Distribution over time and space of PM2.5 in Beijing- Tianjin-Hebei region and its influence of meteorological factors

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Abstract. As the capital economic belt and the political center of China, Beijing-Tianjin-Hebei region has always been faced with the problem of air pollution. In this study, the emission, seasonal and geographical changes of PM2.5 in this region is analyzed with spatial-temporal distribution. It is found that the concentration of PM2.5 shows a spatial distribution of decreasing from southwest to northeast. In winter, the daily average concentration of PM2.5 is significantly higher than that in other seasons. The influence of meteorological factors on PM2.5 in each city is discussed by cluster analysis, and the correlation between these factors and PM2.5 is studied. The results indicate that the daily average precipitation and wind speed are negatively correlated with PM2.5 concentration, while the daily average relative humidity is positively correlated with it. Finally, this study also puts forward suggestions for PM2.5 control in this area according to the types of cities' PM2.5 discharge affected by meteorological elements.

Keywords: Beijing-Tianjin-Hebei region; Spatial and temporal distribution; PM2.5; meteorological factors.

1. Introduction

With the advancement of socialist modernization, the air quality problem in Beijing-Tianjin-Hebei region, as the key to urban modernization, has received more and more public attention. Although all cities have increased investment in environmental protection construction. The air quality of some cities has been significantly improved, but many cities still face a huge burden of environmental pollution.

The main factors causing air pollution is the discharge of pollutants, but the actual observed pollution level value does not only depend on the degree of pollution discharge, but also meteorological factors have great influence to the diffusion of pollutants. Some research results show that the environmental improvement in some cities belongs to "human efforts", while that in some cities should mainly be attributed to "Heaven's help". Therefore, it is very important to analyze the impact of meteorological factors on the air pollution degree and explore the scientific assessment of meteorological factors on the real emission level of pollutants in various cities.

In this paper, the distribution over time and space of PM2.5 of meteorological elements in Beijing-Tianjin-Hebei region was analyzed by cluster analysis and multiple linear regression, and the influence of different meteorological elements on PM2.5 concentration and distribution were also studied. Based on this, different prevention, and control measures of PM2.5 pollution were put forward for the regions with obvious differences in meteorological factors in Beijing Tianjin Hebei region.

2. Method

2.1. Reaseach area

As a key city in China's modern industrial construction. The Beijing-Tianjin-Hebei Urban Agglomeration includes two municipalities i.e., Beijing and Tianjin directly under the management of central government many areas in Hebei Province. Among them, Hebei Province, and Tianjin, as China's "cradle of modern industry", have contributed a lot to the construction of modern China, However, due to the urgent need for industrial construction, this area has always been a serious disaster area of air quality problems.

2.2. Data resource

The data sources are the daily air quality data of 366 cities in China from 2019 to 2020 released by China national environmental monitoring station and the meteorological data of more than 400 stations in China from 2019 to 2020 generated by the national climate data center of the United States, including temperature, dew point, air pressure, wind direction and speed, cloud amount and precipitation.

2.3. Analysis method

Time series analysis [1]: It is a method for statistical analysis that can be applied to meteorological data processing. This method is based on mathematical statistical analysis of meteorological elements to explore the distribution characteristics of PM2.5 with time and space.

Cluster analysis [2]: Cluster analysis refers to the classification of cities into different combinations based on their similarity. In this paper, to make the evaluation criteria universal and portable and avoid the evaluation criteria being only valid for a single city and not valid for other cities, systematic cluster analysis (Q-type) is used to cluster the cities with similar pollution levels and study the common characteristics of each class of cities, thereby giving the evaluation criteria.

3. Result

3.1. Distribution over time and space

In the study of Li Min [3], the research method of the distribution over time and space of PM2.5/PM10 in Shanghai is given, and in the study of Li Zhuojian [4], the research method of the distribution over time and space of PM2.5 in Taiyuan is shown. Therefore, the distribution over time and space of PM2.5 in Beijing-Tianjin-Hebei region will be analyzed as follow.

3.1.1 Spatial distribution

The PM2.5 monthly average mass concentration data in January, April, July and October of 2019 and 2020 are respectively selected to represent the PM2.5 pollution degree in winter, spring, summer and autumn. Fig.1 shows the PM2.5 concentration in different seasons in Beijing-Tianjin-Hebei region, and difference of PM2.5 pollution degree in two years is analyzed.

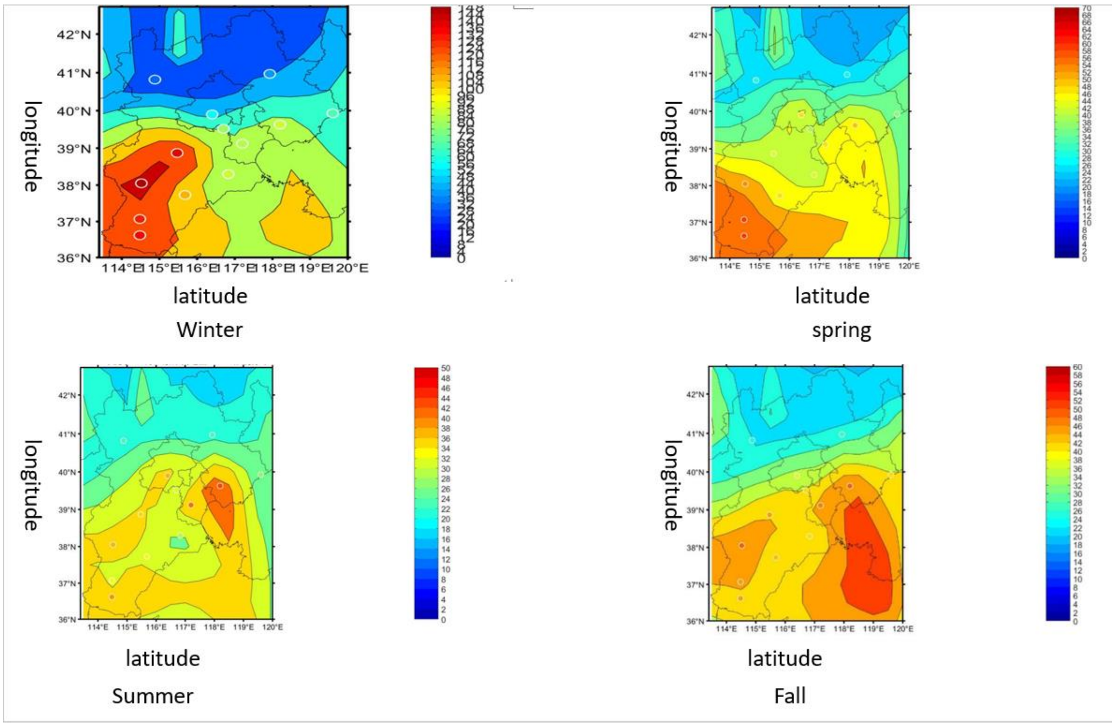

Fig. 1 PM2.5 concentration distribution in Beijing- Tianjin- Hebei region in 2019

According to the obtained concentration distribution, in the Beijing-Tianjin- Hebei region, the PM2.5 concentration distribution shows a decreasing trend from the southwest to the northeast. In terms of the changes in 2019 and 2020, the PM2.5 cleanliness in the whole region decreased in winter, increased in spring, decreased in summer, and decreased in autumn.

The change trend is mainly related to the regional conditions. In the southwest of Beijing-Tianjin-Hebei region, industrial zones are developed, and the emission of many fossil fuels has led to an increase in the content of a series of air pollutants such as PM2.5. In the northeast of Beijing Tianjin region, urban functions have become more diversified, and the proportion of industrial parks has begun to decrease, resulting in a lower concentration of PM2.5 than in the southwest.

3.1.2 Time distribution

According to the seasonal and spatial distribution of pm2.5/pm10 in the atmospheric environment of Shanghai by Li Min et al. And the PM2.5 data analysis method adopted by Li Zhejiang et al. In the study on the Seasonal and spatial distribution characteristics of PM2.5 concentration in the urban area of Taiyuan City average mass concentration of PM2.5 is calculated, the data is visualized with Excel software (broken line chart), and the time series diagram of PM2.5 average mass concentration of all cities in Beijing-Tianjin-Hebei region is drew. The general situation is shown in fig.2.

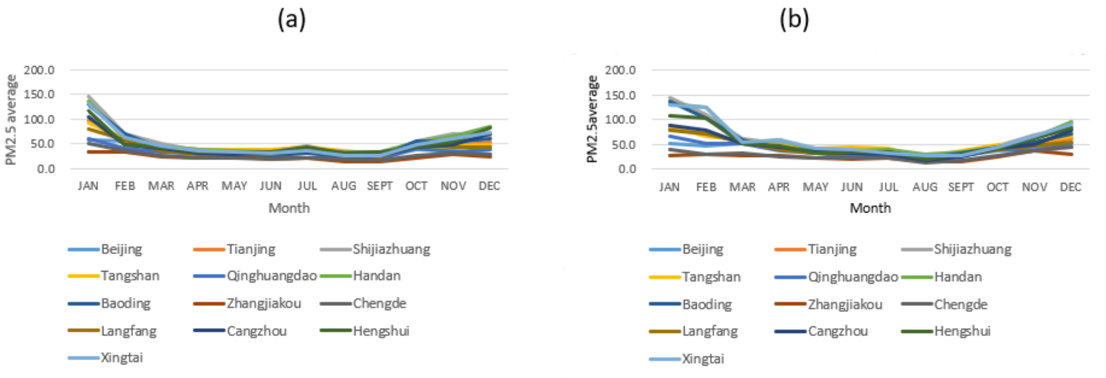

Fig. 2 Monthly average PM2.5 concentration of cities in Beijing-Tianjin-Hebei region-(a)2020, (b)2019

The change curve of PM2.5 daily average mass concentration with time in all cities showed a "U" type which means the PM2.5 concentration in other seasons is significantly lower than that in winter. The temporal change law of PM2.5 mass concentration in 2019 and 2020 is: Winter > autumn > spring > summer. While the main temporal change of PM2.5 content in 2029 is winter > spring > autumn > summer

For the annual change trend from 2019 to 2020, it is consistent with the results obtained in the color block diagram in 3.1.1.

The reason why PM2.5 shows a "U" shape change trend in the whole year is due to the joint effect of meteorological factors and human factors. As for the reason why the PM2.5 is too large in winter, it is mainly due to the low temperature in winter, the need for heating in northern cities, the rapid increase of chemical fuel combustion and the longer driving time of motor vehicles, and the increase of PM2.5 emission. Meanwhile, the low relative humidity in winter is conducive to the moisture absorption growth of particulate matter in the air and increases the concentration of PM2.5. The more likely it is that gaseous pollutants in the air will be converted into solid pollutants and secondary pollution will occur, resulting in an increase in PM2.5 value. The Beijing-Tianjin-Hebei region has a warm temperate continental monsoon climate. The temperature and relative humidity are both on the high side, and the precipitation reduces the concentration of PM2.5.

3.2. Assessment of pollution status of each city

In this paper, the urban pollution in Beijing-Tianjin-Hebei region is analyzed by cluster analysis. The specific situation is as shown in Table 1.

Table 1. Cluster analysis results of pollution situation of cities in Beijing-Tianjin-Hebei region

Cluster analysis results	
Type	City
Type1	Zhangjiakou
	Chengde
Type2	Qinhuangdao
Type3	Beijing
	Langtang
Type4	Tianjin, Shijiazhuang, Tangshan, Handan, Baoding, Changzhou, Heng Shui, Xing Tai

1. In class I cities (Zhangjiakou and Chengde), the PM2.5 pollution level is light throughout the year, and the number of days with mild pollution level or above is less than 25 days. The PM2.5 pollution in Beijing- Tianjin- Hebei region is serious in winter, but the PM2.5 pollution in class I cities in winter is not related to the overall pollution level in the region, and the air quality level is mostly excellent.

2. In the second-class cities (Qinhuangdao), the PM2.5 pollution level is relatively light throughout the year, and the number of days with mild pollution level or above is between 25 and 50 days. In the winter when the pollution in Beijing, Tianjin and Hebei is the most serious, the second-class cities only show a weak correlation with the overall pollution level in Beijing, Tianjin, and Hebei. The PM2.5 pollution is slightly increased, and the air quality level is mostly excellent or good.

3. In the third-class cities (Beijing and Lang fang), PM2.5 pollution may occur in a year. The number of days with mild or above pollution level in the whole year is between 50 and 65 days, and there is a certain correlation between the overall pollution level of Beijing- Tianjin- Hebei region in winter and PM2.5 pollution increases in winter. The air quality grade in winter is mostly good or slightly polluted.

4. In the fourth-class cities (Tianjin, Shijiazhuang, Tangshan, Handan, Baoding, Changzhou, Heng Shui and Xing Tai), PM2.5 pollution may occur frequently in the whole year. The number of days

with mild pollution or above in the whole year is more than 65 days. The overall air quality of the whole year is poor, and the pollution degree in winter is significantly increased. The air quality is poor. Many days are mild or moderate pollution.

3.3. Influence of meteorological factors on PM2.5 distribution

In the research of Liu Daman [5], the author discussed the relationship between the combustibles, precipitation, wind speed and other meteorological factors in Beijing. In the research of Yang Xingchuan [6]and Jiang Mengqi [7], the authors of the two articles discussed the influence of precipitation and air temperature on PM2.5 as well as PM10 in Beijing-Tianjin-Hebei region in 2016 and 2017 respectively. In the research of Zhang Xingke [8], the influence of winter temperature on PM2.5 in Chongqing was shown.In Zhang Yunlin's article [9], the author discussed the distribution over time and space characteristics of PM2.5 in Guangdong, Hong Kong and Macao Bay area and its relationship with meteorological elements. In Guo Tianxiu's study [10], the author also studied in detail the spatial and temporal effects and influencing factors of PM2.5 concentration in China's eight major comprehensive economic zones. Based on the above research and the conditions of warm and humid summers and dry and cold winters in Beijing-Tianjin-Hebei region, the precipitation, wind, and the relative humidity is selected as the meteorological elements of the studied.

3.3.1 Wind

Wind direction and wind speed have a decisive influence on the diffusion and transmission of air pollutants. The wind speed determines the transport capacity of pollutants. The wind speed is proportional to the speed of pollution propagation. And the wind direction determines the transmission direction of pollutants.

To compare the impact of wind speed and direction on PM2.5 pollution in Beijing-Tianjin-Hebei region, the daily average wind rose chart and wind speed histogram on the pollution days and clean days of each city is drew as fig. 3, Since the daily average PM2.5 pollution of Baoding city belongs to the range of pollution days, only the pollution days are plotted in the picture of Baoding City.

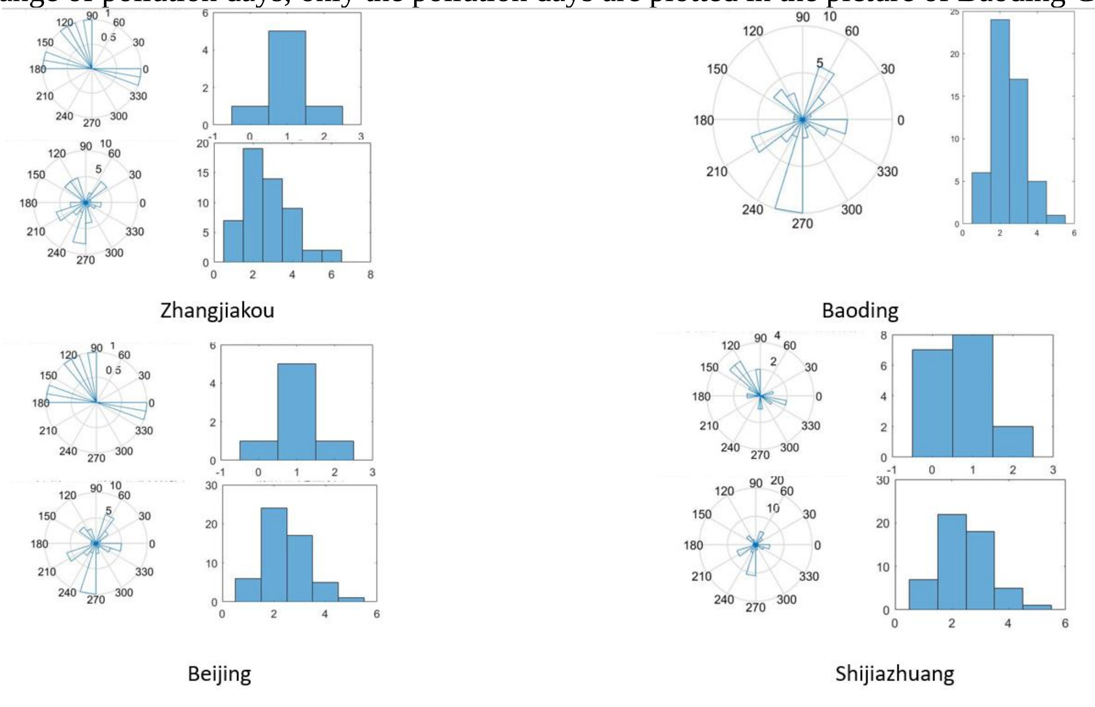

Fig. 3 The average wind rose chart and wind speed histogram of each city on the pollution day and clean day of the year.

It is observed that on the day of severe pollution, the prevailing wind direction is mainly northeast wind. Meanwhile, With the increase of wind speed, the concentration of PM2.5 decreases. It is found that when the wind speed is greater than 2m / s, the concentration of PM2.5 is significantly weakened.

The daily average wind speed of PM2.5 heavy pollution is below 2m / m, and the probability of breeze is high. It indicates that when the wind speed is low, the influence on pollution diffusion is small, and it is easy to cause PM2.5 pollutants to accumulate near the ground, forming a polluted weather.

3.3.2 Precipitation

Precipitation is one of the main ways of atmospheric pollutant deposition. To further analyze its correlation, the daily average PM2.5 mass concentration and daily precipitation changes of four cities is plotted as follows.

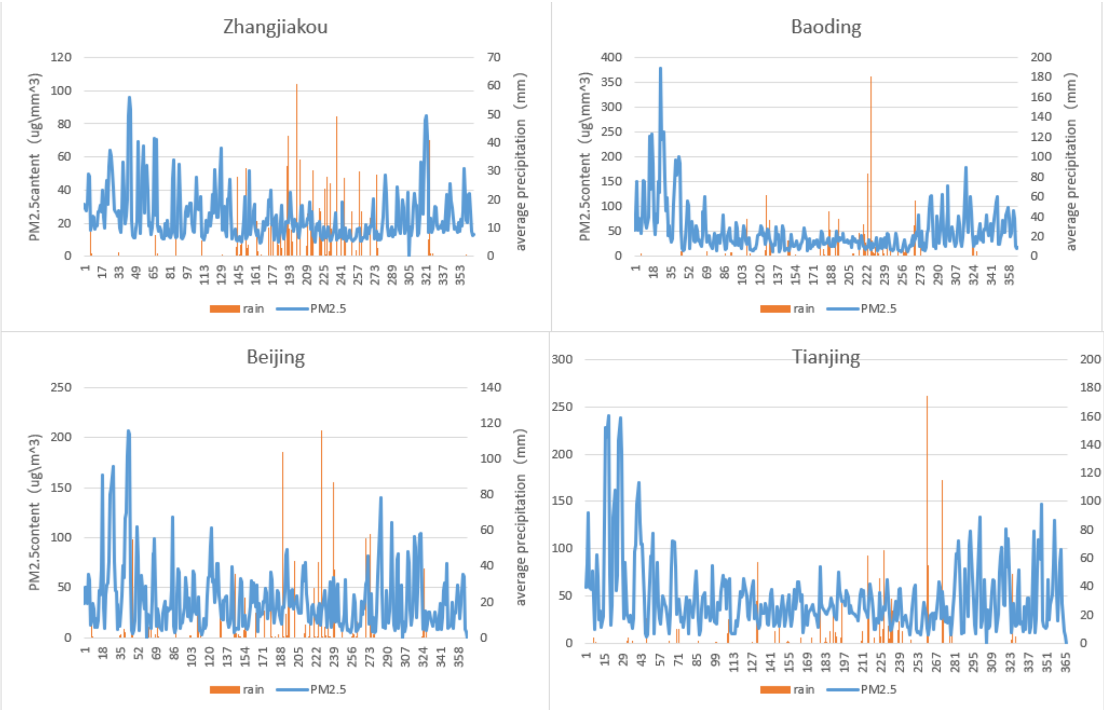

Fig. 4 Daily average PM2.5 mass concentration and daily precipitation change in cities

When there is precipitation, The more precipitation, the lower the PM2.5 concentration. That is, with the increase of precipitation, the PM2.5 concentration gradually decreases, and the continuous precipitation process has the most obvious effect on the reduction of PM2.5. For example, during the continuous precipitation from the 225th to the 239th day in Beijing, the air quality quickly changed from moderate pollution to excellent or good. However, when the precipitation is small in some time, the PM2.5 concentration also increases (such as the 99th day in Tianjin).

3.3.3 Relative humidity

Humidity mainly affects the concentration of PM2.5 by affecting the diffusion degree and diffusion speed of pollutants to further analyze the daily average concentration of PM2.5 is affected by humidity, one of the four cities (the four cities classified according to the similar and different pollution levels in question 1) is selected to explore the correlation between relative humidity and PM2.5 as fig. 5.

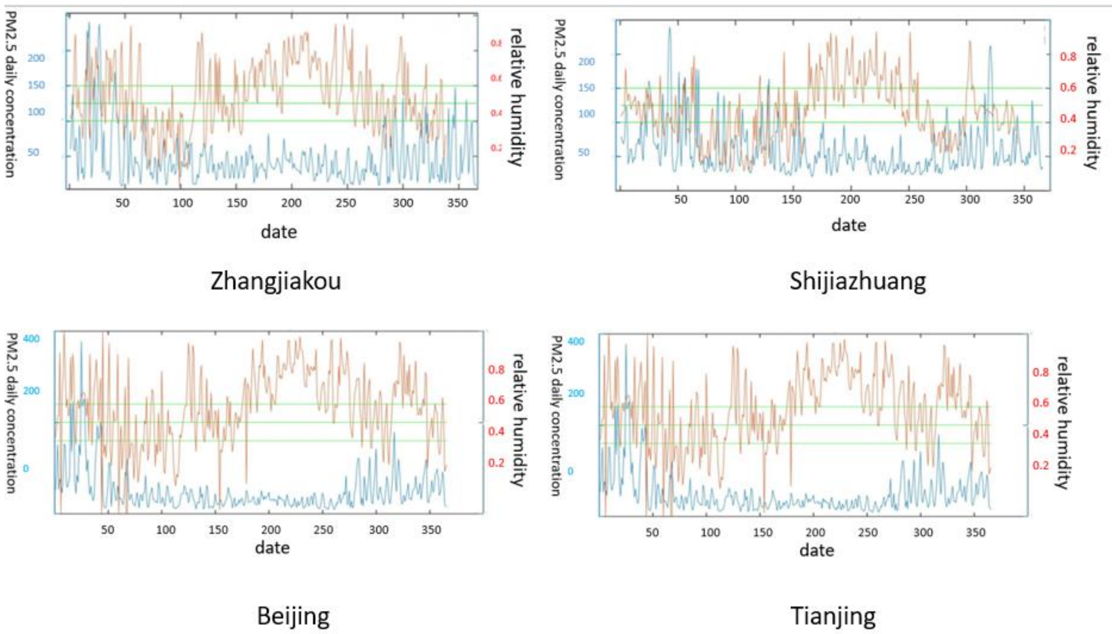

Fig. 5 Relationship between daily average relative humidity and PM2.5 concentration

Therefore, that in autumn, winter, and spring is gotten, when the relative humidity is greater than 60%, there is a significant negative correlation with PM2.5, and there is a certain negative correlation trend when the relative humidity tends to be in the range of 50-60. Through the analysis of precipitation in (2), we can think that in summer, precipitation plays a dominant role in the concentration change of PM2.5, resulting in a small impact on the relative humidity. In other seasons, the daily relative humidity has a greater impact on the concentration of PM2.5.

4. Discussion

To explore the impact on different types of regions caused by the difference of meteorological elements and put forward practical suggestions for PM2.5 pollution control in cities with different climate types. First, based on the research results of the second question: when the relative humidity is greater than 60%, the wind speed is greater than 2m / s, and the daily average precipitation is greater than 0.3mm, meteorological elements will reduce the concentration of PM2.5. By using the threshold value when the meteorological elements have a significant reduction effect on PM2.5, the number of days affected by each city in the whole year is counted, and different regions with different effects of meteorological elements on PM2.5 are divided accordingly. Specific standards are shown in Table 2.

Table 2. Classification criteria

Classification criteria	Precipitation influence (>30mm)	Influence of relative humidity (HE>60%)	wind speed>2m/s
Stronger	>70 days	>150 days	>85 days
Weaker	<70 days	<150 days	<85 days

The Beijing-Tianjin-Hebei region is divided into six regions where the PM2.5 mass concentration is strongly and weakly affected by precipitation, strongly and weakly affected by wind speed, and strongly and weakly affected by relative humidity as shown in Table 3.

Table 3. Different regions where meteorological elements have different effects on PM2.5

Region	City
Cities strongly affected by precipitation	Yu county (Zhangjiakou), Fengning (Chengde), leting (Tangshan), Botou (Cangzhou)
Cities less affected by precipitation	Xing Tai, Baoding, Beijing, Tianjin
Cities less affected by relative humidity	Xing Tai, Baoding, leting (Tangshan), Botou (Cangzhou)
Cities strongly affected by relative humidity	Yu county (Zhangjiakou), Fengning (Chengde), Beijing, Tianjin
Cities strongly affected by wind speed	Yu county (Zhangjiakou), Fengning (Chengde), Botou (Cangzhou)
Cities less affected by wind speed	Xing Tai, Baoding, leting (Tangshan), Beijing, Tianjin

4.1. Suggestions for areas greatly affected by precipitation

For the areas where the PM2.5 content is greatly affected by precipitation, from the analysis of time distribution it can be gotten that the precipitation in summer is significantly higher than that in other seasons. And considering the wind field conditions in Beijing-Tianjin-Hebei region as shown in fig.6, the following suggestions can be proposed:

(1) Centralized production and centralized settlement. The precipitation is concentrated in summer, and the settling speed of the pollution gas is fast. We can consider concentrating on industrial activities that produce more air pollutants in summer.

(2) Formulate regional pollution control policies. In spring, summer and autumn, there is less precipitation, so it can be considered to formulate regional pollution control policies to achieve comprehensive treatment of the whole region for prevention and control. By strictly formulating the method of pollutant discharge, we can control the discharge to be at the level of rapid precipitation, without causing pollutant accumulation.

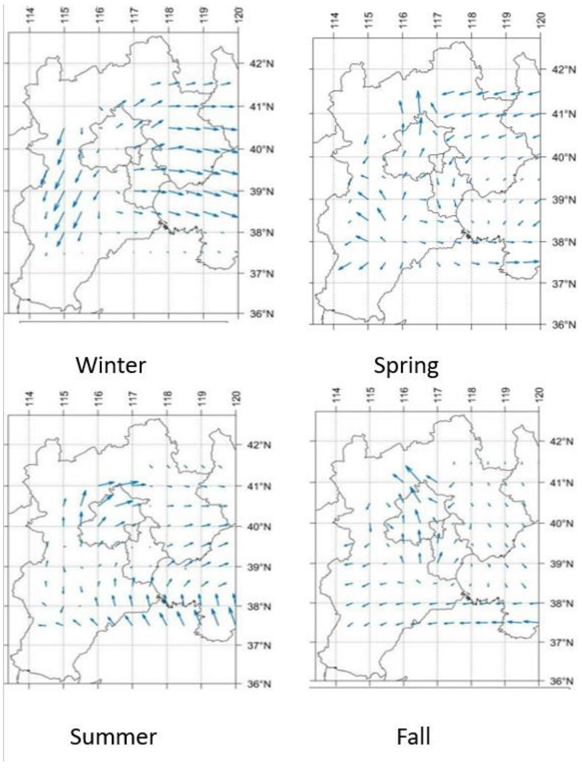

Fig. 6 Wind field map of Beijing- Tianjin- Hebei region in 2020

4.2. Suggestions for areas affected by wind

Under the current background of high-intensity pollutant discharge, adverse meteorological conditions with near ground wind speed less than 2 m / s occur, which is very easy to generate local accumulated pollution. For areas where PM2.5 content is greatly affected by wind, we propose the following suggestions:

(1) For areas with low wind speed throughout the year, it is suggested to take the development of light industry and service industry as the guide and reduce the number of local heavy industry and heavy pollution enterprises. In case of adverse weather conditions with wind speed less than 2 m / s, some heavy polluting enterprises will be temporarily closed.

(2) According to the main wind direction of the four seasons (such as the four seasons wind in Beijing, Tianjin, and Hebei), the emission source should be based on the wind direction in the current season. The pollution source in the wind direction should reduce the emission as much as possible to avoid the diffusion of pollutants to the monsoon destination area due to the monsoon.

(3) Reasonable site selection to avoid secondary pollution. Factories and residential areas that discharge more pollutants shall be concentrated in the leeward area during site selection to avoid the diffusion of pollutants to other areas due to the diffusion effect of wind.

(4) Pretreatment shall be conducted before pollutant discharge. For industrial equipment discharging strong pollutants, we first use plasma membrane filtration method and activated carbon adsorption method for preliminary decontamination. Prevent secondary pollution after discharge.

For areas where PM2.5 content is greatly affected by relative humidity, we propose the following suggestions: Real time drying. By reducing the relative humidity of drying, reduce the moisture absorption of particles, make it difficult for particles to gather, and ease the diffusion of pollutants Reduce the use of high-pressure dust suppression gun trucks in cities. In urban areas where the dust is not serious, the direct use of high-pressure spray dust removal will greatly increase the relative humidity, be conducive to the moisture absorption growth of particulate matter and increase the mass concentration of PM2.5. When the dust is serious, reduce the use and find other alternative dust removal methods.

5. Conclusion

In this study, the distribution over time and space of PM2.5 in Beijing-Tianjin-Hebei region was discussed. Finally, it was concluded that the concentration of PM2.5 in the industrial area showed the characteristics of gradually decreasing in winter, autumn, spring, and summer, and was stronger than that in other regions in space. Finally, combined with the actual layout and climatic characteristics of Beijing-Tianjin-Hebei region, the concentration of PM2.5 is concluded in the industrial area was stronger than that in other regions, and the concentration in winter was stronger than that in other regions. After that, we classified the major cities in Beijing Tianjin Hebei region into four levels based on the pollution degree of PM2.5 from high to low through cluster analysis. This study also discussed the correlation between PM2.5 and wind, precipitation and relative humidity, and concluded that PM2.5 is negatively correlated with wind speed and precipitation, while the correlation between relative humidity and PM2.5 is small in summer, Finally, we divided the main cities in Beijing Tianjin Hebei region into regions with large wind impact on PM2.5 and regions with large precipitation impact, and gave treatment suggestions respectively, providing a feasible reference scheme for haze control in Beijing Tianjin Hebei region, which can help the government to make decision-making analysis to a certain extent. However, this study also needs to be improved: there are few data used to describe the spatial-temporal distribution, resulting in certain errors. In future applications, to make the results more accurate, data samples should be collected.

References

[1] Jiang Qiyuan, Xie Jinxing, ye Jun, mathematical model (Fourth Edition), Beijing: Higher Education Press, 2003

[2] Han Zhonggeng, mathematical modeling methods and Applications (Third Edition), Beijing: Higher Education Press, 2017

[3] Li Min, he Hongdi, Hao Yangyang, distribution over time and space characteristics of pm2.5/pm10 in the atmospheric environment of Shanghai, 41 (2): 2019323:332

[4] Li Zhuojian, Zhao shangmin, Guo Pengcheng, distribution over time and space characteristics of PM2.5 concentration in urban area of Taiyuan City

[5] Liu Da Mn, Ma Yong Sheng, Gao Shaopeng, Huang Jie, pollution level and influencing factors of atmospheric particulate matter from combustion sources in Beijing in spring [J], modern geology, 19 (4): 2005627:633

[6] Yang Xingchuan, Zhao Wenji, Xiong Qiulin, Wang Lili, Zhao Wenhui, 2016, distribution over time and space characteristics of PM2.5 in Beijing- Tianjin- Hebei region and its relationship with meteorological factors [J], Journal of ecological environment, 26 (10): 20171747:1754

[7] Jiang Mengqi, relationship between PM2.5 concentration and meteorological factors in Beijing Tianjin Hebei region, Shandong chemical industry, 45 (9): 2016, 148:151

[8] Zhang Xinke, Hu Changjin, he Yue, Liu Ruijia, meteorological factors, and regional transmission characteristics of PM2.5 pollution in winter in Rongchang District of Chongqing [J], drought meteorology, 39 (1): 2021120:111

[9] Zhang Yunlin, Sui Jinling, Wu Xian, Lin MEIXIA, Chen long, Chen Tianyi, distribution over time and space characteristics of PM2.5 in Guangdong, Hong Kong and Macao Bay area and its relationship with meteorological elements [J], Journal of ecology 41 (6): 20212272:2281

[10] Guo Tianxiu, study on the temporal and spatial effects and influencing factors of PM2.5 concentration in the eight comprehensive economic zones of China [D], Qingdao: Qingdao University, 2018