

Research Article

Human Health Risk Prediction Method of Regional Atmospheric Environmental Pollution Sources Based on PMF and PCA Analysis under Artificial Intelligence Cloud Model

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In order to solve the problem that atmospheric particulate matter has become the primary pollutant with serious harm and complex sources in recent years, this paper proposes an accurate identification method of pollution sources based on a receptor model to obtain the contribution rate of each pollution source category. This method takes the 75-day measured environmental receptor data of an area under the artificial intelligence cloud model as the basic data, uses the `normrnd()` function to expand the receptor data, and uses the positive definite matrix factor analysis (PMF) and principal component analysis (PCA) models to verify the rationality of the data expansion. The results are as follows: the number of extended simulated receptor component spectra has a certain effect on the PCA analysis results, but the effect is smaller than the extended range. All relative errors are less than 14%, and the relative error is the smallest when the six simulated receptor component spectra are expanded, that is, the PCA analysis results of the expanded data are most consistent with the measured data; the number of expanded simulated receptor component spectra has a certain influence on the PMF analysis results. But the relative error is less than 40%. When extending the spectrum of six simulated receptor components, the relative error is the smallest, that is, the PMF analysis results of the extended data are most consistent with the measured data. It is proven that this method provides a more direct basis for the targeted treatment of pollution sources that are more harmful to human health.

1. Introduction

With the continuous expansion of industrial enterprises, rapid economic development, and rapid growth of people's living consumption, China's air pollution is becoming more and more serious [1]. PM10 itself contains many toxic and harmful substances, and its large specific surface area makes it easier to adsorb toxic and harmful substances and become the carrier of other pollutants [2]. People are gradually realizing that atmospheric particulate matter has a great impact on human health [3]. Exposure to high concentrations of particulate matter can increase the morbidity and mortality of respiratory diseases and cardiovascular and cerebrovascular diseases. The small increase in atmospheric particulate matter will also increase the diseases and mortality of the respiratory and

cardiovascular systems. In addition, it also has an impact on the immune system and nervous system [4]. The International Agency for Research on Cancer identified outdoor atmospheric particulate matter as a carcinogen in October 2013.

PM10 not only causes harm to human health but also has a certain impact on the atmospheric environment, such as reducing visibility, affecting radiation balance, atmospheric temperature, affecting the pH of precipitation, and cloud physical and chemical processes [5]. At present, the atmospheric particulate matter pollution in China's cities is generally serious and basically presents the composite pollution characteristics of multiple pollution sources superposition, multiple pollutants coexistence, multiscale correlation, multiple process coupling, and multimedia interaction [6].

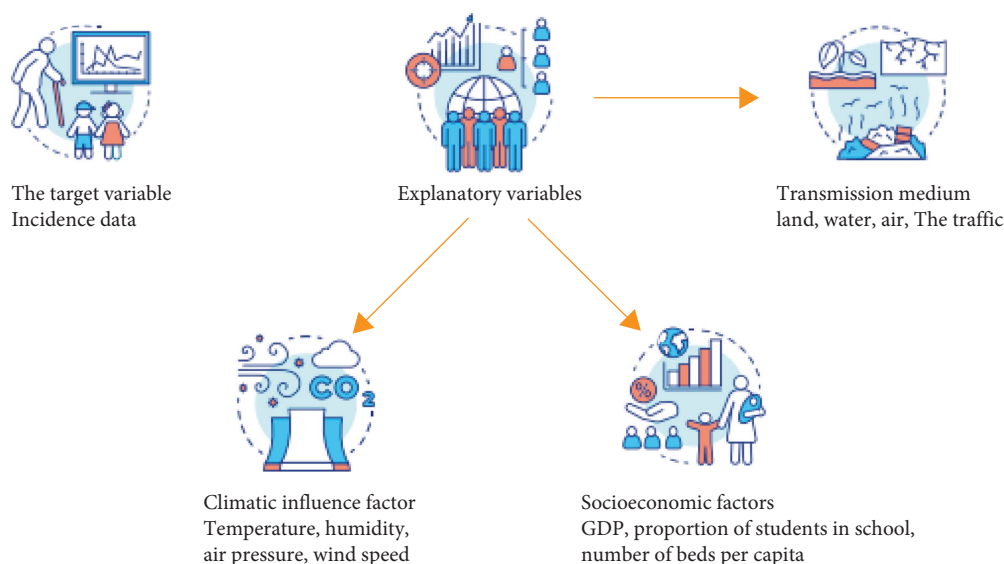


FIGURE 1: Human health risks of regional atmospheric environmental pollution sources.

Pollutants discharged from pollution sources will cause health hazards to people exposed to them after diffusion, mixing, and reaction. If we can distinguish which pollution sources discharge pollutants with high toxicity or contribution rate, it is conducive to further taking targeted treatment plans. Therefore, it is of great significance to determine the contribution of pollutants in concerned areas, pollution source categories, and health risk contribution rate as shown in Figure 1.

2. Literature Review

Source analysis technology can give the source of pollutants qualitatively and the contribution rate of pollution sources quantitatively. It is the basis for formulating air pollution prevention and control measures and the basic data for urban regional development planning and decision-making. The research methods of pollutant sources at urban and regional scales generally include the source list method, the diffusion model method, and the receptor model method [7]. Among them, the source list method requires a detailed list of emission sources, and the selection of emission parameters has a great impact on the analysis results, and the calculation process of the model is complex. Using the diffusion model, it is necessary to obtain the process parameters of atmospheric particulate generation, dissipation, and transportation, which are complex and difficult to obtain in practice [8]. Compared with the diffusion model, the operation of the receptor model does not depend on the data of pollution source emission conditions, meteorological conditions, or topographic characteristics, nor does it need to know the diffusion and migration processes of particles, which reduces the complexity of analysis. Compared with the diffusion model, the receptor model is simple and convenient. After years of development, the receptor model has been widely used and proved to be an important tool in source analysis and a more effective method in pollution source analysis [9].

The receptor model takes the receptor as the research object. Under the assumption of mass conservation, through the calculation and analysis of the physical and chemical characteristics of the source and receptor samples, the pollution source categories that contribute to the receptor and the corresponding contribution rate are identified [10]. Among them, the chemical statistical method is the most mature method in the receptor model, which is developed on the premise of mass conservation and combined with mathematical-statistical methods, mainly including the chemical mass balance method (CMB), factor analysis method (FA), positive definite matrix factor analysis method (PMF), enrichment factor method (EF), and multiple linear regression method (MLR) [11]. The objects of source analysis have gradually expanded from TSP and PM₁₀ to organic matter and heavy metals in PM_{2.5} [12]. The research scope has also developed from outdoor to indoor particulate matter. Some scholars also study the changes of pollutant sources in special weather conditions and different seasons.

Although the source analysis technology in China started late, it has also made some achievements after a lot of practice [13]. Nankai University has cooperated with nearly ten cities in northern China to establish their own source composition spectrum database, including soil aeolian dust composition spectrum. Tsagkaraki M. used CMB to analyze the source of atmospheric PM₁₀ and PM_{2.5} in a certain place and concluded that urban dust, coal dust, and motor vehicle exhaust dust are the three major pollution sources of atmospheric PM₁₀ and PM_{2.5} [14]. Wang T. analyzed the source of atmospheric PM₁₀ in a place by using the CMB model and concluded that dust is the main source of PM₁₀ [15]. Miszczak E. analyzed the sources of nonmethane hydrocarbons in the atmosphere of a place in 2006 by the PMF method and obtained that gasoline volatilization, automobile exhaust, combustion source, industrial emission, and plant emission are five possible sources of nonmethane hydrocarbons [16]. Wang G. analyzed the source of PM_{2.5} in

a certain place by using correlation analysis, cluster analysis, principal component analysis, and enrichment factor and explained the combined effect of soil dust source, construction dust source, motor vehicle exhaust, coal combustion, and industrial emissions [17].

Based on the current research, this paper normally expands the measured receptor atmospheric environment data with less data and establishes an expansion method that can meet the requirements of the receptor data volume of an unknown source component spectrum receptor model. In addition, outliers reflect the characteristics of drastic changes in pollution sources or meteorological conditions. This study proposes two processing methods for such data to make the source analysis more in line with the average state.

3. Research Methods

3.1. Receptor Model. The basic principle of the receptor model is mass conservation. With the help of a multivariate statistical method, the pollution source types and contribution rates that contribute to the receptor are finally obtained, that is,

$$C_i = \sum_{j=1}^p F_{ij}S_j + \Delta E, \quad (i = 1, 2, 3, \dots, m), \quad (1)$$

where C_i is the measurement of the concentration of elements in the atmospheric particulate matter of the receptor, $\mu\text{g}/\text{m}^3$; S_j is the calculated value of the contribution concentration of class j source (contribution), $\mu\text{g}/\text{m}^3$; F_{ij} is the content of elements in the particulate matter of type j source, also known as source strength, %; ΔE is the uncertainty, $\mu\text{g}/\text{m}^3$; m is the number of elements, $i = 1, 2, 3, \dots, m$; p is the number of source classes, $j = 1, 2, 3, \dots, p$.

If F_{ij} is known, S_j can be obtained directly from the above equation; If F_{ij} is unknown, S_j and F_{ij} need to be given by the statistical method [18]. According to F_{ij} , whether it is known or not, the receptor model can be divided into known source component spectrum receptor model (such as CMB) and unknown source component spectrum receptor model (such as multivariate statistical model) [19]. These two types of models are widely used at present, but there are some problems in practical operation [20].

The commonly used receptor models of unknown source component spectrum include orthogonal matrix factorization (PMF), principal component analysis (PCA), and UNMIX, which all need a large amount of receptor data. However, in the actual research, the amount of receptor data is difficult to meet such requirements. The main reasons are as follows.

3.1.1. Heavy Workload and High Cost. Receptor data can only be obtained through multistep processes such as sampling point selection, sample collection, pretreatment, and determination, and some components, such as metal elements, need to be analyzed by specific means and

instruments, with a heavy workload and high analysis costs [21].

3.1.2. Few Hand Receptor Samples in Special Periods. At present, the traditional particulate matter sampling is to take one sample every 24 hours. For the study of pollution source analysis under special circumstances, such as during the Spring Festival or heavy pollution period, even if sampling every day, the number of receptor data cannot meet the requirements of a multivariate statistical model for data volume [22].

3.1.3. Classification Analysis to Reduce Receptor Data. Air pollution is affected by pollution sources, meteorological conditions, and other factors. Significant changes in pollution sources and meteorological conditions will lead to changes in the sources of receptor pollutants, resulting in changes in the receptor composition spectrum at the same sampling point and even the sources of pollutants at the same sampling point at different times of the same pollution period [23].

3.2. Receptor Data Expansion. Without considering the change in source intensity and special meteorological conditions, the chemical composition of environmental receptor particles will show random variation with the emission characteristics of pollution sources, meteorological conditions, and topographic characteristics [24]. This study does not consider the particularity of pollutant concentration change but only starts with the continuity and randomness of concentration change and uses normal distribution to expand the environmental receptor data.

A normal distribution is a probability distribution function that is widely used in statistics. The random variables conforming to normal distribution $N(1, 0)$ take the mean μ as the center point and the standard deviation σ as the data dispersion distribution [25]. The probability of random variables satisfying the normal distribution appearing near the mean value is the highest, and the probability decreases with the increase of the distance from the mean value. In this study, the normal distribution was used to expand the environmental receptor data.

According to the known mean value μ and standard deviation σ , by calling the `normrnd` (u, σ, m, n) function in MATLAB, m random numbers subject to normal distribution $N(\mu, \sigma^2)$ are generated, where m is the amount of data generated and n is the number of columns of the output matrix. When expanding the concentration of chemical components of particles, it should be noted that there should be no negative value in the environmental receptor data, that is, the concentration of chemical components should not be less than 0. See Figure 2 for the flow chart of normal expansion.

According to Figure 2, as long as the mean μ and standard deviation σ are known and the amount of extended data m is given, a group of random numbers conforming to normal distribution can be generated.

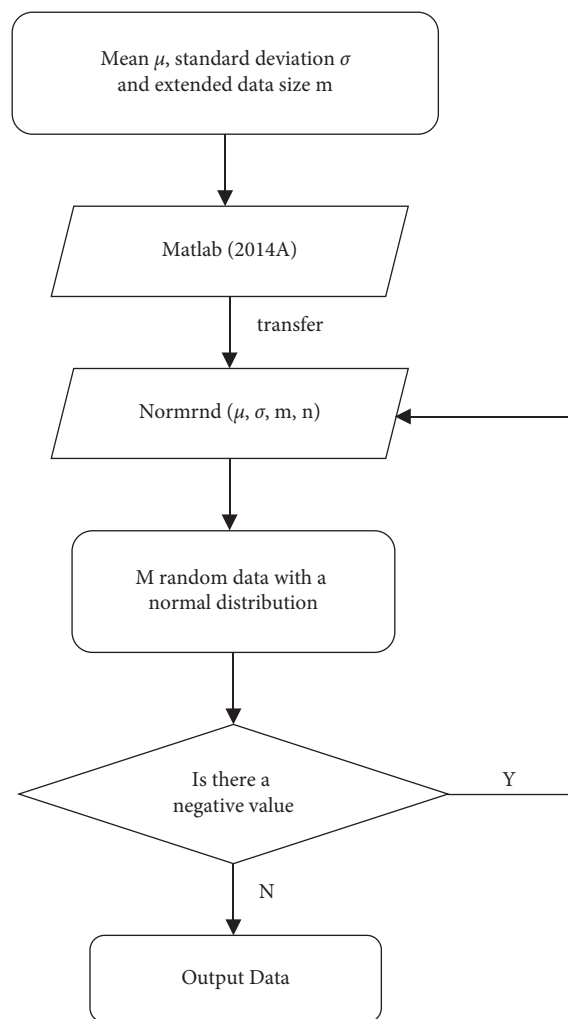


FIGURE 2: Normal expansion flow chart.

Based on the 75-day measured environmental receptor data of an area (included in the PMF model), including 22 chemical components of Al, NH_4^+ , Br, Ca, Cl^- , Cu, EC, Fe, Pb, Mn, Ni, NO_3^- , OC, K, Si, Na^+ , SO_4^{2-} , Ta, Sn, Ti, V, and Zn, and the concentration and uncertainty of PM2.5. Taking the concentration of chemical components as the mean value μ , the standard deviation is obtained through uncertainty conversion to verify the feasibility and correctness of data expansion.

3.3. Data Processing Method. In order to better explain the rationality of normal extended data, this paper carries out “75-day receptor data \rightarrow all/monthly mean and standard deviation \rightarrow normal expansion \rightarrow 75 day extended data \rightarrow verification.” The results show that the extended data obtained by normal expansion after all or on a monthly average cannot get reasonable results after PMF and PCA operations. The reason for analysis may be that there are some values representing the characteristics of drastic changes in pollution sources or meteorological conditions in the measured receptor data. Because the receptor data is affected by factors such as pollution sources and meteorological conditions, when the pollution sources and meteorological conditions change greatly, the receiver data will

also change greatly, which will affect the accuracy and representativeness of source analysis results. More reasonable results can be obtained only after processing them.

The idea of the 53 h algorithm is to use a median filter to generate a smooth estimation and then compare whether the difference between the measured data and the estimated value exceeds the given threshold to determine whether the measured data exceeds the fluctuation range of this group of data. If so, replace it with the estimated value; otherwise, the original signal will be retained.

In this paper, the 53 h algorithm is introduced to mark the value filtered by the 3-point Hanning smoothing filter in each chemical composition time series, that is, the value representing the characteristics of drastic changes in pollution sources or meteorological conditions, and the corresponding estimation value is given. The marked values are eliminated completely, the RE exceeding 80% of the estimated value is eliminated, and the rest is replaced with the estimated value. Then, through K-means clustering, the average value and standard deviation of each type of receptor data (with x_1, x_2, \dots, x_p , p is the number of clusters) are calculated, which are, respectively, used as μ and σ in normrnd. Each type is expanded into x_i ($i = 1, 2, 3, \dots, p$) and combined into extended receptor data in chronological order. Finally, the PMF and PCA models are used to analyze the receptor data before and after removing/replacing the values representing the characteristics of drastic changes in pollution sources or meteorological conditions. Through the comparison results, the rationality of the 53 h algorithm for processing the values representing the characteristics of drastic changes in pollution sources or meteorological conditions in the time series of chemical components is verified. See Figure 3 for details.

4. Result Analysis

4.1. Analytical Results of Extended Data Varying the Number of Extended Receptor Component Spectra. Select the standard deviation of 0.5 times as the extended range and keep it unchanged. After the normal expansion of one measured receptor component spectrum, 2, 3, 4, 6, 8, 12, and 24 simulated receptor component spectra are obtained. The expanded data are substituted into the PMF model. The setting is the same as the analysis process of measured data for analysis. Now, take the extended 7 groups as an example to get the analysis results. See Table 1 for the contribution rate of each pollution source class obtained from the analysis of measured data and 7 groups of normal extended data.

The analysis of 7 groups of normal extended data obtained from nitrate source, soil wind sand dust, biomass combustion source, industrial source, sulfate source, and fuel source. The pollution source category and source contribution rate obtained from the analysis of measured data are defined as the standard values. The RE of the analysis source contribution rate of extended data and measured data under different numbers of extended simulated receptor component spectra are 2.63% \sim 34.21%, 2.26% \sim 39.55%, 2.84% \sim 27.01%, 0.58% \sim 14.74%, and 0% \sim 35.53%, respectively. See Figure 4 for details.

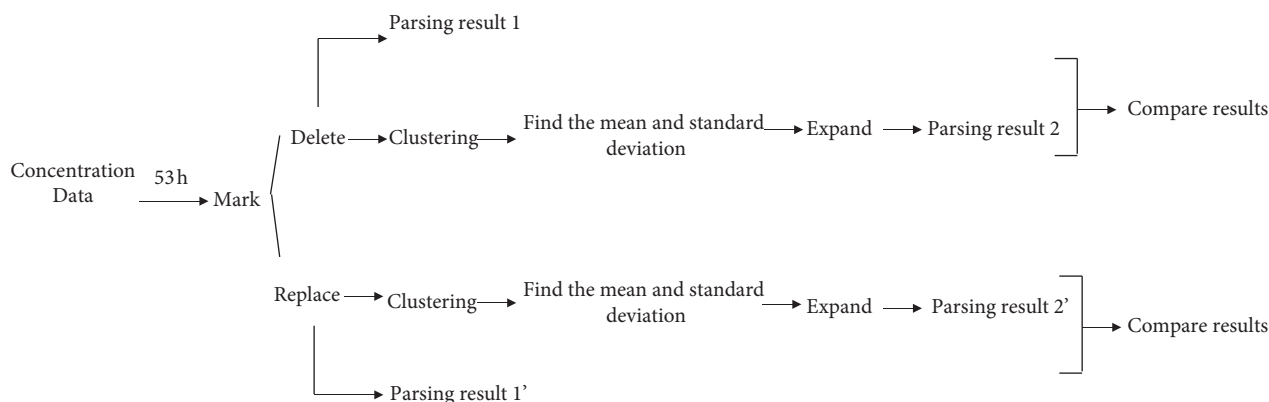


FIGURE 3: Data processing diagram.

TABLE 1: Comparison of source contribution rates between measured data and normal extended data (unit: %).

	Nitrate source	Soil aeolian sand source	Metallurgical source	Sulfate source	Fuel source
Measured data	19	17.7	21.1	34.6	7.6
2	25.5	11.5	23.8	32.3	7
3	24.8	10.7	24.6	32.3	7.6
4	20.7	16.1	20.5	32.4	10.3
6	19.6	17.3	20.1	35.4	7.5
8	19.5	19.1	20.6	34.4	6.4
12	23.9	15.4	15.4	29.5	7
24	25.3	10.9	23.3	32.5	8

It can be seen from Table 1 and Figure 4 that the type of pollution source obtained from the analysis of the extended data is consistent with the judgment of the standard value, and the distribution level of the contribution rate of various pollution sources is basically consistent with the distribution level of the standard value, and the main contribution source is sulfate. The number of extended simulated receptor component spectrum has a certain impact on the PMF analysis results, but all RE are less than 40%. When the six simulated receptor component spectra are extended, the RE is the smallest, that is, the PMF analysis results of the extended data are in the best agreement with the measured data.

4.2. Analytical Results of Extended Data of Receptor Component Spectrum of Change Expansion Simulation. The PCA model can carry out statistical analysis on a large number of observation data and reduce the dimension of observation data without losing the main information of measured data. Starting from the correlation coefficient matrix of observation data, several comprehensive factors that can reflect the main information of the original data and control all data are obtained. At this stage, PCA has been widely used in the source analysis of atmospheric particulate pollution.

In this paper, the PCA model is used to analyze the receptor data obtained from the expansion of normal distribution, compare the analysis results of measured data and normal expansion data, and analyze and verify the applicability and rationality of the data expansion method.

PCA analysis was carried out for seven groups of extended data under the component spectrum of each

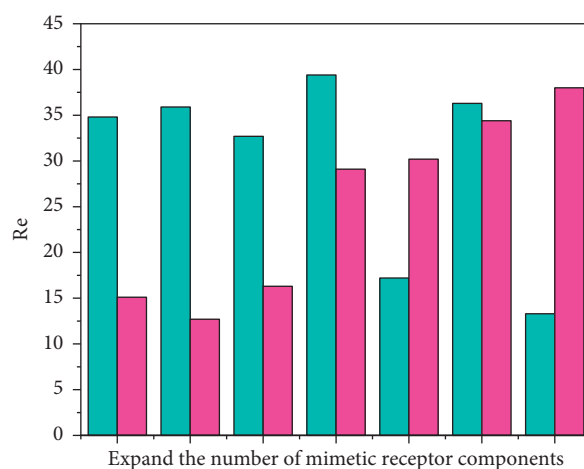


FIGURE 4: Comparison between the contribution rate of each source of extended data and the analytical contribution rate of PMF of measured data under different numbers of extended simulated receptor component spectra.

extended simulated receptor, in which KMO was greater than 0.8 and less than 0.9. The seven principal components were analyzed as secondary source, fuel source, soil wind sand dust source, coal source, metallurgical source I, sea salt particle source, and metallurgical source II. The analysis results are shown in Table 2.

It can be seen from Table 2 that the range of cumulative variance and extracted common factor variance changes little with the increase in the number of extended simulated receptor component spectra, and the cumulative variance is

TABLE 2: PCA analysis results of extended data under various extended simulated receptor component spectra.

	Principal component 1	Principal component 1	Principal component 1	Principal component 1	Principal component 1	Principal component 1	Principal component 1	Principal component 1	Cumulative variance	Extract common factor variance
2	Characteristic root	5.1	3.5	3.7	1.3	1.4	1.2	1.1	—	0.710~0.972
	Explain variance	24.1	16.5	17.4	6.1	6.8	5.6	5.1	81.6	—
3	Characteristic root	5.4	3.4	3.3	1.3	1.3	1.3	1.1	—	0.726~0.972
	Explain variance	25.5	16.0	15.9	6.3	6.2	6.3	5.0	81.3	—
4	Characteristic root	5.6	3.4	3.0	1.4	1.3	1.3	1.0	—	0.714~0.974
	Explain variance	26.7	16.2	14.5	6.4	6.4	6.2	4.9	81.4	—
6	Characteristic root	5.4	3.4	3.3	1.4	1.3	1.2	1.1	—	0.715~0.976
	Explain variance	25.6	16.2	15.7	6.7	6.1	5.8	5.1	81.3	—
8	Characteristic root	5.6	3.3	3.2	1.3	1.4	1.3	1.1	—	0.700~0.982
	Explain variance	26.6	15.7	15.3	6.2	6.5	6.0	5.0	81.3	—
12	Characteristic root	5.5	3.3	3.2	1.3	1.4	1.3	1.1	—	0.715~0.983
	Explain variance	26.3	15.7	15.2	6.3	6.6	6.2	5.1	81.4	—
24	Characteristic root	5.5	3.3	3.2	1.3	1.3	1.3	1.0	—	0.725~0.981
	Explain variance	26.4	15.8	15.1	6.3	6.3	6.3	5.1	81.3	—

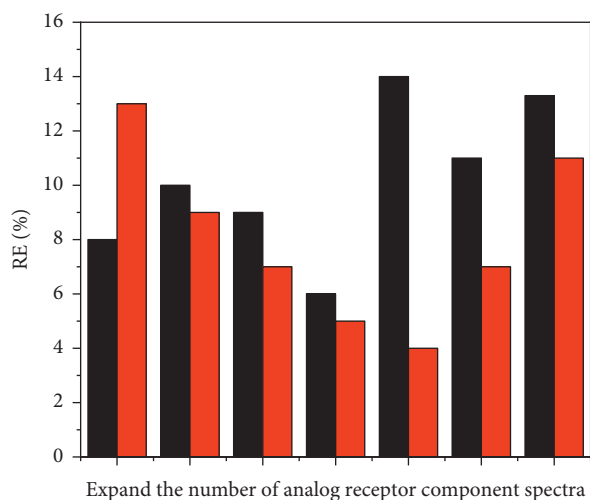


FIGURE 5: RE diagram of the contribution rate of each source of extended data relative to the PCA analytical contribution rate of measured data under different extended simulated receptor component spectra.

greater than 80%. The RE of the analytical contribution rate of PMF of each source category of the extended data relative to the measured data under the number of component spectra of different extended simulated receptors is calculated, which are 0.78%~6.59%, 0.61%~3.68%, 0.62%~9.38%, 8.57%~12.86%, 0%~7.94%, 0%~8.62%, and 0%~3.92%, respectively. See Figure 5 for details.

It can be seen from Figure 5 that the number of extended simulated receptor component spectra has a certain impact on the PCA analysis results, but it has less impact than the extended range. All RE are less than 14%, and when the six simulated receptor component spectra are extended, the RE is the smallest, that is, the PCA analysis results of the extended data are the most consistent with the measured data.

5. Conclusion

This study introduces human health risk assessment, combined with the receptor model in source analysis, to analyze the impact of pollution sources on the environment. Firstly, aiming at the problems existing in the receptor model, this paper establishes an expansion method that can meet the requirements of the unknown source component spectrum receptor model for the amount of receptor data and verifies the established method of alternative source component spectrum, so as to provide a theoretical basis for formulating more guiding pollution prevention and control measures. The following conclusions are obtained:

- (1) The receptor data are normally expanded to obtain the extended data. Verified by PMF and PCA models, the extended data can not only meet the requirements of the multivariate statistical model for the amount of receptor data but also accurately reflect the pollution status represented by the measured data. The best expansion condition is that the expansion range is 0.5 times the standard

deviation, and the number of extended simulated receptor component spectrum is 6.

- (2) The 53 h algorithm is introduced to eliminate more than 80% of the residuals representing the characteristics of drastic changes in pollution sources or meteorological conditions relative to the estimated value and replace them with the estimated value. The PCA analysis of the extended data can accurately obtain the pollution source category and contribution rate of the main contribution. If all these values are eliminated, they can only be verified by PMF. The judgment of pollution source class in the analysis results of extended data and measured data is the same, but the source contribution rate of individual pollution source classes with small contributions is quite different. In practice, it is recommended to use the 53 h algorithm to mark the values representing the characteristics of drastic changes in pollution sources or meteorological conditions in the time series of chemical components, and combined with the given estimated values, investigate the RE of marked values and estimated values and adopt two processing methods of replacement and elimination for different marked values, which will get more reasonable analytical results. This method can be applied to the source analysis when the amount of receptor data is small, the data contain values representing the characteristics of drastic changes in pollution sources or meteorological conditions, and the multivariate statistical method of passive component spectrum needs to be used for analysis, and the results cannot be given.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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