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Jin-Yu Fan, Bo-Hong Zheng, Bo-Yang Zhang, Bo Chen

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Jin-Yu Fan

School of Architecture and Art,
Central South University,
Hunan, 410011, China
and
College of Architecture and Urban Planning,
Guizhou University,
Guizhou, 550025, China
Email: 234241077@qq.com

Bo-Hong Zheng*

School of Architecture and Art,
Central South University,
Hunan, 410011, China
Email: bohong@mls.sinanet.com
*Corresponding author

Bo-Yang Zhang

School of Architecture and Art,
Central South University,
Hunan, 410011, China
and
School of Urban and Rural Planning and Architectural Engineering,
Guiyang University,
Guizhou, 550025, China
Email: 171385646@qq.com

Bo Chen

College of Architecture and Urban Planning,
Guizhou University,
Guizhou, 550025, China
Email: 943023779@qq.com

Abstract: In order to overcome the problems of poor pollutant concentration correlation and poor simulation effect in the traditional simulation results of air pollution concentration temporal and spatial distribution characteristics, a new simulation method of air pollution concentration temporal and spatial distribution characteristics in residential areas based on random forest is proposed. First, divide the indicators of air pollutants in residential areas, and setup the data series of the temporal and spatial distribution characteristics of air pollutant concentration. Then, build the feature judgement matrix and complete feature extraction. The simulation model of temporal and spatial distribution characteristics of pollutant concentration is constructed by using random forest, and the model is solved to realise the simulation of temporal and spatial distribution characteristics of pollutant concentration. The experimental results show that the proposed method has good correlation and high simulation accuracy.

Keywords: random forest; residential areas; air pollution concentration; temporal and spatial distribution; feature simulation.

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Biographical notes: Jin-Yu Fan is a teacher in the School of Architecture and Urban Planning, Guizhou University, who has been awarded the title of Mid-level Engineer since 2018. She has issued several papers about residential environment. Currently, she is a PhD student in the School of Architecture and Art, Central South University, who received his Master's in Architecture from Central South University, in 2013.

Bo-Hong Zheng is a Doctoral Supervisor in the School of Architecture and Art of Central South University. His research field is urban and rural planning, and he has published several papers on human settlements.

Bo-Yang Zhang is a PhD student in the School of Architecture and Art, Central South University, who received his Master's in Architecture from Central South University, in 2013. He is currently a Lecturer in the College of Architecture of Guiyang University. His research interests include green building and smart city research.

Bo Chen is a teacher of Urban and Rural Planning in the School of Architecture and Urban Planning of Guizhou University, with the title of an Associate Professor. He has been engaged in urban and rural planning research for many years and has published several papers on human settlements.

1 Introduction

With the accelerating process of industrialisation, cities are developing rapidly. Air pollution has become a derivative of the current rapid economic development (Cao et al., 2019). The concentration of air pollutants can be expressed by mass concentration or volume concentration, which is applicable to the measurement concentration of gas pollutants. The concentration of air pollutants has obvious seasonal variation characteristics. In recent years, the air pollution concentration in China has decreased year by year, but the air quality in urban residential areas is still facing a severe situation (Nourani et al., 2021). The control of air pollution has become a key problem that is difficult to solve at present. When the concentration of pollutants in the air in the residential area exceeds the standard value, it will lead to bad weather such as haze, which will have a serious impact on people's life, health and travel (Huang et al., 2021; Tripathee et al., 2019). The temporal and spatial distribution of pollutant concentration refers to the difference of pollutant concentration in different residential areas. In order to improve the environment of urban residential areas and effectively control air pollution, the temporal and spatial distribution characteristics of air pollutant concentration in residential areas are simulated.

Wang et al. (2020) proposes a simulation research method for the temporal and spatial distribution characteristics of air pollutant concentration in residential areas based on contribution factors. Firstly, this method analyses the air pollution data monitored in Jiaozuo area in recent three months, analyses the changes of air pollution data in this area in recent years, and analyses the characteristics of air pollution in residential areas in different seasons, taking this characteristic data as the basis of research, calculate the contribution factor of air pollution, determine the main source of air pollution in this area, and accurately analyse the temporal and spatial characteristics of air pollution. This method can be used as the basis for simulating the temporal and spatial distribution of air pollution, but this method considers little pollution characteristics and correlation in this area, and has some limitations. Zeng et al. (2020) proposes a simulation research method for the temporal and spatial distribution characteristics of air pollutant concentration in residential areas based on characteristic peak. This method takes Liuzhou City as the research object and determines the temporal and spatial distribution characteristics of air pollution according to the actual measurement. Firstly, the method counts the concentration data of various air pollutants in six monitoring stations in the region in 2018, summarises the date when the air pollution concentration exceeds the standard, determines the main air pollutants in the core area based on the data, analyses the peak value of the substance change, and determines the pollution change characteristics in different seasons by determining its peak value, on this basis, build a pollution model as the key of the research. This method can effectively analyse the temporal and spatial distribution characteristics of air pollutants in urban core area, but there are some deficiencies in the concentration analysis of different particles. Chen and Yu (2019) propose a simulation research method for the temporal and spatial distribution characteristics of air pollutant concentration in residential areas based on the calculation model. This method first constructs the calculation model for the temporal and spatial distribution of pollutants, then predicts the distribution of pollutants through the provided meteorological data, and then constructs a capacity margin method to complete the analysis of air pollution concentration and its characteristics. This method can effectively predict the current regional pollution concentration, but the measurement range of this method is small, which still needs to be improved continuously and expand the data range.

In view of the shortcomings of the above methods, a new simulation method of spatial-temporal distribution characteristics of air pollutant concentration in residential areas based on random forest is designed in this paper. The overall research technical route of this method is as follows:

1 Data collection of air pollution in residential areas: determine the air pollutants in residential areas through the pollutant concentration monitored by the air pollution monitoring station and the air quality index.

2 Setup the data sequence of the spatial-temporal distribution characteristics of air pollutant concentration, determine the correlation of the spatial-temporal distribution of air pollutant concentration in residential areas, and complete the feature extraction. On this basis, the simulation model of spatial-temporal distribution characteristics of air pollutant concentration in residential areas is constructed by using random forest, and the model is solved to realise the simulation of spatial-temporal distribution characteristics of air pollutant concentration in residential areas.

3 Simulation experiments are analysed to verify the effectiveness of the simulation.

2 Simulation of temporal and spatial distribution characteristics of air pollutant concentration in residential area

2.1 Quality index of air pollutants in residential areas

In order to improve the effectiveness of the simulation of the temporal and spatial distribution characteristics of air pollutants in residential areas, it is necessary to determine the air pollutants in residential areas. There are many kinds of air pollutants in residential areas, and the more common are sulphur dioxide, nitrogen dioxide, carbon monoxide, inhalable substances, etc. In order to determine the main air pollutants in residential areas, this paper determines the types of air pollutants in residential areas through the concentration of main air pollutants monitored by air pollution monitoring stations and air quality index (Wen et al., 2019).

The data monitored by the air pollution monitoring station is calculated through the air quality index to determine different levels of air pollutants. The higher the index value, the lower the pollution level. The value range of this index is [0, 500]. In the calculation of air quality index of air pollutants in residential areas, the value of air pollution data in current residential areas is taken as the calculated index (Liu et al., 2019) to determine the concentration of different kinds of pollutants. At this time, the air quality index of air pollutants in residential areas is calculated as follows:

$$z_i = \frac{a_i - b_i}{v_i - v_j}\left(Q - v_j\right) + b_i \tag{1}$$

where z_i indicates the quality score of air pollution species in residential areas, Q represents the current concentration of air pollutants, v_i represents the concentration index corresponding to the air mass scores of the residential area, a_i represents the fraction of the residential area air pollution quality fraction corresponding to the concentration index, and b_i represents the air quality score.

After determining the air quality index of air pollutants in the residential area, the control quality of pollutants in the residential area is determined by calculating the maximum value of the air quality sub-index of all pollutants in the residential area, that is:

$$w_i = \text{MAX}\left\{a_i \mid i = 1, 2, 3, \ldots, n \,|\right\} \tag{2}$$

In the formula, w_i indicates the air quality score index value in residential areas, and n represents the total category of air pollutants in the residential area. According to the determined quality index of air pollution in residential areas, we can know the pollution concentration of different pollutants in residential areas. Therefore, this study mainly focuses on the main pollutants in residential areas. The main pollutants and details determined in this paper are shown in Table 1.

Table 1 Air pollutants in residential areas and details

Quality index number	*Level*	*SO_2 μg/m³/h*	*NO_2 μg/m³/h*	*$PM_{2.5}$ μg/m³/h*
0–50	Excellent	0–150	0–100	0–35
51–100	Good	151–500	101–200	36–75
101–150	Mild contamination	501–650	201–700	76–115
151–200	Middle level pollution	651–800	701–1,200	116–150
201–300	Heavy pollution	-	1,201–2,340	151–250
More than 300	Severe contamination	-	2,341–3,060	251–350

In the determination of air pollutant quality index of residential area, firstly, determine the air pollutants in residential area, including sulphur dioxide, nitrogen dioxide, carbon monoxide, inhalable substances, etc., and determine the air pollutants in residential area through the pollutant concentration monitored by air pollution monitoring station and air quality index.

2.2 Quantitative study on air pollutant index in residential area

Based on the above determined air pollutant index of residential area, in order to achieve the purpose of this study, the above determined air pollutants of residential area are quantified. The factors of air pollution in residential areas include population factors, meteorology, transportation and other factors. Before quantifying the air pollutant index of residential areas, it is necessary to divide the air pollutants in residential areas (Chun et al., 2020), as shown in Table 2.

Table 2 Air pollution indicators of residential areas

Overall performance	*Secondary indicators*	*Level 3 indicators*
Natural environment	Meteorological environment	Precipitation, temperature, land use, grassland, water area, etc.
Economic environment	Economic performance	Economic status of residential area
Cultural environment	Population size	Resident population and other activities

According to the determined air pollution indicators of residential areas (Table 2), the determined indicators are quantified. In this study, this paper uses the calculation of information entropy to determine the pollution degree of air pollutants in residential areas, which can be used as the key information for the simulation of the temporal and spatial distribution characteristics of air pollutants in residential areas.

Assuming that the air pollutant type is U and the range of this pollutant is: $U = (u_1, \ldots, u_n)$, the probability of this pollutant appearing in the residential area is: $G = (G(u_1), \ldots, G(u_n))$.

At this time, the information entropy (Wang and Sun, 2019) of pollutants in the residential area is:

$$R(U) = -\sum_{i=1}^{n} p(u_i)\log 2\left(p(u_i)\right) \tag{3}$$

In formula, $R(U)$ represents uncertainty about the occurrence of a contaminant, the quantification of the degree of contaminant that quantify the consequences, and $p(u_i)$ represents the probability that this contaminant appears.

In the quantitative study of air pollutant index in residential area, the air pollutant index in residential area is divided, and the pollution degree of air pollutants in residential area is determined by the calculation of information entropy, which is used as the key information for the simulation of spatial-temporal distribution characteristics of air pollutant concentration in residential area.

2.3 *Simulation of temporal and spatial distribution characteristics of air pollutant concentration in residential areas based on random forest*

2.3.1 *Extraction of temporal and spatial distribution characteristics of air pollutant concentration in residential areas*

After the above quantified air pollutant concentration in residential area, the obtained quantitative data is used as the basis of its concentration temporal and spatial distribution characteristics. In order to realise effective simulation, the temporal and spatial distribution characteristics of air pollutant concentration in residential area after quantification are further extracted. The feature extraction is realised with the help of grey correlation analysis method, and its implementation steps are as follows:

Step 1 Firstly, determine the data sequence of spatial-temporal distribution characteristics of air pollutant concentration in residential areas, which is mainly divided into reference sequence and comparison sequence (Samad and Vogt, 2021). According to the air pollutant quality index, the data sequence for setting the temporal and spatial distribution characteristics of air pollutant concentration is as follows:

$$Y = \left(y_1, y_2, \ldots, y_j, \ldots, y_n\right) \tag{4}$$

According to the selected different index sequence variables, the characteristic judgement matrix is constructed as follows:

$$Y' = \begin{pmatrix} y_1 \\ y_2 \\ \cdots \\ y_i \\ \cdots \\ y_n \end{pmatrix} = \begin{pmatrix} y_{1,1}, y_{1,2}, y_{1,j}, y_{1,n} \\ y_{2,1}, y_{2,2}, y_{2,j}, y_{2,n} \\ \cdots \\ y_{i,1}, y_{i,2}, y_{i,j}, y_{i,n} \\ \cdots \\ y_{m,1}, y_{m,2}, y_{m,j}, y_{m,n} \end{pmatrix} \tag{5}$$

In the formula, n represents the total number of influence variables, and m represents the participation properties of each influence variable.

According to the temporal and spatial distribution characteristics of air pollutant concentration in residential areas extracted above, they are standardised and normalised (Baek et al., 2019), and the following results are obtained:

$$e_i = fy_{i,j}\sqrt{\sum_{i=1}^{n} y_{i,j}^2} \tag{6}$$

In formula, e_i represents the properties of the normalised sequence characteristics of the variables, and f represents the sequence characteristics of the standardised prevariable features.

After determining the temporal and spatial distribution characteristics of air pollutant concentration in residential areas, determine the correlation of the pollution in the temporal and spatial distribution of air pollutant concentration in residential areas, and the obtained correlation coefficient is:

$$\varphi_{ij} = \frac{p\min\{\min(e_i - Y')\} + \rho\max(e_i - Y')}{\min(e_i - Y') + \rho\max(e_i - Y')}\sum \mu\tau \tag{7}$$

In the formula, p represents the resolution coefficient, μ represents the association coefficient value, and φ_{ij} represents the degree of association.

Assuming that the correlation degrees in the characteristic series of air pollutants in residential areas are different components and their corresponding index weights are corresponding respectively, the correlation degree of each comparison series relative to the characteristic series is:

$$B_{ij} = \sum_{i=1}^{n} w_j \times \varphi_{ij} \tag{8}$$

In formula, w_j represents the spatial and temporal characteristic correlation of air pollutants in residential areas.

In the feature extraction of spatial-temporal distribution of air pollutant concentration in residential areas, the data series of spatial-temporal distribution characteristics of air pollutant concentration are set according to the air pollutant quality index, and the feature judgement matrix is constructed and standardised according to the selected different index sequence variables. Based on this, the correlation of spatial-temporal distribution of air pollutant concentration in residential areas is determined, complete feature extraction.

2.3.2 Simulation model of temporal and spatial distribution characteristics based on random forest

In order to simulate the temporal and spatial distribution characteristics of air pollutant concentration in residential areas, after determining the temporal and spatial distribution characteristics and characteristic correlation of pollutant concentration, this paper constructs a simulation model of its distribution characteristics with the help of random forest. Random forest is an integrated learning algorithm. Based on the classification results of the research object, the research on the implementation method of constructing tree decision model has fast operation speed and accurate calculation results. When the algorithm classifies tasks, the result determined is the mode. If the regression task is studied, the average number needs to be determined (Wen et al., 2019). In the application of this paper, the random forest is regarded as a tree classifier, which is set as:

$$\left\{h\left(x, °C_x\right), x=1,2, \ldots, ntree\right\} \tag{9}$$

Among these, $\{h(x, °C_x)$ represents the original classifier of the algorithm and $°C_x$ represents random independently distributed vectors. When constructing the simulation model of this paper through this algorithm, decisions need to be made based on the growth process of the tree.

The construction process of the simulation model of temporal and spatial distribution characteristics based on random forest is as follows.

Firstly, through the initial set of temporal and spatial distribution characteristics of air pollutant concentration in residential areas, determine the duplicate sample data in this feature set as N, and the original set of spatiotemporal distributed feature samples was:

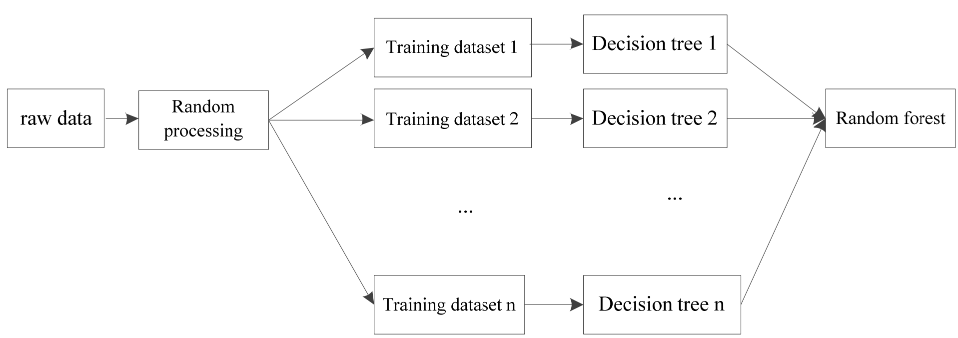
$$S=\left\{S_1, S_2, \ldots, S_n\right\} \tag{10}$$

Then, according to the above determined feature set, a random forest decision tree is constructed. By determining the pollution dataset in the feature set and determining the temporal and spatial distribution characteristics of air pollutant concentration in residential areas, the pollution characteristics are divided on the basis of determination, and the splitting process is repeated until the preset conditions are reached.

Secondly, the above decision trees are combined to form a random forest containing the temporal and spatial distribution characteristics of air pollutant concentration in residential areas.

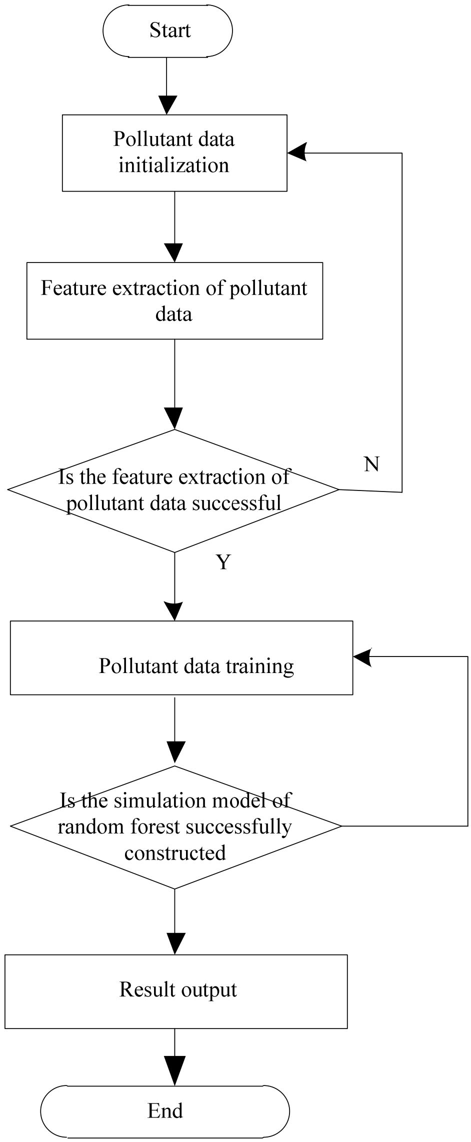
Finally, the spatial-temporal distribution characteristics of air pollutant concentration in residential areas are input into the above constructed random forest (Zhao and Liu, 2021), and the simulation model of spatial-temporal distribution characteristics of air pollutant concentration in residential areas is constructed. The simulation model of temporal and spatial distribution characteristics of air pollutant concentration in residential areas is shown in Figure 1.

Figure 1 Simulation model of temporal and spatial distribution characteristics of air pollutant concentration in residential area



Through the above-mentioned simulation model of spatial-temporal distribution characteristics of air pollutant concentration in residential areas, the simulation model of spatial-temporal distribution characteristics of air pollutant concentration in residential areas is completed.

Figure 2 Simulation flow of temporal and spatial distribution characteristics based on random forest



According to the above simulation model to determine the temporal and spatial distribution characteristics of air pollutant concentration in residential areas, the classification research is carried out with the help of random forest algorithm. Transform the node set of the obtained decision tree, judge the similarity between all decision trees by cosine similarity, train the sample data by random forest method, and solve the optimal result of the simulation. The following results are obtained:

$$\varpi = \frac{A \cdot B}{\| A \| \| B \|} = \frac{\sum_{i=1}^{n} A_i \times B_i}{\sqrt{\sum_{i=1}^{n} (A_i)^2} \times \sqrt{\sum_{i=1}^{n} (B_i)^2}} \tag{11}$$

where A and B represent the vectors of two contaminated data, and n represents the dimension of the data. After calculating the vector value of pollution data, the optimal parameter d is selected to simulate the temporal and spatial distribution characteristics of air pollutant concentration in residential areas. The simulation process of temporal and spatial distribution characteristics based on random forest is shown in Figure 2.

3 Experimental analysis

3.1 Design of experimental protocol

In order to verify the effectiveness of this method, a simulation experiment is designed. In the experiment, taking a residential area in a certain place as the experimental object, the air pollutant concentration in the residential area for nearly three months (May–July) is collected by air monitoring instrument as the experimental sample data, and the temporal and spatial distribution characteristics are simulated through the collected data. The detailed data of air pollutant concentration collected in the experimental sample area are shown in Table 3.

Table 3 Detailed data of air pollutant concentration concentrations collected in the sample area

Month	*Main pollution components*	*Maximal value (μg/m³/h)*	*Minimum; minimum value (μg/m³/h)*
May	SO_2	400	30
	NO_2	800	50
	$PM_{2.5}$	200	38
June	SO_2	350	34
	NO_2	750	46
	$PM_{2.5}$	180	37
July	SO_2	620	25
	NO_2	520	32
	$PM_{2.5}$	170	35

Conduct simulation analysis according to the collected detailed data of air pollutant concentration. In the experimental simulation, the correlation of pollutant concentration and the simulation accuracy of spatial-temporal distribution of air pollutant concentration in residential areas are taken as the experimental comparison indexes. The simulation method in this paper, the simulation method in Zeng et al. (2020) and the simulation method in Chen and Yu (2019) are used to determine the effect of the simulation method in this paper by comparing the three methods.

3.2 Design of experimental indicators

In this experimental analysis, the experimental indicators are set as the correlation of pollutant concentration and the accuracy of simulation. Among them, the accuracy of simulation refers to the comparison between the simulation method and the ideal method, and the simulation result is approximately consistent with the ideal value, which means that the simulation effect is good.

3.3 Analysis of experimental results

3.3.1 Correlation analysis of pollutant concentration by different methods

The correlation of pollutant concentration in the residential area is the key index to measure the effectiveness of the simulation method. Therefore, the effectiveness of this method, the simulation method in Zeng et al. (2020) and the simulation method in Chen and Yu (2019) on the correlation analysis of pollutant concentration in the sample area is experimentally analysed. The results of pollutant concentration correlation analysis are shown in Figure 3.

By analysing Figure 3, it can be seen that there are some differences in the effectiveness of pollutant concentration correlation analysis in the sample area by using the method in this paper, the simulation method in Zeng et al. (2020) and the simulation method in Chen and Yu (2019). Among them, the correlation coefficient of pollutant concentration in the sample area of this method is close to the ideal value, while the other two methods have greater dispersion between the correlation coefficient of pollutant concentration in the sample area and the ideal value. It can be seen that the correlation of this method is better, because this method determines the main pollutants in the residential area before simulation. The limited range is determined to verify the effectiveness of this method.

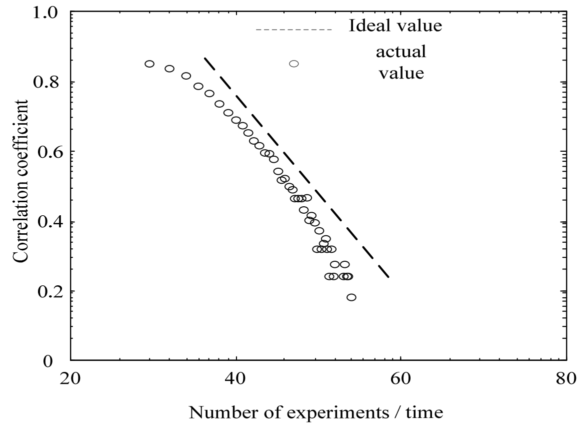
3.3.2 Accuracy of spatial-temporal distribution simulation of air pollutant concentration in residential areas by different methods

In order to further verify the effectiveness of the proposed method, the simulation accuracy of this method, the simulation method in Zeng et al. (2020) and the simulation method in Chen and Yu (2019) on the temporal and spatial distribution of pollutant concentration in the sample area is experimentally analysed. The simulation accuracy comparison results are shown in Table 4.

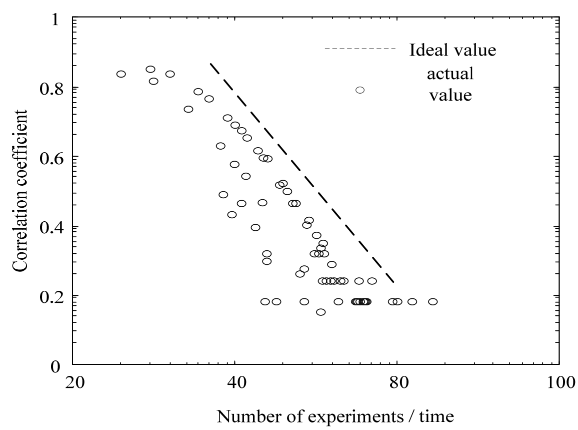
Table 4 Accuracy of spatial-temporal distribution simulation of air pollutant concentration in residential areas by different methods (%)

Number of simulations / times	*This paper method*	*Zeng et al. (2020) simulation method*	*Chen and Yu (2019) simulation method*
20	95	90	89
40	94	89	84
60	95	88	83
80	95	85	80
100	94	84	82

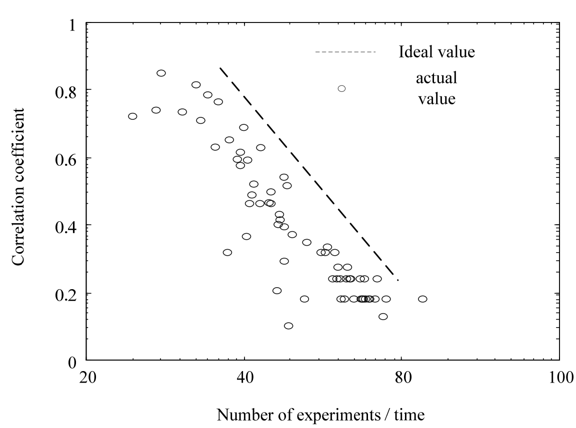
Figure 3 Correlation analysis results of pollutant concentrations by different methods, (a) simulation method in this paper (b) Zeng et al. (2020) simulation method (c) Chen and Yu (2019) simulation method



(a)



(b)



(c)

By analysing the experimental results data in Table 4, there are some differences in the simulation accuracy of pollutant concentration temporal and spatial distribution in the sample area by using the method in this paper, the simulation method in Zeng et al. (2020) and the simulation method in Chen and Yu (2019). Among them, the accuracy of the simulation method in this paper is basically stable at about 95%, and the accuracy of the simulation method in Zeng et al. (2020) shows a downward trend, and the quasi certainty is low; Although the simulation accuracy of the simulation method in Chen and Yu (2019) for the temporal and spatial distribution of pollutant concentration in the sample area has increased to a certain extent, the range is not large. In contrast, the simulation effect of this method is better. This is because this method trains the numerical values to be simulated with the help of random forest intelligent algorithm, and constructs the simulation model to improve the simulation effect.

4 Conclusions

In order to improve the air quality of residential area, a simulation method of temporal and spatial distribution characteristics of air pollutant concentration in residential area based on random forest is proposed. The performance of the method is verified theoretically and experimentally. This method has high correlation analysis results and simulation accuracy when simulating the temporal and spatial distribution characteristics of air pollutant concentration. Specifically, compared with the method based on characteristic peak, the reliability of pollutant concentration correlation analysis results is improved; compared with the method based on the calculation model, the simulation accuracy is greatly improved, and the accuracy of the simulation method in this paper is basically stable at about 95%. Therefore, it fully shows that the proposed simulation method based on random forest can better meet the temporal and spatial distribution characteristics of pollution concentration in residential areas.

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