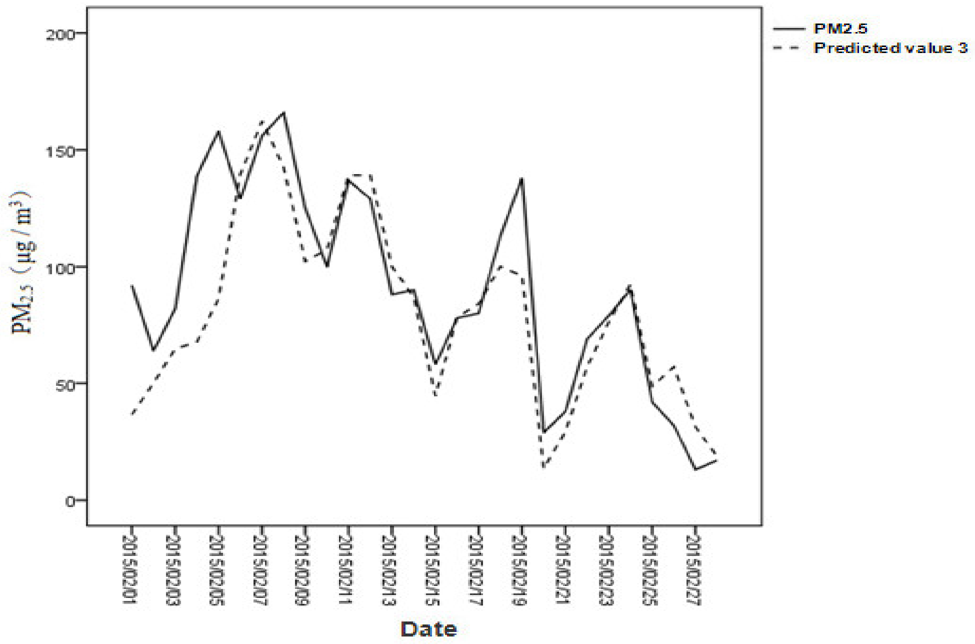


**Figure 4:** The verified results of regression model of $PM_{2.5}$.

large deal of fine particulate matter. And in spring not only the heavy rainfall could erode and dilute the pollutants, but also the convective weather could purify the air.

## The correlation between $PM_{2.5}$ and $PM_{10}$

$PM_{10}$ also is an important indicator and has a close relationship with $PM_{2.5}$ on study of air pollution. So it's meaningful to investigate the ratio between $PM_{2.5}$ and $PM_{10}$ for determing the composition and sources of air pollution, which could display the type of pollution and possible contamination material sources.

There existed obvious seasonal characteristics of the ratio of $PM_{2.5}$:$PM_1$ in Changsha in 2014. The ratio was abnormal with 2.9 in the late fall and winter, while it kept stable in spring and summer with 0.6-0.9. It indicated that the type of air pollution was different with season changing. And such human activities as the increased heating combustion emissions and fireworks brought out many kinds of contamination. Besides, the Low-lying South High of "dustpan shape" Terrain in the north area of Changsha and rather strong low-level inversion phenomenon accumulated lots of $PM_{2.5}$ that stayed in the air for a long time, thus brought out more $PM_{2.5}$ and the $PM_{2.5}$ air pollution. At the same time Changsha Environmental Protection Department pointed burning straw in north also could bring foreign pollutant input pollution outside of Changsha [9]. especially increase pollution of $PM_{2.5}$ in fall and winter. When it's spring and summer, late fall to winter heating combustion emissions increases, increasing the frequency of use of fireworks and other kinds of pollution caused by human activities, with the south than in the north area of Changsha "dustpan shape" Terrain and unusually strong low-level inversion phenomenon makes staying in the air for a long time to accumulate $PM_{2.5}$ concentration, thus giving rise to the main $PM_{2.5}$ air pollution. At the same time pointed out that the environmental protection department in northern Changsha lot of burning straw can also lead to the occurrence of foreign contaminants enter in Changsha pollution [9], especially in the autumn and winter are more likely to increase the $PM_{2.5}$ pollution. It was easy to spread and dilute pollutants to decrease the concentration of $PM_{2.5}$. Although the convective weather was great in spring and summer, the dust was also became greater to lead a high value of $PM_{10}$ and air pollution.

Zhu [10] measured the annual average ratio of $PM_{2.5}$ and $PM_{10}$ from two monitoring sites of Changsha railway station and high school attached to Hunan normal university in Changsha from 2011 to 2012. The results were 0.597 and 0.633 in 2011, 0.608 and 0.639 in 2012, respectively. And many publications showed that the ratio was 0.55-0.72 [11] in most areas of North China. In this research the result was 1.1 which was much more than that from the previous documents. The reasons were as followed: One reason was that perhaps the air pollution increased dramatically in recent years in Changsha region. And the $PM_{2.5}$ pollution was became heavier with a growing concentration of $PM_{2.5}$ in fall and winter, resulting a high ratio between $PM_{2.5}$ and $PM_{10}$. The other reason was that the concentration of $PM_{2.5}$ should be less than $PM_{10}$ in theory when monitoring the concentration of $PM_{2.5}$ and $PM_{10}$ simultaneously. But in the actual monitoring the concentration of $PM_{2.5}$ may be higher than $PM_{10}$ called as '$PM_{2.5}$ and $PM_{10}$ upside down' phenomenon. The difference in monitoring methods, with or without compensation device, the hot and humid weather conditions and the impact from monitoring equipment, etc. also could cause this phenomenon [12]. Many researchers believed that although imported many monitoring equipment abroad, there still were significant difference in concentration of $PM_{2.5}$, humidity and composition. For example, it's hard to distinguish solid particles and droplet because of high humidity in South China, leading a high concentration of $PM_{2.5}$ and 'upside down' phenomenon of $PM_{2.5}$ and $PM_{10}$.

## The forecasting model of $PM_{2.5}$

This investigation obtained two groups data of multiple linear regression models with $PM_{2.5}$ and air pollutants. One model took background value of $PM_{2.5}$ as one of the dependent variable for considering the influence of background value of $PM_{2.5}$ to air pollutants.

The optimal regression model showed a significant regression effect with $R^2$=0.788, F=441.249 and P<0.001 as followed.

$$[PM_{2.5}]=-39.241+0.394 \times [PM_{10}]+44.253 \times [CO]+0.4 \times [BPM_{2.5}]$$

It could be drawn the regression effect was good from the profile of $PM_{2.5}$ between the fitted value and true value, but there is a certain bias in the individual large value. The correlation coefficient of fitted value and true value of $PM_{2.5}$ was 0.887 and the root-mean-square error was 22.00 μg/m³. The fit method applied to short time forecasting in using the observations from previous day but not the fitted results. Then we verified the results with data of February, 2015 in Changsha region. Two results were obtained by the two different methods. The root-mean-square error was respectively 23.68 μg/m³ and 22.00 μg/m³ between short time and long term forecasting. It demonstrated the model could predict $PM_{2.5}$ to some extent and it's appropriate to progress short time forecasting. When the forecasting value was applied to predict the next results, it would cause a certain degree of deviation accumulation so as to increase the long-term prediction error. The other kind of model established a regression model ignoring the influence of background values of $PM_{2.5}$ to $PM_{2.5}$ considering the deviation accumulation from last data. The regression model was as followed.

$$[PM_{2.5}]=-43.979+0.462 \times [PM_{10}]+70.083 \times [CO]$$

It showed a dramatical regression effect and statistical significance with $R^2$=0.682, F=384.329 and P<0.001. Though the fitting effect was good, but it's still a little worse than the other model. The correlation of fitted value and true value was 0.826 and the root-mean-square error was 25.98 μg/m³. Although the coefficient of determination $R^2$ of the second model was lower than the first, both the root-mean-square errors were close to each other. It indicated that the results were stable in second model which could hold a certain error. But the accuracy was lower than the first model. Therefore, the first model was appropriate to apply to short time forecasting with a better accurate, while the second model should be used in long term prediction with a relatively stable error.

The Air Quality Index includes six indicators of $PM_{2.5}$, $PM_{10}$, $NO_2$, $SO_2$, CO and $O_3$. The research by Wang [5], Sun [13] pointed there was even no correlation between $PM_{2.5}$ and $O_3$, which was consistent with document [14]. Therefore, the data of $O_3$ did not apply to this research.

The concentration of particulate matter in the atmosphere was also closely related to weather conditions (wind speed, wind direction, barometric pressure, temperature, humidity, precipitation, atmospheric stability, degree) [15]. Thus it should be increase the weather conditions and samples to promote the forecasting effect and establish an optimal model.

## Limitation

- The data in this research was limited and with few missing values and outliers. And the outliers was not corrected or removed, which would cause a certain bias to the final result.
- The data of daily average concentration was obtained from only Changsha city without involving the Changsha surrounding suburbs. So there was no control group in this study.
- The effects of air pollutants was the only one consideration in the multiple linear regression models of $PM_{2.5}$ without any other factors about weather conditions. So the regression effect had limitations to some extent and needed to be optimized.
- The evaluation of effect of regression models was too simple.

## Conclusion

- The annual average concentration of $PM_{2.5}$ was 74.33 μg/m³ in Changsha region, which was 2.12 times as high as the national ambient air quality standard and the excessive ratio was 36.8% in the whole year. The seasonal variation characteristic of concentration of $PM_{2.5}$ was higher in autumn and winter and lower in summer. And the monthly average concentration was the highest up to 161.93 μg/m³ in January, 2014 than other months.
- There existed dramatically seasonal variation characteristic with the ratio of $PM_{2.5}$ to $PM_{10}$. The ratio was abnormally high in late fall and winter, while stable in spring and summer.

The short-time multiple regression model about air pollutants of $PM_{2.5}$ in Changsha region was as followed: $[PM_{2.5}]=-39.241+0.394 \times [PM_{10}]+44.253 \times [CO]+0.4 \times [BPM_{2.5}]$; while the long term regression was $[PM_{2.5}]=-43.979+0.462 \times [PM_{10}]+70.083 \times [CO]$. Both the two models could predict $PM_{2.5}$ in order to investigate the air quality.

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