Study on Temporal and Spatial Distribution of Air Pollutant Concentration Based on Wavelet Analysis

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Abstract

In order to analyze the temporal and spatial sequence characteristics of air pollution concentration in Guigang City, Dau bechies(db) wavelet was used to analyze the daily concentration series of SO_2, NO_2, O_3, PM_{10} and $PM_{2.5}$ in Guigang City from 2015 to 2018. The seasonal characteristics of NO_2 and particulate matter ($PM_{2.5}$ and PM_{10}) are high in autumn and winter and low in summer. The highest probability of O_3 pollution is in summer and autumn. There are obvious spatial differences among the monitoring points. The spatial distribution of the pollution exceeding the standard is the highest concentration of NO_2 at Guicheng Station, the highest concentration of O_3 at Dezhi Station, and the highest daily concentration of particulate matter at Jiangnan Station. In order to gain a deeper understanding of the daily variation characteristics of atmospheric pollutants in Guigang City, Morlet wavelet was used to analyze the hourly concentration sequence of pollutants. The results show that when the concentration of $PM_{2.5}$ is higher at 7-23 o'clock than 0-5 o'clock. The high value areas of several typical $PM_{2.5}$ pollution incidents often appear after 15 o'clock of major festivals. The high value center of O_3 day change appeared at 11-22 o'clock of the pollution day. These changes in atmospheric pollutant concentration can provide a reference for subsequent pollution prevention and control in Guigang City.

Keywords

Db wavelet, Morlet wavelet, Space-time distribution, PM2.5, PM10.

1. Introduction

Along with the development of industrialization, the problem of environmental pollution in the context of urbanization is also increasing. In recent years, the problem of 'smog' has frequently occurred. The problem of air pollution has gradually attracted the attention of domestic governments and scholars. Tracing back to the source, the formation of 'smog' weather is directly related to the content of various particulate matter in the atmosphere, especially $PM_{2.5}$ and PM_{10}. At present, there are relatively few studies on the trend of atmospheric pollutants in southwest China. City Guigang is located in the vast of southeast Guangxi province. The city's energy structure is dominated by coal. During the period of 'Twelfth Five-Year Plan', the total coal consumption of City Guigang was 39.686 million tons, the total exhaust emissions were 568.834 billion cubic meters. And the emissions of sulfur dioxide, nitrogen oxides and soot were 113153.05. Tons, 206,282.21 tons and 265,019.31 tons, taking Guigang City as an example to study the trends and causes of atmospheric pollutant concentrations in Southwest China.

Since the fluctuation of the concentration sequence of pollutants is relatively large and there is noise interference, the evolutionary trend can only be roughly judged from the time series. The multi-scale characteristics in the evolution process cannot be deeply analyzed. The wavelet analysis method has a good effect on the decomposition and reconstruction of digital signals [1-2]. Xu Chengjuan [3] used Daubechies (db) wavelet to analyze the variation characteristics of NO_2 concentration in Hefei City in the past 5 years. It was found that Hefei had two peaks in 2013 and 2016, and the overall growth trend after 2013. The seasonal characteristics were winter pollution has the highest frequency, followed by spring and autumn. Wang Yong [4] selected $PM_{2.5}$ concentration observation sequences in five cities of Beijing, Shenyang, Shanghai, Guangzhou and Chengdu in recent years. The wavelet transform method was used to obtain the conclusion that $PM_{2.5}$ concentration change was the highest in winter and lowest in summer. The $PM_{2.5}$ concentration changes to a bimodal change.The $PM_{2.5}$ concentration in the south is lower than the $PM_{2.5}$ concentration in the north. Feng Qi [5] used the time series of PM_{10} air pollution index in Wuhan as an example. The time scale analysis was carried out by using complex Morlet wavelet. It was found that it had 340d, 180d, 50d and 18d change scales, especially the scale of 340d.

This paper intends to use wavelet analysis method to study the temporal and spatial distribution characteristics of air pollutants in City Guigang in recent years. Trace the source of heavy pollution, analyze the pollution change scale and mutation period. Explore the interaction between sulfur oxides, nitrogen oxides, ozone, and particulate matter. The synergy between particles provides new ideas and methods for the prediction and evaluation of air pollution, in order to provide decision-making support for relevant departments to take pollution prevention measures in advance, with certain scientific value and social benefits.

2. Information and methods

2.1 Data source

The daily and hourly monitoring data of ambient air quality comes from Guigang Environmental Monitoring Center, including SO_2, NO_2, O_3, $PM_{2.5}$ and PM_{10}. The concentration limits of pollutants are in accordance with the Ambient Air Quality Standard (GB3095-2012) of relevant regulations. At present, there are 4 national air quality monitoring points in Guigang City, namely Guicheng Station, Jiangnan Station, Hecheng Station and Dezhi Station. Among them, Dezhi Station is the reference point for ambient air quality. The data does not participate in the city's hourly average concentration and daily average concentration statistics. Among the 4 monitoring points, Guicheng Station, Hecheng Station and Dezhi Station are located in Gangbei District, and Jiangnan Station is located in Gangnan District. There are 5 key pollution source enterprises in Guigang City: China Resources Cement (Qintang District), Taiwan Cement (Qintang District), Guigang Steel Plant (Gangbei District), Guitang Sugar Factory (Gangbei District), Huadian Power Plant (Gangbei District). As shown in Fig.1.

2.2 db wavelet

Daubechies wavelet is a wavelet function constructed by wavelet analyst Inrid Daubechies. Db wavelets are commonly used to decompose and reconstruct signals for use as filters. This study uses Db wavelet, which has good regularity. This wavelet has no explicit analytical expression. The effective support length of the wavelet function δ and the scale function Φ is 2N -1 and the vanishing moment is N. The vanishing moment is higher, the smoothness is better. It is more flexible to increase the length of the support, increase the concentration of energy, and solve the boundary effect.

The db wavelet obtains the approximation coefficient A and the detail coefficient D of each layer by decomposing the signals in multiple layers, as shown in Equation 1. The denoising process is performed to obtain the reconstructed signal, and at the same time, the noise signal is obtained by adding 0 to the detail coefficients of each layer[6].

$$y = A_{nt} + D_{1t} + \ldots + D_{nt} \tag{1}$$

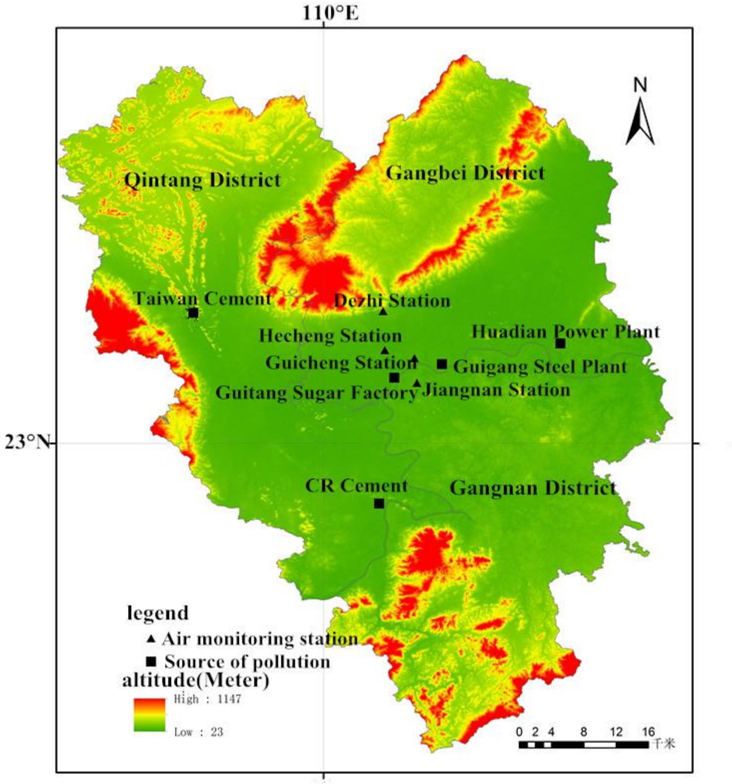

Fig. 1 Geographical map of weather station, air monitoring stations,souce of pollution in Guigang

2.3 Morlet wavelet

Complex wavelets (Complex Morlet Wavelets) have more advantages in applications than wavelets in real form. It can be thought of as the product of a Fourier transform's basis function and a Gauss function. Similar to the windowed Fourier transform, their fundamental difference is that the size of the window changes differently[7]. Therefore, Morlet wavelets can be used for periodic analysis. It reflects the local characteristics of the signal more than the window Fourier analysis. The Fourier transform formula is shown in equation (2). W*f*(a, b) is the wavelet coefficient.The two-dimensional contour map is made by the wavelet coefficient, so that the wavelet features of time series changes can be obtained. The wavelet coefficients at different time scales can reflect the evolution characteristics and mutations of the system at this time scale[8-9].

$$W_f(a,b) = |a^{-1/2}| \int_R f(t)\overline{\psi}\left(\frac{t-b}{a}\right)dt \tag{2}$$

Where f(t) is the signal integrable function; a is the scaling scale $1/a$ is the frequency; b is the translation parameter, which is the translation b of the length relative to the time t.

3. Results and analysis

3.1 db wavelet analysis results

According to the test of different vanishing moments N, it is finally determined that the db5 wavelet transform method is used to perform three-layer decomposition reconstruction of the daily concentration series of atmospheric pollutants in four substations (Fig.2). The low-frequency coefficient A3 is composed of the overall information, reflecting the overall trend and period of pollutants evolution.Various abnormal mutations and interference noise constitute high-frequency coefficients D1～D3, reflecting the sudden and small fluctuations of pollutants [10-11]. The wavelet filter map is smoother than the original time series map, more intuitively reflecting the change of each pollutant concentration with time.

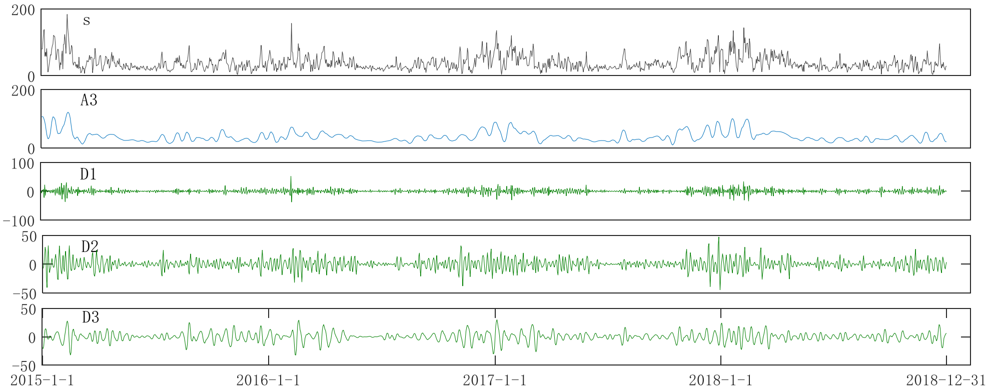

Fig. 2 Taking the PM2.5 of Dezhizi Station as an example, the result of three-layer decomposition of db5 wavelet

3.1.1 Time distribution characteristics of atmospheric pollutants

According to the consistency and difference of the daily variation trend of pollutant concentration in four air automatic monitoring stations, combined with the geographical location of the pollution source enterprise, road traffic, construction site, biomass burning, and residents' activities, analyze the spatial distribution characteristics of pollutants and trace the source of atmospheric pollutants.

Fig.3 shows the high-frequency component (D3) reconstruction of the SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ time series in Dezhi Station in 2015-2018. Dezhi Station is a clean control point.Its location is outside the Beihuan Road of Guigang City, surrounded by farmland. The time trends of the four pollutants (NO_2, $PM_{2.5}$, PM_{10}) in this substation are relatively close, which generally show four distinct cycles, corresponding to low winter and high summer. In 2015, Dezhi Station had a low NO_2 content.Because there were few mobile sources such as motor vehicles in the area and pollution caused by industrial production. With the increase of traffic volume in the Beihuan Road, the NO_2 concentration in 2016-2018 has a significant upward trend. Dezhi Statiom has an increase in O_3 concentration in spring, summer and autumn. Dezhi Station serves as a clean control point, where vehicles and people are not densely populated, and buildings are relatively few. Ozone precursors such as VOCx produced in the surrounding industrial zone can be transported to the Dezhi Station with the wind. Oxygen is sufficient and the light is strong, which is conducive to the formation of ozone. The cultivation of crops around Dezhi Station is two-year-old. Every year from July to August and from November to December, there will be biomass burning activities such as burning straw, which will contribute to the increase of NO_2 and particulate matter.

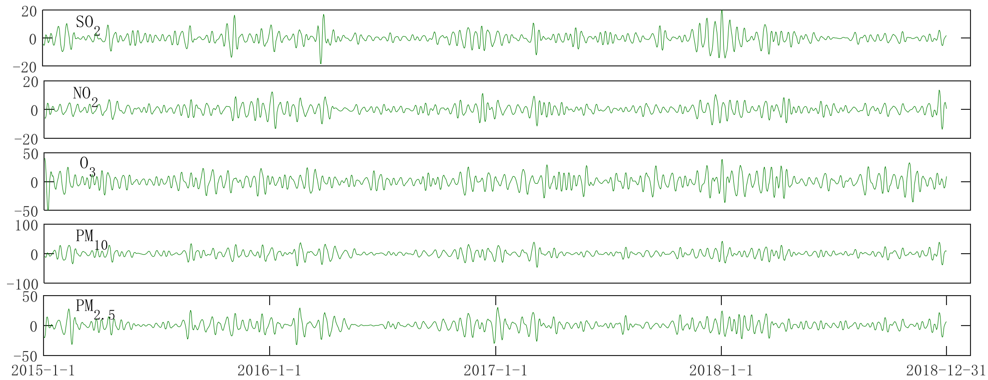

Fig. 3 Reconstruction of high-frequency component (D3) of pollutants in Dezhi station

Jiangnan Station is located at the top of Jiangnan Middle School in Guigang City. It is about a dozen kilometers away from Jiangnan Industrial Park and adjacent to Jiangnan Avenue. It can be seen from Fig.3 that the SO_2 content of Jiangnan Station in autumn and winter of 2015 is relatively high, and gradually decreases and stabilizes after 2016. This is due to the government's replacement of clean coal for boiler coal combustion, a series of measures such as peak production, production restriction and production stoppage. From 2015 to 2018, the NO_2 content in the region is high in autumn and winter, which is caused by the exhaust gas emissions from nearby Jiangnan Industrial Park and automobile exhaust emissions. The fluctuation trend of O_3 concentration sequence is similar to that of Dezhi Station. The concentration trends of PM_{10} and $PM_{2.5}$ are similar to those of SO_2 and NO_2, indicating that the influence of particulate matter is significantly affected by the primary pollutants of the precursor.

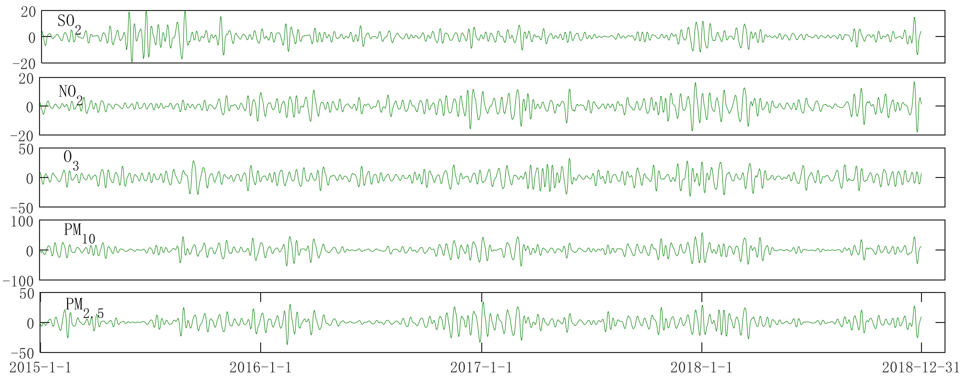

Fig. 4 Reconstruction of high-frequency component (D3) of pollutants in Jiangnan station

Guicheng Station is located at the top of the Second Middle School of Guigang City. The location is located in the old town, with a large traffic volume, close to the Guigang Iron and Steel Plant and the Guitang Sugar Factory. Due to the impact of pollution source emissions, the SO_2 content of Guicheng Station in 2015 and 2016 is relatively high. Since 2017. The SO_2 content has been decreasing year by year, which is related to the replacement of raw coal by coke, power supply and natural gas for the replacement of coal, the improvement of industrial emission end desulfurization control technology. The concentration of NO_2 is affected by industrial emissions and automobile exhaust, which is characterized by high autumn and winter and low summer. NO_2 pollution incident occurred on January 21-25, 2015. The trends of PM_{10} and $PM_{2.5}$ show a high degree of consistency, which is the same as that of SO_2 and NO_2, indicating that the SO_2 and NO_2 emitted by the factory are easily converted into water-soluble ions such as sulfate and nitrate in the atmosphere as particulate important constituents exist.

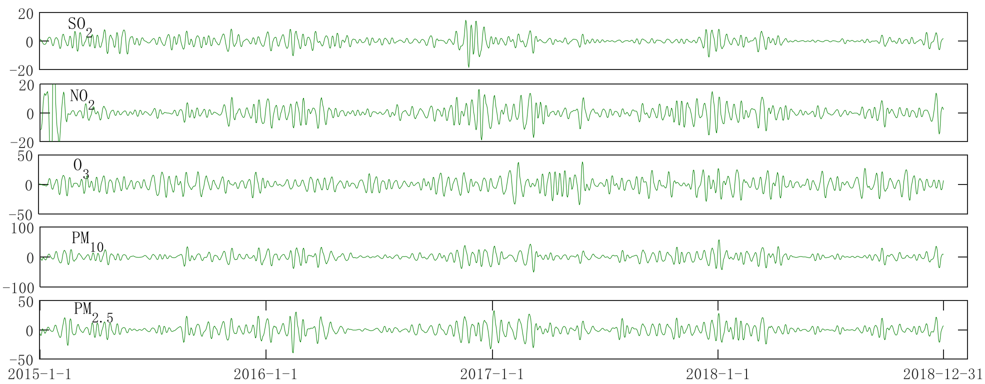

Fig. 5 Reconstruction of high-frequency component (D3) of pollutants in Guicheng station

The Hecheng Station is located at the top of the Environmental Protection Agency.It is adjacent to the Golden Harbor Avenue and the state-controlled pollution source enterprise Guitang Sugar Factory. The sugar plant produce in the December to March of next year (autumn and winter) and the pollutants emitted by the production process are mainly NOx. This indicates that the content of particulate matter in the city is affected by factors such as automobile exhaust and other factors. The pollution caused by industrial pollution has become the main factor for the high concentration of particulate matter in the Hecheng station. Since 2016, with the standardization of waste control and treatment of state-controlled enterprises, the emissions of the Guitang sugar plant have reached the national control standards. Therefore, the SO_2, NO_2 and particulate matter contents of the Hecheng Station have improved compared with 2016. However, the ozone concentration sequence maintained a high level in spring and summer.

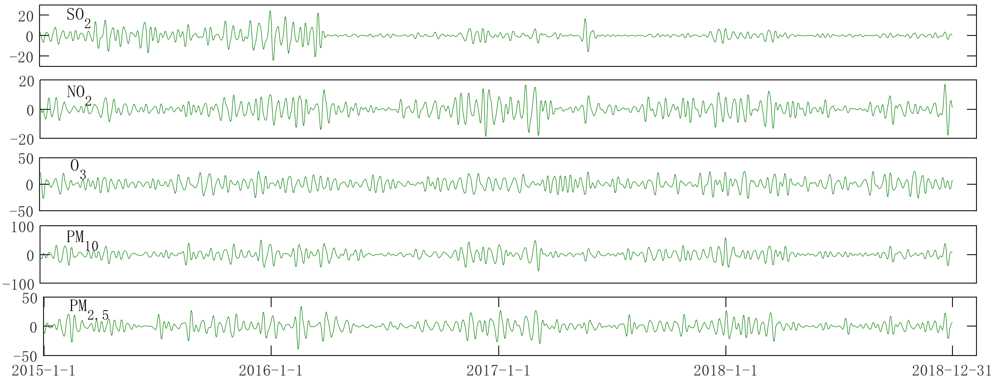

Fig. 6 Reconstruction of high-frequency component (D3) of pollutants in Hecheng station

3.1.2 Spatial distribution characteristics of main pollutants

From Table 1, the average values of five pollutants in Dezhi Station, Guicheng Station, Hecheng Station and Jiangnan Station are relatively close. However, due to geographical specificity, the four monitoring stations have obvious differences in pollution status.Therefore, the mean value of pollutants in the region is not sufficient to indicate the level of pollution and spatial differences in various regions.

Fig.2 shows the low-frequency component reconstruction of db5 wavelet decomposition SO_2. The daily SO_2 concentration of the four substations is lower than the national ambient air quality standard secondary standard (150$ug{\cdot}m^{-3}$). Among them, Guicheng Station and Hecheng Station have large fluctuations throughout the year. Guicheng Station was significantly higher in the spring of 2015 and the spring and winter of 2016 than the other three substations. The concentration of SO_2 in the autumn of 2015 and 2016 was also higher in Hecheng Station. SO_2 emissions have significant regional distribution characteristics and seasonality. However, since 2017, there have been significant downward trends in the four substations. It shows that industrial desulfurization and emission reduction work in Guigang and surrounding areas has achieved good results.

The daily concentration of NO_2 at Dezhi Station, Jiangnan Station and Hecheng Station is lower than the national secondary air quality standard. Only the Guicheng Station has a concentration exceeding the secondary limit on January 21-25, 2015. The concentration of NO_2 in 2015-2018 is represented by Guicheng Station > Hecheng Station > Jiangnan Station > Dezhi Station (Fig.3). In January 2015, the concentration of NO_2 in Guicheng Station was more than double that of Jiangnan Station and Hecheng Station. The concentration of NO_2 in Guicheng Station increased significantly on January 21-25 (concentration of 188$ug{\cdot}m^{-3}$ on the 22nd), far exceeding Grade II. The daily average of emission standards (80$ug{\cdot}m^{-3}$) indicates that there is significant NO_2 point source pollution on the day of monitoring. The NO_2 concentration of the four stations in 2016-2018 is on the rise, which may be related to the increase of mobile sources and the idle speed of vehicles caused by road construction traffic congestion.

Table 1 Daily average of SO_2, NO_2, O_3, PM_{10} and $PM_{2.5}$ in 4 Monitor station 2015-2018/$ug{\cdot}m^{-3}$

	SO_2	NO_2	O_3	PM_{10}	$PM_{2.5}$
Dezhi Station	16.65	18.28	62.47	54.15	38.35
Jiangnan Station	17.14	21.87	53.40	62.60	41.22
Guicheng Station	17.13	24.80	54.20	59.21	41.76
Hecheng Station	14.51	22.60	58.14	63.20	37.91

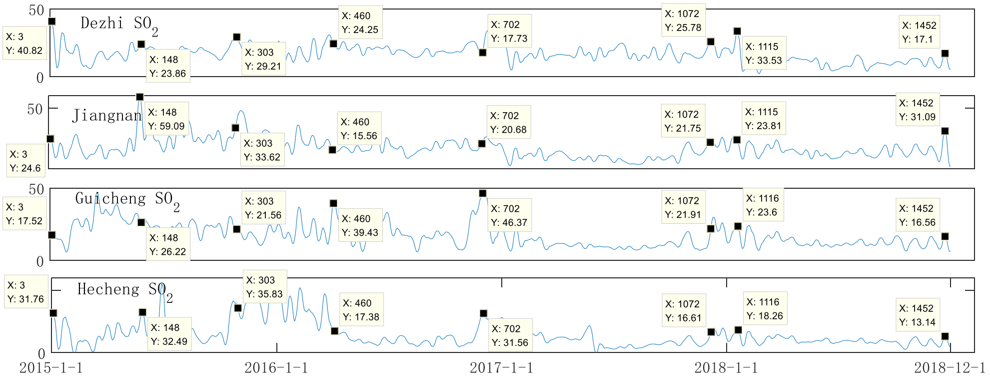

Fig.7 SO_2 low frequency component (A3) reconstruction map

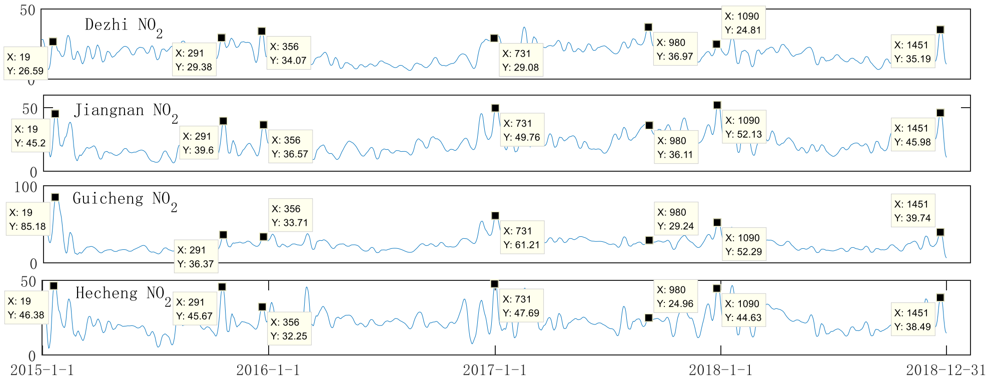

Fig 8 NO2 low frequency component (A3) reconstruction map

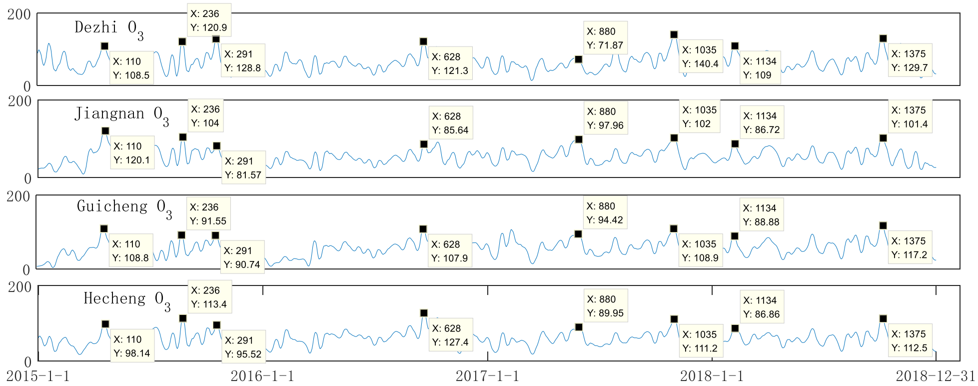

Fig 9 O3 low frequency component (A3) reconstruction map

O_3 is a secondary pollutant, and the production of O_3 is mainly controlled by NOx, HC, and so on. NOx and HC form O_3 under ultraviolet light and gradually increase as the radiation intensity increases. The spatial distribution of O_3 concentration in Guigang is the highest in summer and autumn in Dezhi Station (Fig.4). As a clean control point, Dezhi Station is located in the suburbs. Its monitoring data has certain reference and contrast effects. Compared with other stations, it can truly reflect the change characteristics of O_3 under the influence of large environmental pollution sources. In addition, the CO and NO emissions in urban areas with large traffic volume are large.NO can chemically react with O_3 to consume some ozone. However, the O_3 pollution situation at Jiangnan Station, Guicheng Station and Hecheng Station is also severe. The four stations in 2015-2018 are generally on the rise, which may be related to increased VOCx emissions and climate change.

There is also a significant spatial difference in the concentration of PM_{10} (Fig.5). Several pollution processes are performed to show the highest concentration of PM_{10} in Jiangnan Station. Since the Jiangnan Station is located beside Jiangnan Avenue. The traffic volume is large and the vehicle emissions are high. Exhaust gas and road dust have important effects. The Hecheng Station is slightly higher than the PM_{10} concentration of Guicheng Station. It is attributed to the increase in the construction sites and road construction near the Hecheng Station, resulting in an increase in coarse particles. In 2015-2018, the three urban stations of Jiangna Station, Guicheng Station and Hecheng Station showed a first decline and then rebounded.But Dezhi Station maintained a stable trend.

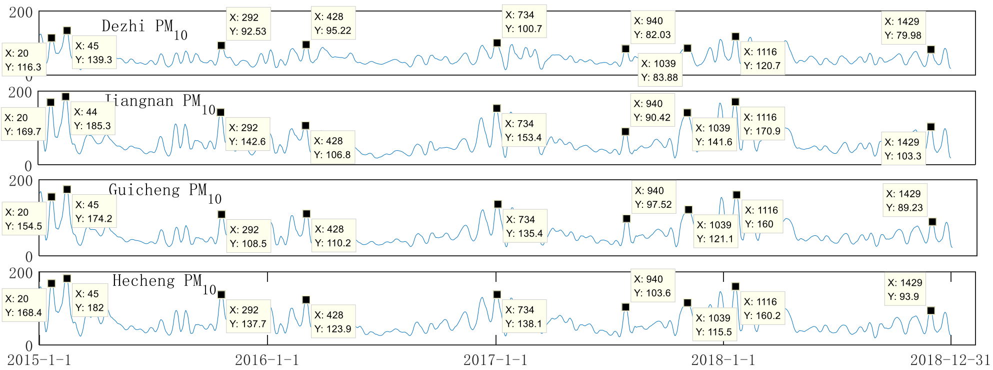

Fig 10 PM10 low frequency component (A3) reconstruction map

Fig.11 shows the pollution severity of $PM_{2.5}$ in each station during each heavy pollution process. The concentration when $PM_{2.5}$ exceeded the standard is Jiangnan Station>Guicheng Station>Hecheng Station>Dezhi Station, which is PM_{10} The spatial distribution is similar, indicating that PM_{10} contains some $PM_{2.5}$. The polymerization of $PM_{2.5}$ can be converted to PM_{10} at any time. Overall, the four stations have seen more frequent highs and fluctuations in 2017-2018 than in 2015-2016, and tend to be more serious.

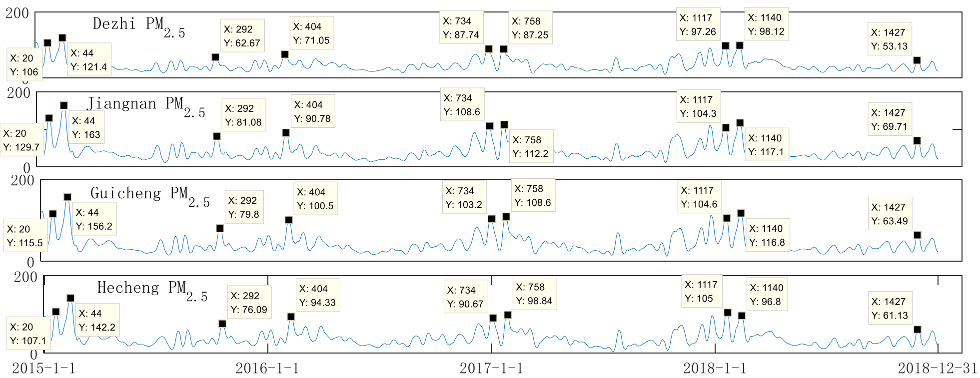

Fig.11 PM2.5 low frequency component (A3) reconstruction map

3.2 Morlet wavelet analysis results

According to the air quality monitoring data, the air quality rate in Guigang City was 88.2% in 2015-2018. A total of 173 days of mild and above polluted weather occurred. $PM_{2.5}$, PM_{10} and O_3 all appeared as the primary pollutants in Guigang City. The days of $PM_{2.5}$ and O_3 as primary pollutants were 137 days and 34 days, respectively. PM_{10} was only 2 days as primary pollutants. The frequency of occurrence of $PM_{2.5}$ as the primary pollutant is much higher than that of O_3 and PM_{10}. The air pollution in the Guigang area has gradually transitioned from the traditional fine particulate matter ($PM_{2.5}$) pollution to the regional composite air pollution characterized by high concentrations of $PM_{2.5}$ and O_3. Using morlet wavelet analysis to analyze the $PM_{2.5}$ and O_3 hour concentration values of the four stations, the characteristics of interannual variation and daily variation of the primary pollutants in Guigang City were discussed in depth.

Fig.12 clearly shows the time-scale changes, the distribution of the breakpoints and the phase structure of the $PM_{2.5}$ hour concentrations of the four monitoring substations. The magnitude of the concentration is reflected by the positive and negative of the wavelet coefficient. The wavelet coefficient is larger, the concentration is higher. The $PM_{2.5}$ time change trend of each substation is in good agreement with the db wavelet analysis. The highest value of $PM_{2.5}$ is one year in the fall and winter . According to the 24-hour scale analysis, the $PM_{2.5}$ concentration at 7-23 o'clock is slightly higher than 0-5 o'clock in pollution day, which is due to the increase of $PM_{2.5}$ caused by the traffic time. The high-value area pollution of $PM_{2.5}$ often appears after 16 o'clock. Because fine particles are not easy to settle, and it is easy to exceed the standard after slowly accumulating. At 11:00 on February 18, 2015 and at 16:00 on February 7, 2016 the $PM_{2.5}$ content increased significantly .This is due to the increase in SO_2 and NO_2 levels in the atmosphere caused by the firecrackers of the Spring Festival. In turn, it promotes the increase of $PM_{2.5}$ content, which is caused by two typical firecracker discharges. On February 11, 2017 and February 14, 2017 there is a high value area from 8:00 to 24:00, which is due to the Lantern Festival firecrackers and the increase in traffic on Valentine's Day.

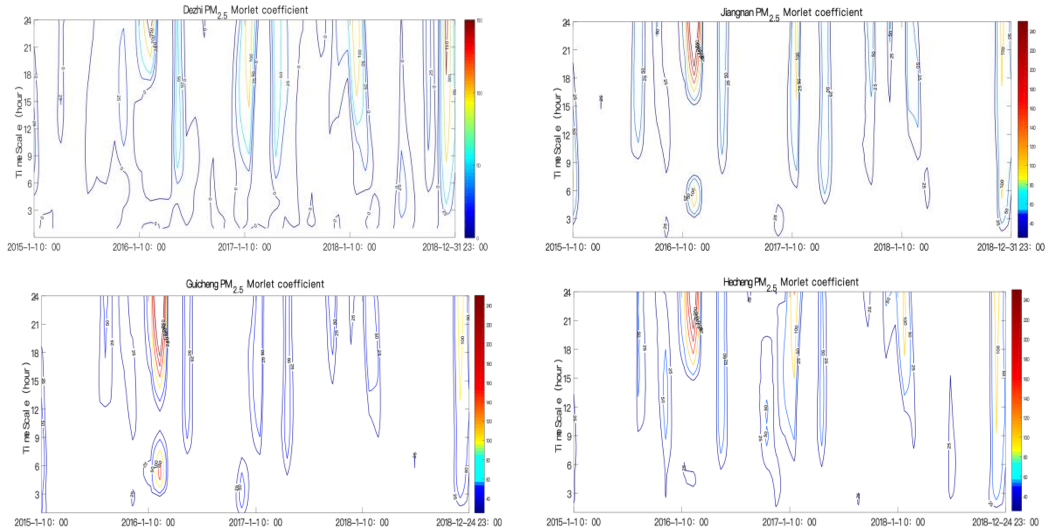

Fig.12 Two-dimensional contour map of $PM_{2.5}$ wavelet at each monitoring station

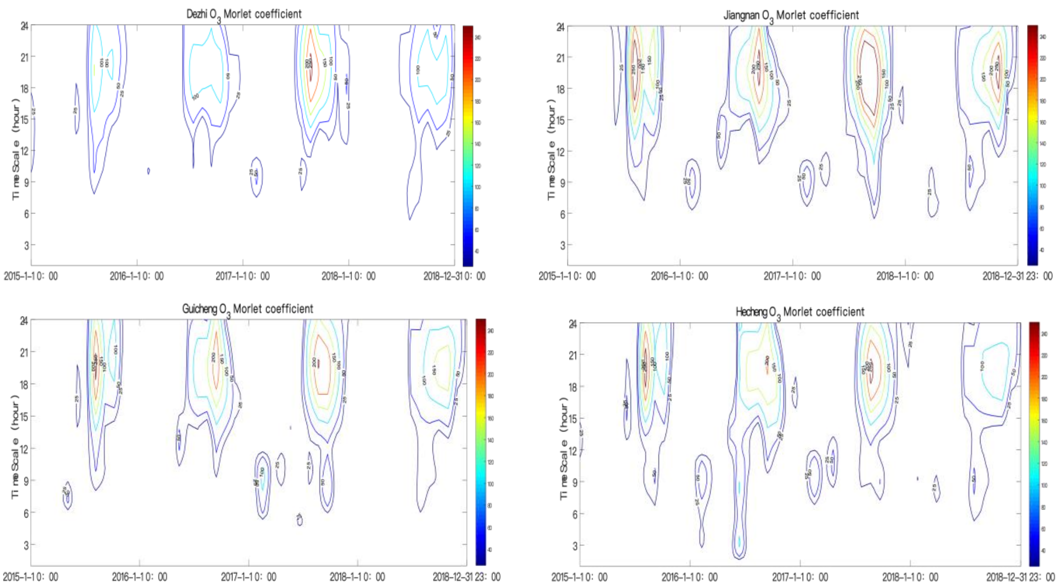

Fig.13 Two-dimensional contour map of O_3 wavelet at each monitoring station

By analyzing the O_3 concentration hour series, a two-dimensional contour map of the wavelet coefficients is obtained (Fig.13). The interannual high value area of the pollution process occurs in summer and autumn. The daily high value center is at 11-22 o'clock in pollution day. As the temperature drops and the sun disappears at night, the O_3 concentration slowly decreases. Taking the ozone pollution process of Guigang on October 2-8, 2018 as an example, the ozone precursor NOx is easily accumulated due to the low-level northerly airflow and the downdraft airflow around the typhoon “Connie”. In addition, the light is sufficient, resulting in strong atmospheric photochemical reaction during the day. The ozone concentration rises rapidly at 12 o'clock, and the highest ozone concentration in Jiangnan Station reaches 190$ug \cdot m^{-3}$.

4. Discussion and conclusion

(1) Using db wavelet to analyze the daily concentration series of pollutants in Guigang, the peaks of NO_2 and particulate matter concentration(local maximum, relatively heavy pollution) appear in autumn and winter, while the troughs (local minimum, relatively light pollution) appear in summer. The spatial distribution of the pollution exceeded the highest concentration of NO_2 in Guicheng Station, the highest concentration of O_3 in Dezhi Station, and the highest concentration of particulate matter in Jiangnan Station.

(2) The $PM_{2.5}$ and O_3 hour concentration series of the four substations were analyzed by morlet wavelet. The results show that the interannual trend and period are consistent with the db wavelet analysis results. The particulate matter is high in autumn and winter and low in summer. O_3 is high in summer and autumn. On the 24-hour scale, when the $PM_{2.5}$ concentration is higher at 7-23 o'clock than 0-5 o'clock.The high-value areas of several typical $PM_{2.5}$ pollution events often appear after 15:00 of the major festival. The O_3 daily change high value center appears at 11-22 o'clock of the pollution day.

(3) The frequent occurrence of particulate matter in autumn and winter as the primary pollutant is determined by the pollution source and meteorological conditions. The seasonal production of autumn and winter industry (sugar factory), the increase of coal-fired energy consumption, and the burning of biomass such as straw make the concentration of SO_2 and NO_2 worse. In terms of meteorological conditions, the wind direction in autumn and winter is changed to the northerly wind. The air mass of the northern pollution source (Shika Industrial Park) is transported to the urban area. The increase of the boundary layer height and the increase of air pressure (pot effect) are not conducive to the dilution and diffusion of particulate matter , prone to serious pollution.

(4) Summer and autumn are the peak period of O_3 pollution, which is related to meteorological factors such as high temperature, strong sunshine and low humidity. Ozone is an unstable substance and photodecomposition occurs. So it is not easy to accumulate. Most of them cause mild pollution.

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