Simulation Analysis of NO₂ Pollution Diffusion Law Based on Gauss Plume Model: A Case Study from Hebei Province

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Abstract. Controlling the large-scale haze in Beijing-Tianjin-Hebei region has become a social issue of great attention to government departments and the public. This paper establishes the NO₂ diffusion model based on the Gauss plume model, by selecting Shijiazhuang city of Hebei Province as a case which is influenced seriously by NO₂ pollution, and analyses the diffusion law, diffusion range and concentration change of NO₂. Firstly, the conditions and parameters of the Gauss plume model are introduced, and the related factors affecting the NO₂ diffusion are analyzed. Secondly, the pollution sources are classified into point pollution sources (chimneys) and line pollution sources (automobile exhaust), and combines the yearly weather conditions of Shijiazhuang such as wind speed, wind direction, atmosphere stability etc. Then, simulating the diffusion area and concentration change using Stata 13.1 software platform, we found: (1) The formation of NO₂ pollution in Hebei Province is affected by special topography and unfavorable meteorological conditions; (2) The atmospheric stability is basically higher in autumn and winter; (3) Industrial emissions are the main source of NO₂ in Hebei Province; (4) The concentration of NO₂ pollutants near the emission source is the highest, and the concentration gradually decreases with increasing distance. The conclusion of the study has certain practical significance for the design and implementation of government environmental regulation and effective control and reduction of environmental pollution.

1. Introduction

As the main base of the heavy chemical industry in China, Beijing-Tianjin-Hebei region air pollution has become the focus of governments and the public at all levels. Today, air pollution is increasingly restricting the sustainable development of the environment, economy and society [1, 2]). In a recent study, many epidemiological studies have shown that air pollution is the main cause of many diseases, such as acute respiratory infections, heart disease, lung cancer, and chronic bronchitis. It has acute and chronic effects on human health, which will bring about premature mortality and reduce life expectancy [3-7].

According to the Report on the State of the Ecology and Environment in China in 2018, the evaluation results of air quality comprehensive index showed that Hebei province has five cities ranked among the top 20 cities with relatively poor air quality in 169 cities in China. This is mainly because of the fast industrial development in Hebei Province, and mostly for iron and steel, petrochemical enterprises, resulting in a large number of industrial pollutants emissions.
The NO$_x$ pollutant in Hebei Province mainly come from factories, vehicles, etc. [8, 9]. There are two types of NO$_x$: nitrogen dioxide (NO$_2$) and nitrogen monoxide (NO). Although most of NO$_x$ is NO at the time of emission, NO will relatively quickly be oxidized into NO$_2$.

According to environmental statistics, in 2017, the main nitrogen oxide emissions of Hebei Province were 1.056 million tons, ranking second in China. Among them, the vehicles nitrogen oxide pollutant emissions were 0.476 million tons, accounting for 45.08% of the total emission. As an important precursor of secondary pollutants, after entering the human respiratory system, NO$_x$ will cause deposition, absorption, and damage at various parts according to physical and chemical characteristics. Therefore, it is of great practical significance to protect public health, prevent air pollution and improve air quality, by analyzing the pollution diffusion law and the change of pollutant concentration of NO$_2$ in the urban and regional scale in Hebei Province.

Since the 1930s, scholars have formed hundreds of atmospheric diffusion models according to different diffusion theories in the study of atmospheric diffusion models of pollutants at home and abroad [10].

Some scholars examined the dispersion of air pollutants with the analytical Gauss approach, which the Euler and Lagrange descriptions are used for solution of the continuity equation [11, 12]. And estimating the plume dispersion parameters in lateral direction ($\sigma_x$) and vertical direction ($\sigma_z$) by using power law wind speed and the scheme of eddy diffusivity in unstable condition. Comparison among the model and algebraic and integral formulations were held, and find that the model and two other models are in agreement with observed data 12].

Kulanda Duysebekova et al. [13] and Liu et al. [14] used Gauss approach and studied the analysis of the solution of the semi-empirical solution of turbulent diffusion in problems of polluting impurity transfer, and presented an optimization technique to obtain the optimized dispersion parameters, for the sake of enabling the Gauss model to produce fast estimates of CO$_2$ concentration levels and precluded the necessity to set up much more complicated models.

Zhu et al. [15] utilized a modified Gauss plume model and compared the difference between the modified model and the traditional model, when considering plume rise and ground roughness to simulate the release consequence. Furthermore, they analyzed the effects of influencing factors involved in the modified model. The modelling system with a Kalman filter approach is capable to adapt modelled concentrations based on the originating source of the concentrations, more accurately than using simple background estimates, and optimize plume model concentrations using actual observations [16].

Over the decade years, many scholars discussed the classification and development stages of atmospheric diffusion models, and discussed the principles and laws of Lagrange model, Euler diffusion model, box model, Gauss plume model and puff model, and analyzed the advantages and disadvantages of atmosphere diffusion models [17-21].

Based on the standard Gauss diffusion model, many scholars considered various sources of emissions, leakage methods and diffusion conditions to simulate the diffusion law, concentration distribution and leakage range of pollutants [21-26]; There are many scholars who have studied the NO$_2$ pollution in the Beijing-Tianjin-Hebei region [8, 9, 27-29]. However, scholars have obtained the characteristics of atmospheric NO$_2$ pollution in Beijing-Tianjin-Hebei region based on OMI data inversion or ground monitoring, and few studies on the diffusion law and concentration distribution of NO$_2$ pollution sources based on atmospheric diffusion model. In order to solve this problem, this paper used the Gauss plume model to construct the diffusion model of NO$_2$ pollutants, and then selects the Hebei Province, which is seriously affected by NO$_2$, as an analysis case to study the diffusion law of NO$_2$ and the range of the contaminated area.

2. Gauss Model of NO$_2$ Pollution Diffusion

As early as the 1950s and 1960s, the Gauss model has been applied to investigate the concentration distribution of diffusion mass, which is divided into two types: Plume Model and Puff Model [30-32]. Among them, the plume model is suitable for the diffusion of continuous [33], and the puff model is
suitable for the diffusion of short-term leakage [34, 35]). The plume model and the puff model use a normal distribution to indicate the concentration of emission source in the downwind [36]. Although convection and diffusion phenomena are considered, chemical and gravity effects are not considered, it is only applicable to the diffusion of light gases or gases with similar air densities [35, 37]. Although the Gauss model has many shortcomings, many of the standards adopted by the US Environmental Protection Association (EPA) are still based on the Gauss model and are widely [38, 39].

The concentration distribution of NO\textsubscript{2} is usually high in the vicinity of the emission source, and the concentration gradually decreases toward the periphery of the emission source accompanying convection-diffusion. However, the temporal and spatial distribution of NO\textsubscript{2} pollutants and their concentrations are closely related to the distribution of pollutant sources, emissions, topography, geomorphology and meteorology.

2.1. Windy Point Source Normal Gauss Plume Model
When there is wind (the average wind speed is 1.5 m/s or more at a height of 10 m from the ground), and the ground is a total reflector, there are:

\[ C(x, y, z) = \frac{Q}{2\pi \sigma_y \sigma_z \mu} \times \exp \left( -\frac{y^2}{2\sigma_y^2} \right) \cdot \left\{ \exp \left[ -\frac{(z-H_e)^2}{2\sigma_z^2} \right] + \exp \left[ -\frac{(z+H_e)^2}{2\sigma_z^2} \right] \right\} \]  (1)

\( C(x, y, z) \) is the concentration of air pollutants (kg/m\textsuperscript{3}) at a certain point \((x, y, z)\) from emission source in the downwind; \(x\): the downwind distance (m); \(y\): the crosswind distance (m); \(z\): the height from the ground (m); \(Q\): the intensity of the pollutant source, ie the release rate (kg/s); \(\mu\): the wind speed (m/s); \(\sigma_y\): lateral diffusion parameter(m); \(\sigma_z\): vertical diffusion parameter (m); \(H_e\): the effective height of emission source (m); because the concentration of pollutants on the ground is to be predicted, according to formula (1), let \(z = 0\), which can be obtained:

\[ C(x, y, 0) = \frac{Q}{\pi \sigma_y \sigma_z \mu} \times \exp \left( -\frac{y^2}{2\sigma_y^2} \right) \cdot \exp \left( -\frac{H_e^2}{2\sigma_z^2} \right) \]  (2)

\( \sigma_y \) and \( \sigma_z \) are functions of the distance \(x\), which increase as \(x\) increases, and can generally be expressed as a power function form as shown in equation (3). The values are shown in table 1.

\[ \sigma_y = \gamma_1 x^{\alpha_1}; \sigma_z = \gamma_2 x^{\alpha_2} \]  (3)

In addition, the ground concentration of pollutants along the downwind axis, according to formula (1), let \(y = 0\), \(z = 0\), which can be obtained:

\[ C(x, y, 0) = \frac{Q}{\pi \sigma_y \sigma_z \mu} \cdot \exp \left( -\frac{H_e^2}{2\sigma_z^2} \right) \]  (4)

Due to the first term on the right side of equation (4) decreases with the increase of \(x\), the second term increases with the increase of \(x\). As a result of the two interactions, the maximum concentration \(C_{\text{max}}\) must occur at a certain distance \(X_{\text{max}}\). By deriving \(x\) by equation (4) and making it equal to zero, it can be obtained.

\[ C_{\text{max}} = \frac{2Q}{e \sigma \mu H_e P_1}. \]  (5)

\[ X_{\text{max}} = \left( \frac{H_e}{\gamma_2} \right)^{\frac{1}{\alpha_2}} \left( 1 + \frac{\alpha_1}{\alpha_2} \right)^{\frac{1}{\alpha_2}} \]  (6)

Among them,
Table 1. The power function value table of lateral diffusion parameter and vertical diffusion parameter (sampling time: 30 min).

| Diffusion parameter | Atmospheric stability level | $a_1/a_2$ | $\gamma_1/\gamma_2$ | Downwind distance (m) |
|---------------------|-----------------------------|-----------|---------------------|------------------------|
| A                   |                             | 0.901074  | 0.425809            | 0~1000                 |
|                     |                             | 0.850934  | 0.602052            | >1000                  |
|                     |                             | 0.914370  | 0.281846            | 0~1000                 |
|                     |                             | 0.865014  | 0.396353            | >1000                  |
|                     |                             | 0.919325  | 0.229500            | 0~1000                 |
| B                   |                             | 0.875086  | 0.314238            | >1000                  |
|                     |                             | 0.924279  | 0.177154            | 0~1000                 |
|                     |                             | 0.885157  | 0.232123            | >1000                  |
|                     |                             | 0.926849  | 0.143940            | 0~1000                 |
| B~C                 |                             | 0.926849  | 0.143940            | >1000                  |
| C                   |                             | 0.886940  | 0.189396            | >1000                  |
|                     |                             | 0.929418  | 0.110726            | 0~1000                 |
|                     |                             | 0.888723  | 0.146669            | >1000                  |
|                     |                             | 0.925118  | 0.098563            | 0~1000                 |
|                     |                             | 0.892794  | 0.101947            | >1000                  |
| C~D                 |                             | 0.929418  | 0.110726            | 0~1000                 |
|                     |                             | 0.920818  | 0.086400            | >1000                  |
| D                   |                             | 0.929418  | 0.055363            | 0~1000                 |
|                     |                             | 0.896864  | 0.101947            | >1000                  |
|                     |                             | 0.888723  | 0.073335            | >1000                  |
|                     |                             | 1.121540  | 0.079990            | 0~300                  |
|                     |                             | 1.523600  | 0.008548            | 300~500                |
|                     |                             | 2.108810  | 0.000212            | >500                   |
|                     |                             | 0.964435  | 0.127190            | 0~500                  |
|                     |                             | 1.093560  | 0.057025            | >500                   |
|                     |                             | 0.941015  | 0.114682            | 0~500                  |
|                     |                             | 1.007700  | 0.075718            | >500                   |
|                     |                             | 0.917595  | 0.106803            | >0                     |
|                     |                             | 0.838628  | 0.126152            | 0~2000                 |
|                     |                             | 0.756410  | 0.235667            | 2000~10000             |
|                     |                             | 0.815575  | 0.136659            | >10000                 |
|                     |                             | 0.826212  | 0.104634            | 1~1000                 |
|                     |                             | 0.632023  | 0.400167            | 1000~10000             |
|                     |                             | 0.555360  | 0.810763            | >10000                 |
|                     |                             | 0.776864  | 0.111771            | 0~2000                 |
|                     |                             | 0.572340  | 0.528992            | 2000~10000             |
|                     |                             | 0.499149  | 1.038100            | >10000                 |
|                     |                             | 0.788370  | 0.092753            | 0~1000                 |
|                     |                             | 0.565188  | 0.433384            | 1000~10000             |
|                     |                             | 0.414743  | 1.732410            | 1000~10000             |
|                     |                             | 0.788400  | 0.062077            | 0~1000                 |
|                     |                             | 0.525969  | 0.370015            | 1000~10000             |
|                     |                             | 0.322659  | 2.406910            | 1000~10000             |

$\sigma_y = \gamma_1 x_{at}$

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\[ P_t = \frac{2\gamma_1^{\frac{\gamma}{\alpha}}}{\left(1 + \frac{\alpha_1}{\alpha_2}\right)^{\gamma/\alpha_2}} \cdot H e^{\frac{\gamma}{\alpha_1}} \cdot e^{\gamma/\alpha_2} \]  \tag{7}

It can be seen from equations (6) and (7) that under the conditions of source strength and meteorological conditions, the maximum landing concentration of the pollution source increases with the increase of the effective height \( H_e \), and its corresponding appearance position is extended with the increase of the effective height \( H_e \).

2.2. Small Wind and Static Wind Point Source Diffusion Model

In the meteorology, the wind speed \( u \leq 0.5 \text{ m/s} \) is generally referred to as static wind, and the wind speed between 0.5 and 1.5 m/s is called small wind. In the case of static wind and small wind, because the average wind speed is too small and the dominant wind direction is uncertain, the Gauss plume model cannot be applied to predict the atmospheric environmental quality under such conditions.

Taking the ground position of the emission source as the coordinate origin, the downwind direction is the \( X \)-axis, and the calculation formula of the pollutant concentration at any point \((x, y)\) on the ground is as shown in equation (8).

\[ C(x, y, 0) = \frac{2Q}{(2\pi)^\gamma} \frac{\gamma_1^2}{\gamma_1^2} \cdot G \]  \tag{8}

\[ \gamma_1^2 = x^2 + y^2 + \gamma_1^{\frac{\gamma}{\alpha_1}} \cdot H_e^2 \]  \tag{9}

\[ G = \exp \left( -\frac{u^2}{2\gamma_1} \right) \left[ 1 + \sqrt{2\pi} \exp \left( -\frac{s^2}{2} \right) \phi(s) \right] \]  \tag{10}

\[ \phi(s) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{s} \exp \left( -\frac{t^2}{2} \right) dt \]  \tag{11}

\[ s = \frac{ux}{\gamma_1} \]  \tag{12}

Among them, \( \gamma_01, \gamma_02 \): are respectively the regression coefficients of the diffusion coefficients in the lateral and vertical directions, the values are shown in table 2. \( \Phi(s) \): normal distribution function; \( t \): diffusion time (s).

| Atmospheric stability level | \( \gamma_01 \) | \( 0.5 \text{ m/s} \leq u \leq 1.5 \text{ m/s} \) | \( \gamma_02 \) | \( 0.5 \text{ m/s} \leq u \leq 1.5 \text{ m/s} \) |
|---------------------------|---------------|----------------|---------------|----------------|
| A                         | 0.93          | 0.76           | 1.57          | 1.57           |
| B                         | 0.76          | 0.56           | 0.47          | 0.47           |
| C                         | 0.55          | 0.35           | 0.21          | 0.21           |
| D                         | 0.47          | 0.27           | 0.12          | 0.12           |
| E                         | 0.44          | 0.24           | 0.07          | 0.07           |
| F                         | 0.44          | 0.24           | 0.05          | 0.05           |
The formula of the plume model and the puff model includes a formula that considers the deposition of particulate matter based on the diameter of particulate matter. After trying to consider the formula of deposition, we found that the simulation results are not much different from the calculation results without considering the deposition. Therefore, sedimentation is not considered when calculating the concentration of NO2 pollutant.

3. Simulation Analysis of NO2 Pollutant Diffusion Model: A Case Study of Hebei Province

The modified formula of above-mentioned Gauss plume model and puff model were used and the meteorological conditions of various cities in Hebei Province were used for simulation analysis. Because the plume model and puff model assume a linear relationship between emission and concentration, the concentration obtained by the simulation can be divided by the emission amount to calculate “the increase in the concentration of NO2 pollutants caused by the emission of NO2 pollutants per unit amount” (ΔC/ΔE). The specific calculation steps are as follows.

First, calculating the solar elevation angle HA, and the solar elevation angle is calculated as shown in equation (13).

\[ HA = \arcsin (\sin\phi \cdot \sin\delta + \cos\phi \cdot \cos\delta \cdot \cos T_0) \]  \hspace{2cm} (13)

Among them, HA is the solar elevation angle, \( \phi \) is the local latitude, \( \delta \) is the solar declination, and \( T_0 \) is the mid-solar angle. The calculation formula is as shown in equation (14).

\[ T_0 = (TT - 12) \times 15^\circ = (CT + LC + EQ - 12) \times 15^\circ \]  \hspace{2cm} (14)

Among them, TT is the true solar time; CT is the local standard (time zone), China belongs to the 120° E place, which is called Beijing time; LC is the longitude correction (4 min/degree), if the local meridian circle is on the east side of the standard meridian circle, then LC is positive and vice versa; EQ is time difference. The time difference EQ and the solar declination \( \delta \) can be obtained by looking up the table separately.

Secondly, the solar radiation level is determined according to the cloud amount and the solar elevation angle inquiry table 3.

| Cloud amount (1/10) | Solar elevation angle |
|---------------------|-----------------------|
|                     | At night | \( H_A \leq 15^\circ \) | \( 15^\circ < H_A \leq 35^\circ \) | \( 35^\circ < H_A \leq 65^\circ \) | \( H_A > 65^\circ \) |
| \( \leq 4 \) (\( \leq 4 \)) | -2 | -1 | 1 | 2 | 3 |
| 5~7 (\( \leq 4 \)) | -1 | 0 | 1 | 2 | 3 |
| \( \geq 8 \) (\( \leq 4 \)) | -1 | 0 | 0 | 1 | 1 |
| >5 (5~7) | 0 | 0 | 0 | 0 | 1 |
| \( \geq 8 \) (\( \geq 8 \)) | 0 | 0 | 0 | 0 | 0 |

Again, the atmospheric stability level is determined based on the surface wind speed and solar radiation level inquiry table 4. Finally, the simulation is carried out according to the equation (2) of the windy point source normal Gauss plume model and the equation (8) of the small wind and static wind point source diffusion model. The range of simulation calculation, emission, and calculated heights of the concentration are shown in table 5.

Finally, although \( \Delta C/\Delta E \) covers the annual average concentration since there is a nonlinear relationship between meteorological conditions (wind speed, etc.) and concentration in the plume model and the puff model, only one scenario of annual mean weather conditions is simulated, and the concentration change may not be accurately simulated. Therefore, this study first classified the wind direction, wind speed and atmospheric stability of various cities in Hebei Province into several models, and simulated the \( \Delta C/\Delta E \) of each model. Next, the weighting of \( \Delta C/\Delta E \) is weighted by the frequency of each model in each year, and the annual average \( \Delta C/\Delta E \) is obtained. The calculation idea
is shown in figure 1. The data such as wind direction and wind speed used are derived from the National Meteorological Science Data Sharing Service Platform and the National Earth System Science Data Sharing Platform.

Table 4. Atmospheric stability level.

| Ground wind speed (m/s) | Solar radiation level |
|-------------------------|-----------------------|
|                         | 3 | 2 | 1 | 0 | -1 | -2 |
| ≤1.9                    | A | A-B | B | D | E | F |
| 2~2.9                   | A-B | B | C | D | E | F |
| 3~4.9                   | B | B-C | C | D | D | D |
| 5~5.9                   | C | C-D | D | D | D | D |
| ≥6                      | C | D | D | D | D | D |

Table 5. Calculation condition of “the increase in the concentration of NO\textsubscript{2} pollutants caused by the emission of NO\textsubscript{2} pollutants per unit amount” (ΔC/ΔE).

| Condition | Content |
|-----------|---------|
| Calculation range | Calculated to 20 km from the emission source (radius 10 km) |
| Emission | Regarding the discharge rate of primary pollutants, estimate the daily average value of the annual emissions data of NO\textsubscript{2} related to the 2016 Hebei Provincial Environmental Status Bulletin and the Hebei Provincial Motor Vehicle Pollution Prevention Bulletin (assuming that the daily variation of chimney and vehicle emissions is fixed) The chimney emission height is fixed at 15 m and the vehicle discharge height is 1 m high. |
| Calculated height of concentration | Considering the height of human breathing, it is fixed at 1.5 meters above the ground. |

Figure 1. Calculated steps of annual average concentration-related “The increase in NO\textsubscript{2} pollutants concentration caused by the emission of NO\textsubscript{2} pollutants per unit amount” (ΔC/ΔE).
Using the above methods, 10 cities including Zhangjiakou, Chengde, Qinhuangdao, Tangshan, Langfang, Shijiazhuang, Zhangzhou, Xingtai and Hengshui in Hebei Province were used to simulate and analyze the concentration distribution around the emission source of NO₂ pollutants. Among them, the simulation results of the chimney and vehicle emission sources which are calculated according to the meteorological conditions in Shijiazhuang are shown in figures 2 and 3.

![Figure 2. Shijiazhuang City (Chimney).](image1)

Figure 2. Shijiazhuang City (Chimney).

![Figure 3. Shijiazhuang City (Automobile).](image2)

Figure 3. Shijiazhuang City (Automobile).

As shown in the figures, the simulation results of chimney and vehicle exhaust emissions show that in each city, the concentration of NO₂ pollutants near the emission source is the highest, and the concentration gradually decreases with increasing distance. Based on the distance from the emission source, the simulated distribution of concentrations can be obtained from the plume model and the puff model.

In order to calculate “the increase in NO₂ pollutants concentration caused by the emission of NO₂ pollutants per unit amount” ($\Delta C/\Delta E$), it is necessary to summarize the product of the simulated concentration of the primary pollutant and the area of the region within the range of 20 km (radius 10 km) as stated in table 5.

Wind direction, wind speed and atmospheric stability can be respectively divided into total L model, total M model, and total N model. Specifically, as shown in the formula (15), it summarized that the concentration of the NO₂ pollutant obtained by the simulation is multiplied by the circle (ring) area within 2 meters in an interval of 2 meters.

$$\sum_{n=1}^{500} \left[ \pi \cdot (2n)^2 - \pi \cdot (2(n-1))^2 \right] \cdot C(n)$$  \hspace{1cm} (15)

Among them, n: The point is 1 when the distance from the emission source is 2 m, and as the distance increases by 2 meters, the value increases by 1. C(n): annual average concentration of NO₂ pollutants at point n (μg/m³) Calculating “the increase in NO₂ pollutants concentration caused by the emission of NO₂ pollutants per unit amount” $\Delta C/\Delta E$, through the total product which obtained by
simulation according to equation (15) divided by emissions. The calculation results of 10 cities in Hebei Province are shown in table 6.

Table 6. The increase in NO$_2$ pollutants concentration caused by the emission of NO$_2$ pollutants per unit amount ($\Delta C/\Delta E$) (μg/m$^3$·m$^2$/kg/year).

| City          | Chimney | Vehicle |
|---------------|---------|---------|
| Shijiazhuang  | 3.68E+03| 7.22E+03|
| Tangshan      | 1.04E+03| 2.41E+03|
| Baoding       | 2.49E+03| 5.43E+03|
| Cangzhou      | 1.94E+03| 4.42E+03|
| Xingtai       | 1.74E+02| 1.40E+03|
| Langfang      | 4.62E+03| 8.62E+03|
| Chengde       | 4.98E+03| 9.27E+03|
| Zhangjiakou   | 6.83E+02| 2.54E+03|
| Hengshui      | 2.63E+03| 6.14E+03|
| Qinghuangdao  | 4.30E+03| 8.03E+03|

4. Conclusions

The diffusion model of NO$_2$ pollutants is constructed by using the Gaussian plume model in this paper. The Hebei Province, which is seriously affected by NO$_2$, is selected as an analysis case to study the diffusion law of NO$_2$ and the range of the contaminated area. Firstly, this paper introduced the Gauss plume model and analyzed the wind speed, wind direction, atmospheric stability and source strength parameters that affect NO$_2$ diffusion. Then, combined with the actual meteorological conditions in Hebei Province and other factors, under the premise of simulating the same source strength, the emission per unit of NO$_2$ pollution source leads to the increase of NO$_2$ pollution concentration in the regional areas of Hebei Province.

The results show that the formation of NO$_2$ pollution in Hebei Province is affected by special topography and unfavorable meteorological conditions. The atmospheric stability is basically higher in autumn and winter than in spring and summer, and is generally E in winter and A or B in summer. In addition, industrial emissions are the main source of NO$_2$ in Hebei Province. In recent years, a series of environmental governance policy regulations and the introduction of environmental protection equipment in the industrial sector, NO$_2$ pollution had been greatly improved. On the other hand, with a sharp increase in the number of motor vehicles, the share of vehicle exhaust emissions should not be underestimated.

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