American Journal of Environmental Science and Engineering
2018; 2(4): 65-71
http://www.sciencepublishinggroup.com/j/ajese
doi: 10.11648/j.ajese.20180204.13
ISSN: 2578-7985 (Print); ISSN: 2578-7993 (Online)

Quantitative Analysis of Influencing Factors of Air Pollution and Evolution Law of Nitrogen Oxide Distribution in Beijing, Tianjin and Hebei

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To cite this article:
Zuo Zhengdong, Wan Guangcai, Huang Xiaohui, Shao Zhichao. Quantitative Analysis of Influencing Factors of Air Pollution and Evolution Law of Nitrogen Oxide Distribution in Beijing, Tianjin and Hebei. *American Journal of Environmental Science and Engineering*. Vol. 2, No. 4, 2018, pp. 65-71. doi: 10.11648/j.ajese.20180204.13

Received: August 19, 2018; **Accepted**: December 7, 2018; **Published**: January 15, 2019

Abstract: Nowadays,the continuous fog and haze weather has made people more and more concerned about air pollution.And the air pollution problem in the Beijing-Tianjin-Hebei region is the highest in China. The high-density population distribution, crowded urban traffic and large-scale heavy industry bases are the main reasons for this phenomenon.This study analyzes the problem of air pollution sources and changes on gradient of air concentrations. Based on quantitative analysis, variable control, linear fit and two order parabolic partial differential equation,the principal component analysis model and Single Gaussian plume diffusion sources model are developed. Coupled with these models, MATLAB and Microsoft Excel are also further made use of to analyze the gradient of pollutant concentration around the plant at different time and judge the air quality level.Finally, it can be concluded that the main sources are industrial emissions, fuel combustion, vehicle exhaust and industrial waste water as well as the main influencing parameters are PM2.5 and PM10.0. And the farther away from the chimney, the lower the concentration of Nitrogen oxides was.The model is suitable for analyzing the influence of pollutants emitted from plant chimneys on the surrounding area.It can also help the Environmental Protection Department to formulate emission standards to promote sustainable economic development.

Keywords: Pollution Sources, Principal Component Analysis, Gaussian Plume Diffusion, MATLAB

1. Introduction

Nowadays, air pollution has become a common weather phenomenon, and people's intuitive feeling of air pollution is continuous smog weather. The detection of air quality is mainly measured by the PM2.5 index, whose Chinese name is fine particle. The high-density population distribution, crowded urban traffic and large-scale heavy industry bases are the main reasons for this phenomenon.

A lot of scholars have carried out a lot of analyses and researches on air pollution in China. Lu Ranying pointed out that the research on API index of 47 cities in China shows that sand dust has a great impact on urban air quality in China, and air pollutants have the spatial distribution characteristics of the "South Light and North Heavy" obviously [1] . Research results from Ren Zhenhai and others show that the formation of air pollution areas is related to the total coal consumption, atmospheric transport and topography in the region [2]. The source of air pollution can be divided into two broad categories, natural and artificial. The source of man-made air pollution is divided into two categories: coal-fired exhaust gases and tail gas from burning fossil fuels [3-5]. In recent years, the air pollution control in Beijing, Tianjin and Hebei has gradually turned into the regional joint control mode[6]. The PM2.5 in Beijing, Tianjin and Hebei is polluted frequently and the pollution degree is heavy.In 2015, Beijing-Tianjin-Hebei Environmental Quality Bulletin showed that PM2.5 in Beijing-Tianjin-Hebei region average annual concentration (81, 70 and 77 $\mu g \cdot m^{-3}$) seriously exceeded the annual limit (35 $\mu g \cdot m^{-3}$) of Grade II national standards for air quality, and the pollution situation is grim [7-9]. The heavy pollution of PM2.5 in the

Beijing-Tianjin-Hebei region occurs in autumn and winter. According to statistics, from 2013 to 2014, the large-scale heavy pollution process occurred 31 times in the Beijing-Tianjin-Hebei region, of which 23 of them occurred in the autumn and winter [10].Therefore, the study of the law of the evolution and distribution of air pollution sources is of great significance for reducing urban pollution problems and protecting the environment [11-12].

2. Data Sources and Model Assumptions

The real-time monitoring parameters of air quality in different areas of Beijing-Tianjin-Hebei and the main pollution sources and pollution parameters in Beijing-Tianjin-Hebei region in 2015 all come from the State Environmental Protection Administration [14]. In order to solve the problem, the following hypotheses are proposed: (1) the concentration of atmospheric pollution does not change greatly in a short period of time; (2) the mass of pollutants is conserved during the diffusion process; (3) the propagation of gas obeys the law of diffusion, that is,unit time is proportional to its concentration gradient by unit normal flow to area; (4)the three parameters of hydrogen sulfide, hydrocarbons and soot in the Beijing-Tianjin-Hebei region have a weak in fluence on the air quality, which can be ignored here.

3. Analysis of the Nature and Types of Air Pollution Sources in the Beijing-Tianjin-Hebei Region

3.1. Research Ideas

First,data on major pollution sources and pollution parameters in the Beijing-Tianjin-Hebei region are collected from the National Environmental Protection Agency, PM2.5 Monitoring Center and other websites, and pre-processed the data to facilitate the solution of the latter problem[15]; Secondly, the principal component analysis method is used to fit the original multi-correlation influence parameters linearly, so as to find out the new principal component, and construct the principal component analysis model,then calculate and rank the comprehensive evaluation value of each pollution source;Finally, according to the comprehensive evaluation value the nature and types of major pollution sources in the Beijing-Tianjin-Hebei region can be analyzed[16].

3.2. Data Processing

The main pollution sources and pollution parameters in the Beijing-Tianjin-Hebei region are shown in Table 1.

Table 1. *Main pollution sources and parameter values in Beijing-Tianjin-Hebei area.*

Number	Pollution sources	PM2.5	PM10	CO	NO_2	O_3	SO_2
1	Reclamation Burning	283	387	1.257	114	343	31
2	Agricultural emissions	251	325	1.597	43	301	39
3	Industrial waste water	258	386	1.329	111	264	135
4	Industrial waste Gas	316	486	3.565	165	259	253
5	Life Waste Gas	235	347	1.386	75	368	76
6	Fuel burning	164	290	1.583	59	156	50
7	Automobile exhaust	304	428	2.365	50	320	58
8	Sewage treatment	233	379	1.236	76	301	73
9	Dust	139	277	1.165	76	377	131
10	Forest fire	112	302	1.511	73	328	104

a. Standardize processing of the original data, and switch the index a_{ij} into the standardized index $\widetilde{a_{ij}}$:

$$\tilde{a}_{ij} = \frac{a_{ij} - \mu_j}{s_j}, i = 1,2,\ldots,n, j = 1,2,\ldots,m \tag{1}$$

$$\mu_j = \frac{1}{n}\sum_{i=1}^{n} a_{ij}, s_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(a_{ij} - \mu_j)^2}, j = 1,2,\ldots,m \tag{2}$$

μ_j, s_j are the sample mean and standard deviation of the j-th index.

Similarly,

$$\tilde{x}_j = \frac{x_j - \mu_j}{s_j}, j = 1,2,\ldots,m \tag{3}$$

Can be identified as standardized indicator variables.

b. Calculate the correlation coefficient matrix R.

Correlation coefficient matrix R $= (r_{ij})_{m\times m}$,·

$$r_{ij} = \frac{\sum_{k=1}^{n} \tilde{a}_{ki} \bullet \tilde{a}_{kj}}{n-1}, i, j = 1,2,\ldots,m \tag{4}$$

And:$r_{ii} = 1, r_{ij} = r_{ji}$, r_{ij} are the correlation coefficient of the i-th index and the j-th index

c. Compute eigenvalues and eigenvectors. The eigenvalue of the computed correlation coefficient matrix R is $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_m \geq 0$,and the corresponding standardized eigenvector $u_1, u_2, \ldots, u_m$, and $U_j = [u_{1j}, u_{2j}, \ldots, u_{mj}]^T$, t new indicator vectors are composed of eigenvectors.

$$y_1 = u_{11}\widetilde{x_1} + u_{22}\widetilde{x_2} + \cdots + u_{m1}\widetilde{x_t}$$

$$y_2 = u_{12}\widetilde{x_1} + u_{22}\widetilde{x_2} + \cdots + u_{m2}\widetilde{x_t}$$

$$y_m = u_{1m}\widetilde{x_1} + u_{2m}\widetilde{x_2} + \cdots + u_{mm}\widetilde{x_t} \tag{5}$$

And y_m is m-th principal component.

d. Choose p (p≤5) principal components, calculate the comprehensive evaluation value.

Firstly, the information contribution rate and cumulative contribution rate of eigenvalues $\lambda_j, (j = 1,2, \dots, m)$ are calculated.

$$b_j = \frac{\lambda_j}{\sum_{k=1}^{m} \lambda_k}, j = 1,2,\dots,m \tag{6}$$

is information contribution rate of principal component y_j

$$\alpha_p = \frac{\sum_{k=1}^{p} \lambda_k}{\sum_{k=1}^{m} \lambda_k} \tag{7}$$

is cumulative contribution rate of principal component $y_1, y_2, \dots, y_p$.

When α_p is close to 1 $(\alpha_p = 0.85, 0.90, 0.95)$, select the first p indicator variables $y_1, y_2, \dots, y_p$ as p principal components to replace the original m indicator variables, thus p principal components can be analyzed comprehensively.

Secondly, calculate comprehensive scores:

$$Z = \sum_{j=1}^{p} b_j y_j \tag{8}$$

b_j is the j-th principal component of the information contribution rate, which can be evaluated according to the comprehensive scoring value.

3.3. Analysis of Results

a. Use MATLAB software to obtain the first six eigenvalues of the correlation coefficient matrix and their contribution rates are shown in the following table:

Table 2. *Results of principal component analysis for air pollution sources.*

Number	**1**	**2**	**3**	**4**	**5**	**6**
Characteristic value	3.3543	1.0988	0.9947	0.4158	0.0841	0.0522
Contribution rate	0.5591	0.1831	0.1658	0.0693	0.0140	0.0087
Cumulative contribution Rate	0.5591	0.7422	0.9080	0.9773	0.9913	1.0000

It can be seen that the cumulative contribution rate of the first three characteristic roots is more than 90%, and it can be judged that the principal component analysis is very effective.

b. The first three principal components are selected for comprehensive evaluation. The eigenvectors corresponding to the first three eigenvalues are as follows:

Table 3. *Eigenvectors corresponding to the first three principal components.*

	$\tilde{x}1$	$\tilde{x}2$	$\tilde{x}3$	$\tilde{x}4$	$\tilde{x}5$	$\tilde{x}6$
First eigenvector	-0.3996	-0.4999	-0.4698	-0.4442	0.1043	-0.4018
Second eigenvector	0.5694	0.3275	-0.1296	-0.1925	0.5436	-0.4682
Third eigenvector	-0.2725	-0.1007	-0.1515	0.3271	0.7832	0.415

Three principal components can be x, y, z respectively,

$$\mathrm{y} = -0.40\widetilde{x_1} - 0.50\widetilde{x_2} - 0.47\widetilde{x_3} - 0.44\widetilde{x_4} + 0.10\widetilde{x_5} - 0.40\widetilde{x_6}$$

$$\mathrm{y} = 0.57\widetilde{x_1} + 0.33\widetilde{x_2} - 0.13\widetilde{x_3} - 0.19\widetilde{x_4} + 0.54\widetilde{x_5} - 0.47\widetilde{x_6}$$

$$\mathrm{y} = -0.27\widetilde{x_1} - 0.10\widetilde{x_2} - 0.15\widetilde{x_3} + 0.32\widetilde{x_4} + 0.78\widetilde{x_5} + 0.42\widetilde{x_6}$$

Based on the contribution rate of three principal components, a comprehensive evaluation model of principal components is constructed.

$$\mathrm{Z} = 0.5591y_1 + 0.1831y_2 + 0.1658y_3$$

c. Substitute the three principal component values of each pollution source into the above formula, and the comprehensive ranking and comprehensive evaluation results of each pollution source can be obtained, as shown in the following table:

Table 4. *Results and rankings of comprehensive evaluation of pollution sources.*

Pollution sources	**Industrial waste Gas**	**Fuel burning**	**Automobile exhaust**	**Industrial waste water**	**Sewage treatment**
Ranking	1	2	3	4	5
Evaluation value	1.1235	0.378	0.2881	0.1484	-0.0749
Pollution sources	Agricultural emissions	Forest fire	Life Waste Gas	Dust	Reclamation Burning

Pollution sources	**Industrial waste Gas**	**Fuel burning**	**Automobile exhaust**	**Industrial waste water**	**Sewage treatment**
Ranking	6	7	8	9	10
Evaluation value	-0.1568	-0.1603	-0.4322	-0.4819	-0.6319

d. Conclusion Analysis

According to the comprehensive evaluation values of various polluted areas, the main pollution sources affecting air quality are industrial waste gas, fuel combustion, automobile exhaust gas and industrial wastewater. The main influence parameters are PM2.5 and PM10.0. Researches on these four sources of pollution show that it is mainly concentrated in two aspects of industrial pollution and automobile exhaust pollution.

4. Nitrogen Oxide Diffusion and Attenuation Law in the Absence of Wind

4.1. Research Ideas

The nitrogen oxides emitted from the factory chimney can be regarded as a diffusion process caused by continuous point sources in infinite space. In order to study the law of concentration variation with time in the diffusion of nitrogen oxides, a second-order parabolic partial differential equation is established. The influence of the wind is not considered first, and the emitted nitrogen oxides are uniformly spread around, so that at any time, the diffused gas encloses a sphere, and the concentration values are different from the position of the spherical center [17].

4.2. Data Processing

The time to discharge the exhaust gas from the chimney is t=0, the chimney emission point is selected as the coordinate origin, and the waste concentration of the time t infinite space any point (x, y, z) is recorded as C(x, y, z, t). According to the assumption, the unit time through the unit of the normal area of the flow is.

$$\vec{q} = -k * gradC \qquad (9)$$

Where: k is the diffusion coefficient, grad is gradient, the negative sign indicates that the concentration of high to low concentrations of the local diffusion, considering the space Ω,the volume of Ω,V, surrounded by the surface S,and S of the normal outside vector is $\vec{n}$, then during $[t, t + \Delta t]$the flow through the Ω is

$$Q_1 = \int_t^{t+\Delta t} \iint_S \vec{q}\vec{n}\, d\sigma dt \qquad (10)$$

The increment of the gas within the space Ω is

$$Q_2 = \iiint_V [C(x,y,z,t) - C(x,y,z,t+\Delta t)]dV \qquad (11)$$

By the law of mass conservation

$$Q_1 = Q_2 \qquad (12)$$

According to the austenite formula of the curvature area division

$$\iint_S \vec{q}\vec{n}\, d\sigma = \iiint_V div\vec{q}\, dV \qquad (13)$$

where the div is a scatter mark.

It is not difficult to obtain the integral mean value theorem by using the above formula

$$\frac{\partial C}{\partial t} = kdiv(gradC) = k\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right), t > 0, -\infty < x, y, z < +\infty \qquad (14)$$

This is a parabolic partial differential equation of unbounded region. According to the hypothesis, the initial condition is the point source function acting on the coordinate origin, which can be recorded as

$$C(x,y,z,0) = Q\delta(X,Y,Z) \qquad (15)$$

Q represents the total amount of nitrogen oxides gas emitted by chimneys, and $\delta(X, Y, Z)$ is the point source function of the unit strength.

The result is

$$C(x,y,z,t) = \frac{Q}{(4\pi kt)^{\frac{3}{2}}} e^{-\frac{x^2+y^2+z^2}{4kt}} \qquad (16)$$

4.3. Result Analysis

The results show that the equivalent surface of nitrogen oxide concentration C at any time t is spherical $x^2 + y^2 + z^2 = R^2$, and the value of C is decreased continuously with the increase of the spherical radius r. When $R \to \infty$ or $T \to \infty$, $C(x, y, z, t) \to 0$.

5. Nitrogen Oxide Diffusion and Attenuation Law Under Windy Conditions

5.1. Research Ideas

The chimney emission pollutant gas belongs to the elevated point source. When the air flows in the environment, in the uniform turbulent flow field, Gaussian model can be used to calculate the air pollution concentration distribution and air quality grade at different time within a 51 km radius of the project [18].

5.2. Data Processing

It is required to analyze the concentration gradient of pollutants at different time points of 51 km from the factory. According to the conclusion of 3, the concentration of polluted gas when the chimney does not emit pollutant gas can be obtained. When the chimney emits polluting gas, the Gaussian elevated point source diffusion model can be used to obtain the concentration of the polluting gas.

The effect of Gauss diffusion formula depends on the accuracy of each parameter in the formula, especially the estimation of the height Δh and diffusion parameter σ_y and σ_z of the plume. Among them, the average wind speed u takes the regular meteorological data of many years observation, the source strong Q can be calculated according to the data, and σ_y , σ_z and H are closely related to meteorological condition and ground condition. Suppose the atmospheric stability is C.

a. Determination of the height of smoke flow uplift.

The effective height of the chimney should be the sum of the geometric height of the chimney and the rise in smoke, is:

$$H = h + \Delta h \tag{17}$$

There are two reasons for the rise of flue gas: one is the flue gas at the exit of the chimney has a certain initial momentum; the other is the flue gas temperature is higher than the ambient air temperature to produce a certain buoyancy.

b. Determination of diffusion parameters σ_y and σ_z.

The diffusion parameter σ_y , σ_z are the characteristic quantity of the diffusion range and the rate size, and are also the standard deviation of normal distribution function. The diffusion parameter is closely related to the atmospheric stability degree. According to the weather data of wind speed, cloud cover, clouds and sunshine, the atmospheric diffusion dilution ability is divided into six levels of stability, which can be seen in Schedule 4. According to the GB3840-91 *Technical method of establishing local air pollutant emission standards* in our country, the diffusion parameters are determined by the following empirical formula:

$$\sigma_y = \gamma_1 x^{\alpha_1}, \sigma_z = \gamma_2 x^{\alpha_2} \tag{18}$$

$\gamma_1, \gamma_2, \alpha_1, \alpha_2$ are called diffusion coefficient. These coefficients can be traced by GB3840-91's table, which can be seen in Appendix Table 4, 5.

c. Select the point source on the ground of the projection point o as the coordinate origin,and the valid source is located on the z axis at some point, z=H. The height of the effective source of the elevated frame is composed of two parts:$H = h + \Delta h$

If it is assumed that the pollutant reaches the ground and is fully absorbed,where there is no increase of the reflection concentration and the surface concentration of the elevated point source is calculated, then the formula of the pollutant concentration is

$$C(x, y, 0, H) = \frac{Q_i}{\pi u \sigma_y \sigma_z} \exp[-\frac{1}{2}(\frac{y^2}{\sigma_y{}^2} + \frac{H^2}{\sigma_z{}^2})] \tag{19}$$

C is the pollutant concentration of the space point (x,y,z), the unit is mg/m³; Q_i is the source intensity, pollutant emissions per unit of time, the unit is mg/s,(i=1, i=2), i=1 indicates that the factory discharges the pollutant during the morning 9 to 3 o'clock in the afternoon, i= 2 indicates that the plant discharges pollutants at night 10 o'clock-4 o'clock in the morning. u is average wind speed, the unit is m/s; σ_y , σ_z are the diffusion coefficients of flue gas, which is related to atmospheric stability and horizontal distance x, and increases with the increase of x.

5.3. Result Analysis

Using MATLAB software to substitute data according to the Gaussian formula, the change of air pollution concentration gradient within a 51 km radius, 8 o'clock, and 9 o'clock in the factory are as follows:

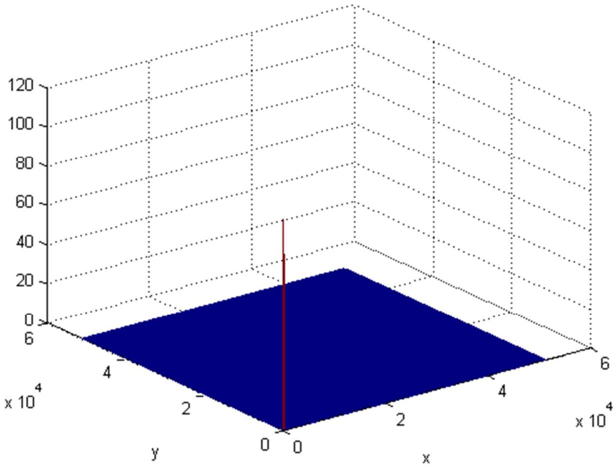

Figure 1. *8 o'clock in the morning air pollution concentration gradient change.*

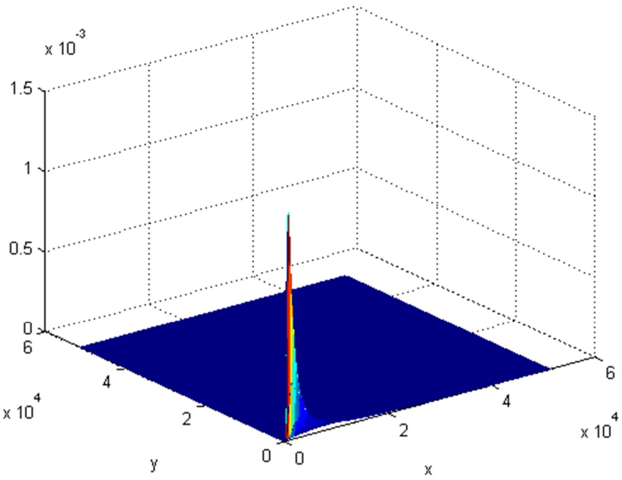

Figure 2. *The variation of air pollution concentration gradient at 12 o'clock Noon.*

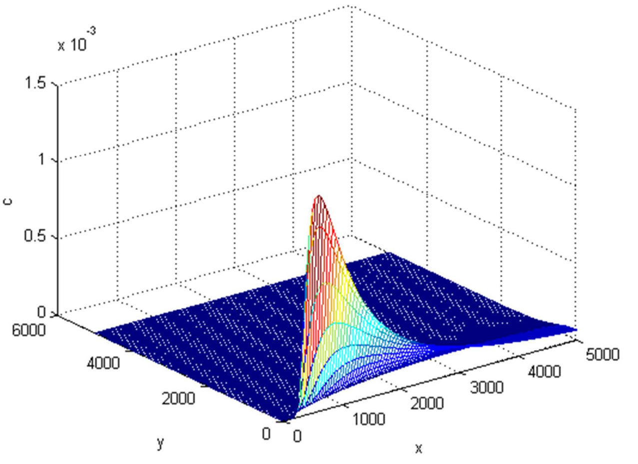

Figure 3. *The variation of air pollution concentration gradient at 12 o'clock Noon.*

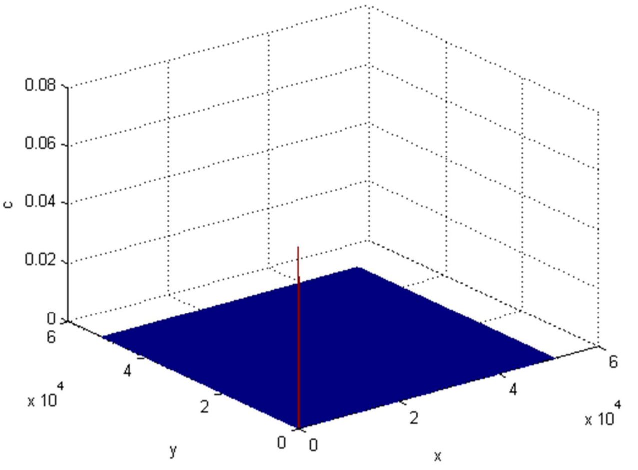

Figure 4. *Night 9 o'clock air pollution concentration gradient change.*

At 8 o'clock in the morning, the nitrogen oxide pollution is almost zero, the air quality level is the first level, and the air quality is excellent. At 12 noon, the nitrogen oxide pollution is farther away from the chimney, and the lower the concentration is, the better the air quality level is. The concentration of pollutants from the factory to the factory decreases within a 51 km radius, and the concentration of pollutants is almost zero 20 km away from the factory; the pollution of nitrogen oxides is almost zero at 9:00, the air quality level is the first level, and the air quality is excellent.

6. Summarize

Aiming at the problem of air pollution source and pollution concentration, a variety of analysis methods are used and corresponding models are established to conduct research, so that the problem can be more comprehensively analyzed, and various software can be used to make various related graphics, which makes the process of data processing and result analysis more complete. The image is easy to understand. Using the second-order parabolic partial differential equation model and the Gaussian model, the gradient of pollutant concentration around the plant at different time can be analyzed, and also the air quality level is judged. The model is suitable for analyzing the impact of pollutants emitted by factory chimneys, and helping the environmental protection department set emission standards to promote sustainable economic development.

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