Study on the Concentration Distribution and Grey Prediction of Gas Pollutants in Beijing -- A Case Study of Nitrogen Oxides

Jianing Li, Hongmei Li*, Shuang Wu

College of Science, North China University of Technology, Beijing 100144, China.

Abstract: With the acceleration of industrialization, air pollution has become a problem that can not be ignored in the process of urban development. Nitrogen oxides (NO_X) are chemically active and hazardous, and play an important intermediary role in the formation of acid rain and other atmospheric complex pollution. for which a series of prevention and control measures have been implemented in Beijing, but due to the late development of NO_X control technology in China, NO_X pollution is still a focus issue, Therefore, this paper investigates the spatial and temporal distribution and concentration changes of NO_X in Beijing. Firstly, based on the relevant concentration data of Beijing from 2014 to 2021, the limits for actual and policy concentrations of NO_X, O_3, CO and SO_2 are compared, and then the spatial and temporal variation trends of NO_X concentrations are described, and a grey prediction model is established by python software to estimate and predict the NO_X concentrations in Beijing from 2022 to 2024. The results show that from 2014 to 2021, the air quality in Beijing will continue to improve and the NO_X concentrations will continue to decrease, with a spatial distribution of "high in the south and low in the north and highest in the middle", and the differences between the north - south and suburban areas of NO_X concentrations will be significantly reduced in 2021. The grey model forecast results show that the NO_X concentration in Beijing will still decrease in the next three years, but the decrease is not significant. It is recommended to further improve the "winter disease and summer treatment" of air pollution in Beijing, continue to carry out in-depth regional joint prevention and control, and strengthen the collaborative pollutant reduction strategy.

Keywords: Air Pollution; Nitrogen Oxides; Air Quality Index; Grey Prediction Mode

---

1. Introduction

In 2021, the CPC Central Committee proposed to "achieve a fundamental improvement in the quality of the ecological environment by 2035, and basically achieve the goal of building a 'beautiful China'", with the core of improving the quality of the ecological environment, fighting a green war of higher standards, and building a harmonious coexistence of man and nature. Therefore, improving the atmospheric environment and air quality is an important task facing the whole country. Beijing, as the capital of China, is located in the north of the North China Plain, the surrounding areas have a diverse industrial structure, a large population and abundant pollution sources, the trans-regional transport of air pollutants is relatively serious. [1] was once one of the cities with high pollution in China, and the control of air pollution has attracted extensive attention.

The Air Quality Index (AQI) is the most intuitive and representative evaluation index in the study of air pollution. According to the AQI size, air quality can be classified into six levels: Excellent, Good, Light pollution, Moderate pollution, Severe pollution, and Serious pollution, and a larger AQI indicates more serious air pollution. As shown in Fig.1, from 2014 to 2021, the air quality in Beijing continued to improve and enhance, and the frequency and degree of serious pollution events were greatly reduced, with only 8 days of heavy air pollution or above in 2021, which is closer to the "blue sky" expectations of Beijing's urban and rural residents, however, the air pollutant emissions in Beijing still exceed the environmental capacity, and the effects of air governance are not yet stable.

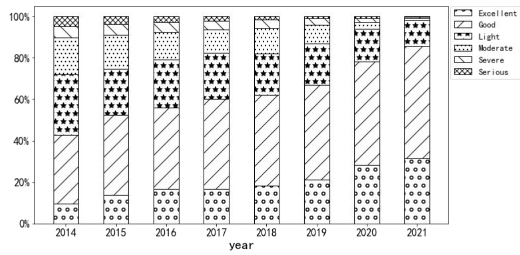

Figure 1　Percentage of polluted days at all levels in Beijing, 2014-2021

Data source: Beijing Ecological Environment Monitoring Center

In addition to the main components such as oxygen, the atmosphere also includes trace gas components such as SO_2 , NO , NO_2 , O_3 , CO,etc, which have an extraordinary role in the atmospheric cycle. Among them, NO and NO_2 are the main components of nitrogen oxide (NO_X) pollutants, which can be produced by high-temperature combustion, lightning and soil emissions. Since the reform and opening up, with the development of society, the increase of population and the rise of industry, there is a composite air pollution represented by acid rain, haze and photochemical pollution, and NO_X plays an important role in these atmospheric composite pollution, in addition to the synthesis of nitric acid to cause acid rain, NO_X and volatile organic compounds (VOCs) can also form photochemical smog and secondary organic aerosols under light conditions, in addition, NO_X can also cause irreversible harm and damage to the human respiratory system, immune system, nervous system and eyes. With the significant increase in energy consumption and vehicle ownership, it is urgent to control NO_X pollution in Beijing. Therefore, in recent years, Beijing has been committed to winning the battle against blue sky by actively implementing the "One Microgram Action" and the comprehensive treatment of regional joint prevention and control of air pollution. 2021 is the first year of the 14th Five-Year Plan, Beijing to NO_X and VOCs deep emission reduction and low carbon emission reduction measures as the main starting point, by adjusting the clean energy mix and transportation structure to overcome difficulties and continue to improve urban air quality. [2]As shown in Fig.2, the NO_X concentration in Beijing from 2014 to 2021 reached the secondary standard of 80ug/m^3 in　Ambient Air Quality Standard, and was reduced to the primary standard of 40ug/m^3 in 2018 for the first time, in addition to the fact that weather conditions generally favor the dispersal of pollutants, there is another important reason that the largest "coal to electricity" project in Beijing in 2017 was fully started, and the NO_X concentration continued to decrease, with the most obvious reduction of spokes in 2020, which should be related to COVID-19 traffic restrictions, but the concentrations of O_3, CO and SO_2 in Beijing from 2014 to 2021 were far below the primary concentration limit, it is evident that the control of NOx is particularly important in the control of air pollution in our country.

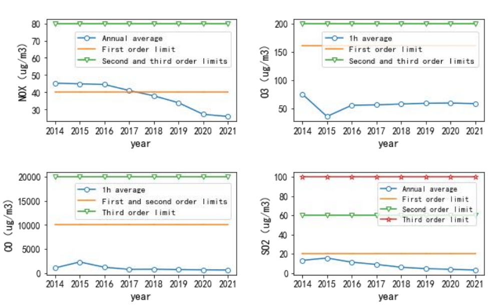

Figure 2　Actual concentrations of trace gas pollutants in Beijing and national standards, 2014-2021

Data source: Beijing Ecological Environment Monitoring Center

To sum up, NOx can cause great harm to atmospheric environment, physical and mental health, and NOx control technology in China is late and insufficient, so NOx pollution is still a focus problem. The spatio-temporal variation characteristics of NO_X were analyzed through historical observation data, and the previous achievements were summarized, to provide a reference for the following research work of comprehensive control by governments at all levels and relevant local departments, It is helpful to actively build ecological civilization and create a clean and livable environment for residents, which is of great significance for the sustainable and coordinated development of Beijing. Then, what is the effect of NO_X pollution control measures in Beijing? How will the NO_X concentration change in the next three years? How will we respond? This paper will be based on this analysis.

2. Data Processing and Model Introduction

2.1 Data processing

This paper mainly applies the AQI index, NO_X , O_3 , CO, and SO_2 published by 35 major monitoring stations of Beijing Environmental Protection Monitoring Center from 2014 to 2021. In order to analyze the characteristics of the geographical distribution of air pollutants, Beijing is divided into five main regions as shown in Table 1 based on the first-level administrative divisions and Beijing air quality release platform division, and the mean of pollutant concentration of all monitoring stations located in their respective administrative area is used as the pollutant concentration of each region.

Table 1 Five Regions of Beijing

Area	Administrative Region
City six	Dongcheng, Xicheng, Chaoyang, Haidian, Fengtai, Shijingshan
Northwest	Yanqing, Changping
Northeast	Huairou, Miyun, Shunyi, Pinggu
Southwest	Mentougou, Fangshan
Southeast	Tongzhou, Daxing, Yizhuang

2.2 Model Introduction

Grey Forecast Model (GFM), is through a small amount of incomplete information, the establishment of a mathematical model to make a forecast method. The most common grey forecasting model in the application is the GM (1, 1) model, that is, the one-time fitting parameter model, the GM (1, 1) model, by adding, subtracting and weighting the original series, a new series with a certain change rule, and then establish a differential equation, solve for the time response function as in Form (2.1), finally, combined with Form (2.2) to obtain the predicted value of the original series to predict the future development trend of the object under study, which has a wide range of applications in various prediction fields.

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right) e^{-ak} + \frac{b}{a} \qquad (2.1)$$

where α is the development coefficient, b is the ash action. Generally, when $\alpha \leq 0.3$, it can be used for med- and long-term prediction; when $0.3 < \alpha \leq 0.5$, it can be used for short-term prediction; when $0.5 < \alpha \leq 1.0$, the model needs to be corrected; when $\alpha > 1.0$, the GM (1, 1) model can not be used for prediction.

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k), (k = 1,2,\ldots,n) \qquad (2.2)$$

The grey prediction model has no strict requirement on sample size and data distribution. It has simple principle and high applicability. It can make prediction without a large amount of time series data and achieve better prediction effect. For studies with strong time-dependent needs and sensitive degree of policy implementation, such as analysis of air pollution, it is not that the more historical data, the better the performance of the model, and the time span needs to be flexibly selected. Therefore, considering the timing of the introduction of relevant policies on air pollution prevention and control in Beijing and the availability of relevant data. Based on data from 2014-2021, this paper selects the GM(1, 1) model, in which data processing and modeling analysis are implemented by python software.

3. Change trend of NOX concentration in Beijing Time change

3.1 Time variation

As shown in Fig.3, the maximum monthly mean concentration of NOX decreased year by year, with a slight increase from 2017 to 2018, and the minimum monthly mean concentration decreased year by year, but the reduction radiation was relatively slow, the difference between the two values increased first and then decreased, with a significant increase from 2014 to 2015 and a significant decrease from 2016 to 2017. To a certain extent, this shows that the measures such as "winter disease and summer treatment" of air pollution in Beijing have been effective, according to the Report on the Work of the Beijing Municipal People's Government, by 2016, 40.58% of the villages in Beijing had been transformed by the "coal to clean energy" project, and the transformation rate increased by 17.85% in 2017 alone, making it the most efficient year for the "coal to clean energy" project, by 2021, 88.7 percent of villages had access to clean energy, combined with the decreasing trend of NO_X concentration, the air pollution "winter disease and summer treatment" work contributed significantly to the reduction of NO_X concentration.

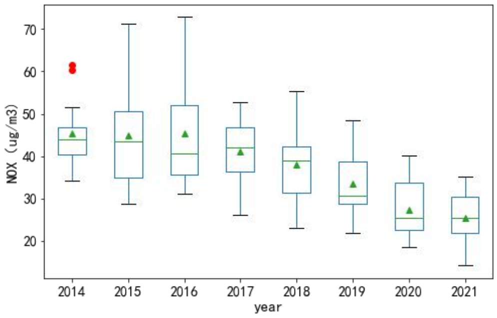

Figure 3 Box plot of mean monthly NOx concentration in Beijing, 2014-2021

Data source: Beijing Ecological Environment Monitoring Center

3.2 Spatial variation

As shown in Fig.4, the overall spatial distribution of NO_X concentration in Beijing shows "high in the south and low in the north, with the highest in the middle", The concentration of NO_X is higher in the six urban areas, the southeast and southwest, and the lowest in the northeast, It was not until 2020 that the average concentration of NO_X in all five regions reached level 1, Compared with 2014, the NO_X concentrations in the high value areas will decrease significantly, and the difference between the concentrations in the north and south and the suburbs will be significantly reduced, so the implementation of relevant policies is effective.

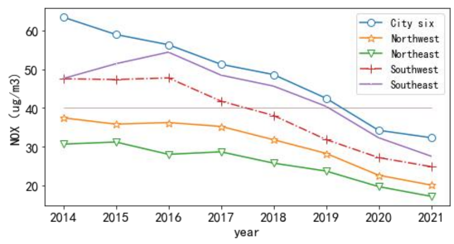

Figure 4 Annual average concentrations of NO_X in regions of Beijing , 2014 - 2021

Data source: Beijing Ecological Environment Monitoring Center

4. Grey prediction model analysis

Based on the introduction of grey prediction model mentioned above, this chapter constructs GM (1,1) model to estimate and predict the change trend of NO_X concentration in Beijing from 2022 to 2024.

4.1 Grade ratio test and judgment

To determine whether the time series has a suitable regularity and whether a satisfactory prediction model can be obtained, it is necessary to carry out the rank ratio test on the series.

Table 2 Annual average concentration of NO_X in Beijing, 2015 - 2021

Year	2015	2016	2017	2018	2019	2020	2021
NO_X concentration (ug/m^3)	44.5521	44.9443	44.5474	41.0831	37.5832	33.3664	27.2359

Data source: Beijing Ecological Environment Monitoring Center

By summing up a total of 7 original series x{0} of the annual NO_X concentration from 2015 to 2021 in Table 2, namely:

$$x^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(7)\} = \{44.5521,44.9443.44.5474,41.0831,37.5832,33.3664,27.2359\}$$

The grade ratio λ(k) is determined according to equation (4.1) :

$$\lambda(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)} \quad (4.1)$$

Get:

$\lambda = \{\lambda(2), \lambda(3), \dots, \lambda(7)\} = \{0.991272,1.008910,1.084326,1.081612,1.138365,1.225091\}$

The higher level ratio test of the series shows that all λ values fall into the feasible region, which means that this data can be used for grey prediction.

4.2 Construction of time response function and model prediction

Combined with formula (4.2), the x sequence data x{0} is accumulated once:

$$x^{(1)} = \{x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(7)\} = \{44.5521,89.4964,134.0438,175.1269,212.7101,246.0765,273.3124\}$$

$$x^{(1)}(k) = \frac{1}{2}x^{(1)}(k) + \frac{1}{2}x^{(1)}(k-1), k = 2,3, \dots, 7 \quad (4.2)$$

According to formula (4.3), the development coefficient $\alpha = 0.090195 \leq 0.3$, and the ash action $b = 53.487182$, according to the applicable conditions of the model introduced in Chapter II, this model can be used for medium and long term prediction.

$$\hat{a} = (a, b)^T = (\beta^T \beta)^{-1} \beta^T y_n \quad (4.3)$$

According to Formula (2.1) the time response function is :

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-ak} + \frac{b}{a} =- 548.466889 \times e^{0.090195k} + 593.0171517$$

Finally, the predicted value of the original sequence can be obtained by Formula (2.2).

4.3 Model test

Before making the prediction, the model needs to be checked, and if the accuracy does not meet the requirements, the model needs to be modified.

4.3.1 Relative residual test

The predicted value and residual detection results of the model are summarized as shown in Table 3, The relative error of the model fluctuates around 5%, the average relative error $\overline{\Delta} = 4.81\%$, the average relative precision $P = 1 > 90\%$, combined with the average relative error and the average relative accuracy result,The prediction results show that the predicted NO_X concentrations in 2022, 2023 and 2024 are 27.5338ug/m^3 , 25.1591ug/m^3 and 22.9892ug/m^3, the predicted concentration has a significant downward trend.

Table 3 Model prediction results and residual test table

Year	True value	Predicted value	Absolute error	Relative error	Residuals
2015	44.5521	44.5521			
2016	44.9443	47.3035	2.3592	0.0525	2.3592
2017	44.5474	43.2237	-1.3237	0.0297	-1.3237
2018	41.0831	39.4958	-1.5872	0.0386	-1.5872
2019	37.9832	36.0894	-1.8937	0.0499	-1.8937
2020	33.3664	32.9768	-0.3896	0.0117	-0.3896
2021	27.2359	30.1327	2.8968	0.1064	2.8968
2022		27.5338			
2023		25.1591			
2024		22.9892			

4.3.2 Mean squared error ratio C test and minimum error probability P test

According to the general accuracy grade division standard of the grey prediction model shown in Table 4, whether the model meets the accuracy requirements is judged. [6]After calculation, the mean square deviation ratio of prediction results $C = 0.080649 < 0.35$, and the prediction accuracy is one level. Small error probability $P = 0.845 > 0.80$, that is, the prediction accuracy is qualified.The prediction accuracy and fitting degree of this model are good.

Table 4 Criteria for classifying the accuracy level of grey model

C-value	P-value	Prediction accuracy level
<0.35	＞0.95	First class (good)
<0.50	＞0.80	Level 2 (qualified)
<0.65	＞0.70	Level 3 (barely pass)
≥0.65	≤0.70	Level 4 (unqualified)

Further, we compared the predicted value of the model from 2015 to 2021 with the real value to obtain Fig. 5, and found that the predicted value of the model and the real value had similar change trends, and the values were close, and the degree of model fitting was visually good.

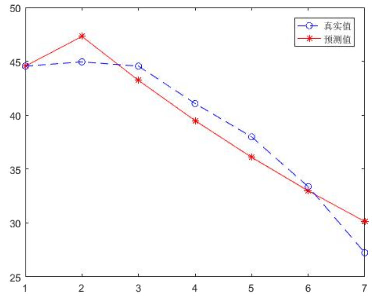

Figure 5 Comparison of true values and model predictions

5. Discussion

Based on the above research, the following conclusions are drawn:

First, with the continuous improvement of air quality in Beijing, the incidence of heavy pollution events has been greatly reduced. O_3 , CO, and SO_2 gas pollutants reached the primary concentration limit in 2014, while NO_X concentration dropped to the primary concentration limit for the first time in 2018.

Second, from the time dimension, the NO_X concentration in Beijing decreased significantly in 2016, which to a certain extent indicates that the prevention and control measures such as the "winter disease and summer treatment" of air pollution are effective.In terms of spatial dimension, the NO_X concentration showed a distribution of "high in the south and low in the north, and the highest in the middle". The NO_X concentration in the six urban areas and the southern area was higher, and the northeast area was the lowest. By 2021, the difference of NO_X concentration between the North and the south and the suburbs of Beijing was significantly reduced.

Third, through the construction of the grey prediction model, it can be obtained that the predicted NOX concentration values in 2022, 2023 and 2024 are 27.5338ug/m^3, 25.1591ug/m^3 and 22.9892ug/m^3, the concentration will still decrease, but the reduction rate is not big compared with the decline rate after 2017.

Accordingly, the following policy recommendations are put forward:

First, further improve the "winter disease and summer treatment" of air pollution in Beijing.Promote the work of "increasing electricity and reducing coal by gas", accelerate the transformation of energy structure, and then improve the efficiency of NO_X pollution treatment in the critical period.

Second, fine planning, scientific assessment.To further improve the air pollution control technology system, strengthen the coordinated emission reduction strategy of NO_X and VOCS in Beijing, focus on promoting the NO_X governance in the six urban areas and the southern region of Beijing, refine the plan, and scientific review.

Third, continue to deepen regional joint prevention and control.When necessary, regional joint prevention and control policies for NO_X pollution should be established according to the actual situation of each district to effectively solve the regional air pollution problem.

References

[1] Lu L, Zhang AW, Kang XY. Spatial and temporal variation of air pollutants in Beijing [J]. Frontiers in Earth Sciences,2018,8(3).

[2] Beijing Municipal People's Government.The government work report [R]. [2016-02-03]. [2017-01-23]. [2018-02-24]. [2019-01-23]. [2020-01-19]. HTTP://www.beijing.gov.cn/gongkai/ jihua/zfgzbg/

[3] Gu ZY, Huang BQ, Hao R. Research progress on NO_X elimination of air pollutants [J]. Chemical Engineering

and Equipment, 2021(04): 237-238.
[4] Wang JN, Wan J, Wang Q. Forty years of reform and opening up and the development of ecological and envi ronmental planning in China. China Environmental Management, 2018,10(06):5-18.
[5] Xiao CC, Guo PK, Chang W.Analysis on the characteristics of air pollution control supervision results and eva luation of policy effect: A case study of air pollution transmission channel cities in Beijing-Tianjin-Hebei Province and its surrounding areas [J]. Journal of AridLand Resources and Environment,2019,33(11):42-48.
[6] Liu SF, Yang YJ, Wu LF. Grey System Theory and Its Application [M]. Shanghai: Science Press,2014:136-155.

Author Biography: Li Jianing (1999.06 --), female, Han nationality, native of Chifeng, Inner Mongolia, Master candidate, North China University of Technology, Research interests: Applied statistics;Corresponding author, Li Hongmei (1971 --), female, Han nationality, native in Jining, Shandong Province, doctor, Associate professor, North China University of Technology, Research direction: Applied statistics;Wu shuang (1999.10 --), female, Han nationality, native of Chifeng, Inner Mongolia, Master candidate, North China University of Technology, Research interests: Applied statistics.