

Analysis of changes and trends in ambient air pollutant concentrations in the Beijing-Tianjin-Hebei region in recent years

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Abstract. The Beijing-Tianjin-Hebei region is a key prevention and control area for air pollution in China. Based on the PM_{2.5}, PM₁₀, SO₂, NO₂ and AQI data published by the Ministry of Ecology and Environment and the online monitoring and analysis platform of air quality, the temporal variation of air pollutant concentrations in the Beijing-Tianjin-Hebei region from 2019 to 2021 and the contribution of each pollutant to air pollution were analyzed by the comprehensive pollution index method and the pollution load factor method. The results show that: (1) The changes in the comprehensive air pollution index and AQI index in the Beijing-Tianjin-Hebei region from 2019 to 2021 show a downward trend. Compared with the annual average concentrations of PM_{2.5}, PM₁₀, SO₂ and NO₂ in 2019, the average concentrations of PM_{2.5}, PM₁₀, SO₂ and NO₂ decreased by 23.72%, 19.28%, 34.28% and 24.03%, respectively. (2) The monthly average change of the concentration of various pollutants in the Beijing-Tianjin-Hebei region from 2019 to 2021 shows a roughly shaped "U", following the governing rule of "high in winter and low in summer, rising in autumn and falling in spring". (3) The average pollution load coefficients of four pollutants in the Beijing-Tianjin-Hebei region, including PM_{2.5}, PM₁₀, SO₂ and NO₂, were 38.18%, 31.64%, 3.84% and 26.34% from 2019 to 2021, respectively. It indicates that the ambient air quality in this area is greatly affected by particulate matter pollution.

Keywords: Beijing-Tianjin-Hebei region; air pollution; comprehensive pollution index; pollution load; space-time features.

1. Introduction

The Beijing-Tianjin-Hebei region is one of the more economically developed regions in the north, and it is also the most important core base for high-tech industries and heavy industries in the north^[1]. It includes not only Beijing, the economic and political center of China, but also typical cities such as Tianjin, Shijiazhuang, Baoding, and Tangshan, which are dominated by heavy industry^[2]. With the rapid economic development of the region, the continuous advancement of urbanization and industrialization, the increasing number of residential motor vehicles^[3], the concentrated consumption of fossil energy, and the winter rural areas and some cities in the region adopt the heating method of loose coal combustion, resulting in PM_{2.5} (referring to particulate matter with an ambient aerodynamic equivalent diameter of $\leq 2.5 \mu\text{m}$, also known as fine particulate matter) and PM₁₀ (respirable particulate matter), SO₂, NO₂ concentrations increased significantly, becoming one of the most polluted areas in China's atmospheric areas^[4-5]. Studies have shown that the rapid development of urban economies often depends on a good local ecological environment^[6]. Therefore, it is urgent to solve the contradiction between the rapid economic development and air pollution in the Beijing-Tianjin-Hebei region.

In order to alleviate the serious air pollution situation in the Beijing-Tianjin-Hebei region, the regional government has actively implemented policies such as the Air Pollution Prevention and Control Action Plan and the 2017 Air Pollution Prevention and Control Work Plan promulgated by the state since 2013. Air quality in the region has improved^[7-8] significantly thanks to cross-regional cooperation between regional governments, such as innovative institutional supply, energy consumption reform, and regional joint prevention and control. However, there is still a lot of room for improving air quality, according to the 2019 "Communiqué on the State of China's Ecological Environment", there are still 5 prefecture-level cities in Hebei Province, namely Xingtai, Shijiazhuang, Handan, Tangshan and Baoding, ranking in the bottom 20 of the 168 key monitoring

cities for air pollution, indicating that the air quality in the region still needs further improvement^[9]. Tang Qian and other scholars used the technical method of air pollution source emission inventory to quantitatively analyze the changes in the emissions of major air pollutants in the Beijing-Tianjin-Hebei region from 2016 to the beginning of 2020, and found that the emissions of major air pollutants in the region dropped by 50%^[10]. However, at present, there are no scholars to analyze the trend of changes in the main air pollutants in the Beijing-Tianjin-Hebei region in recent years. Therefore, based on the monthly average data released by the Ministry of Ecology and Environment, this paper reviews the PM_{2.5}, PM₁₀, SO₂ and NO₂ of the three representative cities in the Beijing-Tianjin-Hebei region: Beijing, Tianjin and Shijiazhuang from 2019 to 2021. The time series data of the concentration of four atmospheric pollutants were analyzed to obtain the change period and rising and falling trend of pollutants. In order to provide a reference for the understanding of the characteristics of atmospheric environmental pollution and pollution control in the Beijing-Tianjin-Hebei region.

2. Research methodology

2.1. Overview of the study area

The Beijing-Tianjin-Hebei region includes 11 prefecture-level cities in Beijing, Tianjin and Hebei Province, located between 113°27'~119°50'E, 36°05'~42°40'N, with an area of about 216×10^4 km², which belongs to the temperate continental monsoon climate, with obvious seasonal changes, warm and rainy summers, and cold and dry winters^[11]. The study area is bordered by the Bohai Sea to the east, the Taihang Mountains to the west, and the Yanshan Mountains to the north. The terrain in the west and north is higher, and the terrain in the south and east is relatively flat, and the overall terrain characteristics of high in the northwest and low in the southeast are presented. The overview of the Beijing-Tianjin-Hebei region is shown in Figure 1.

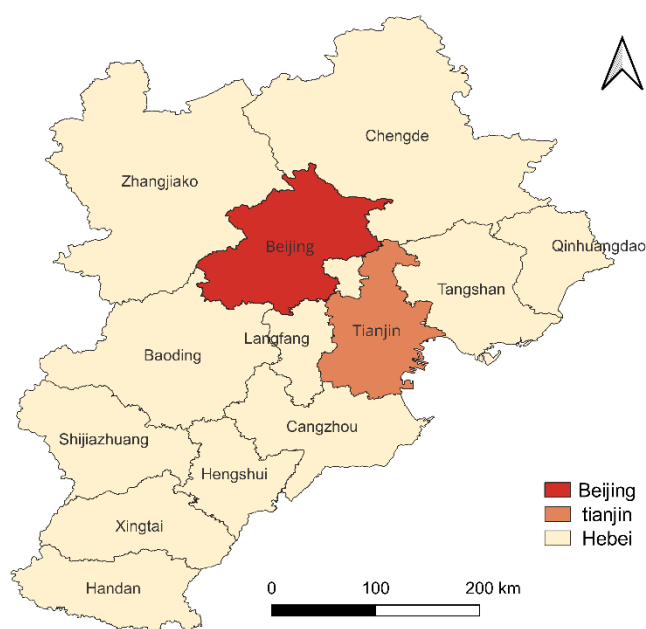


Fig.1 Overview of the Beijing-Tianjin-Hebei region

2.2. Data Sources and Methods

The monthly average data of pollutant concentrations in this study are derived from the monthly urban air quality report published by the Ministry of Ecology and Environment of the People's Republic of China from 2019 to 2021. The monthly average AQI of each city comes from the China Air Quality Online Monitoring and Analysis Platform (<https://www.aqistudy.cn/>). The concentration

limits of each pollutant refer to the Air Environmental Quality Standard (hereinafter referred to as the "Standard") (GB3095-2012), as shown in Table 1.

Tab.1 Limited concentrations of SO₂, NO₂, PM₁₀ and PM_{2.5}(second level)

Concentration limits/ $\mu\text{g}\cdot\text{m}^{-3}$	PM _{2.5}	PM ₁₀	SO ₂	NO ₂
Annual average	35	70	60	40
24h average	75	150	150	80
1h average	-	-	500	200

Based on the comprehensive pollution index method, this study evaluated the changes in air pollutants in Beijing, Tianjin and Shijiazhuang from 2019 to 2021. The comprehensive pollution index method refers to the calculation of the relative pollution index of various pollution indicators, and then derives a numerical value reflecting the degree of pollution. Based on each individual pollution index, a comprehensive pollution index can be obtained by summing. The size of the index can reflect the average and interannual changes of urban ambient air quality to a certain extent, and its calculation formula is (1, 2)

$$P = \sum_{i=1}^n P_i \quad (1)$$

$$P_i = \frac{C_i}{S_i} \quad (2)$$

them, P refers to the air pollution composite index; P_i refers to the sub-index of pollutant i; S_i refers to the concentration limit value specified in the environmental quality standard for pollutant i; C_i refers to the average annual or monthly mass concentration of pollutant i; n refers to the total number of indicators included in the air pollution composite index. The pollution load factor F reflects the contribution rate of each pollutant to the overall air pollution level^[12], which is calculated as (3)

$$F = \frac{P_i}{P} \quad (3)$$

3. Results and analysis

3.1. Time variation of the concentration of each pollutant

2.1.1 The interannual variation of the concentration of each pollutant

The comprehensive air pollution index of the Beijing-Tianjin-Hebei region from 2019 to 2021 is shown in Table 2, and the analysis results show that the annual average concentration of air pollutants in the Beijing-Tianjin-Hebei region from 2019 to 2021 shows a downward trend year by year, and the air quality has improved, PM_{2.5}, PM₁₀, SO₂, NO₂. The annual average concentrations decreased by 23.72%, 19.28%, 34.28% and 24.03%, respectively. Among them, the average values of PM_{2.5} concentrations in each year in the region were 52.22 $\mu\text{g}/\text{m}^3$, 48.22 $\mu\text{g}/\text{m}^3$ and 39.83 $\mu\text{g}/\text{m}^3$, respectively, which were the secondary concentration limits (35 $\mu\text{g}/\text{m}^3$) specified in the "standard" 1.14 times to 1.49 times, indicating that the PM_{2.5} pollution in the area is more serious. The average PM₁₀ concentrations in each year were 87.92 $\mu\text{g}/\text{m}^3$, 75.75 $\mu\text{g}/\text{m}^3$ and 70.97 $\mu\text{g}/\text{m}^3$, respectively, all of which exceeded the secondary concentration limits (70 $\mu\text{g}/\text{m}^3$) specified in the "standard", indicating that PM₁₀ pollution in the area is more prominent. The average SO₂ concentrations in each year were 10.53 $\mu\text{g}/\text{m}^3$, 8.17 $\mu\text{g}/\text{m}^3$ and 6.92 $\mu\text{g}/\text{m}^3$, respectively, which were only the secondary concentration limits (60 $\mu\text{g}/\text{m}^3$) specified in the "standard" 11.5% to 17.6%, indicating that the area is less polluted by SO₂. The average NO₂ concentrations in each year were 41.61 $\mu\text{g}/\text{m}^3$, 36.47 $\mu\text{g}/\text{m}^3$, and 31.61 $\mu\text{g}/\text{m}^3$, respectively, and NO₂ within 3 years. The average concentration was 36.56 $\mu\text{g}/\text{m}^3$, which was slightly lower than the secondary concentration limit (40 $\mu\text{g}/\text{m}^3$) specified in the "standard", indicating that there is still a large room for NO₂ pollution in the air in the region.

Tab. 2 Comprehensive air pollution index of Beijing-Tianjin-Hebei region from 2019 to 2021

city	year	contaminant	Average annual concentration $/\mu\text{g}\cdot\text{m}^{-3}$	Concentration limits $/\mu\text{g}\cdot\text{m}^{-3}$	P_i	P
Beijing	2019	PM _{2.5}	41.92	35	1.20	3.15
		PM ₁₀	67.67	70	0.97	
		SO ₂	4.33	60	0.07	
		NO ₂	36.67	40	0.92	
	2020	PM _{2.5}	38.17	35	1.09	2.70
		PM ₁₀	57.00	70	0.81	
		SO ₂	3.75	60	0.06	
		NO ₂	29.25	40	0.73	
	2021	PM _{2.5}	33.42	35	0.95	2.45
		PM ₁₀	55.58	70	0.79	
		SO ₂	3.08	60	0.05	
		NO ₂	26.00	40	0.65	
Tianjin	2019	PM _{2.5}	51.17	35	1.46	3.79
		PM ₁₀	76.42	70	1.09	
		SO ₂	10.83	60	0.18	
		NO ₂	42.17	40	1.05	
	2020	PM _{2.5}	48.17	35	1.38	3.46
		PM ₁₀	67.67	70	0.97	
		SO ₂	8.42	60	0.14	
		NO ₂	39.17	40	0.98	
	2021	PM _{2.5}	39.58	35	1.13	3.20
		PM ₁₀	70.17	70	1.00	
		SO ₂	8.50	60	0.14	
		NO ₂	37.17	40	0.93	
Shijiazhuang	2019	PM _{2.5}	63.58	35	1.82	4.95
		PM ₁₀	119.67	70	1.71	
		SO ₂	16.42	60	0.27	
		NO ₂	46.00	40	1.15	
	2020	PM _{2.5}	58.33	35	1.67	4.36
		PM ₁₀	102.58	70	1.47	
		SO ₂	12.33	60	0.21	
		NO ₂	41.00	40	1.03	
	2021	PM _{2.5}	46.50	35	1.33	3.52
		PM ₁₀	87.17	70	1.25	
		SO ₂	9.17	60	0.15	
		NO ₂	31.67	40	0.79	

2.1.2 Seasonal variation of the concentration of each pollutant

Figures 2-5 are the changes in the average concentrations of PM_{2.5}, PM₁₀, SO₂ and NO₂ from 2019 to 2021 in three typical cities in the Beijing-Tianjin-Hebei region. The results show that the monthly average change trend of PM_{2.5} and PM₁₀ concentrations in the Beijing-Tianjin-Hebei region from 2019 to 2021 is roughly "U" shaped. Winter (December to February) respirable particulate matter concentration is higher, and often appear the maximum of the year, spring (March to May) occasionally appear local peak, summer (June to August) is low, there are obvious seasonal distribution characteristics, following the "high winter, low summer, autumn rise and fall" change

law. The seasonal changes in SO_2 concentration are characterized by the highest in winter, similar in spring and autumn, and lowest in summer. The change of NO_2 concentration is characterized by the highest in autumn, similar in spring and winter, and lowest in summer.

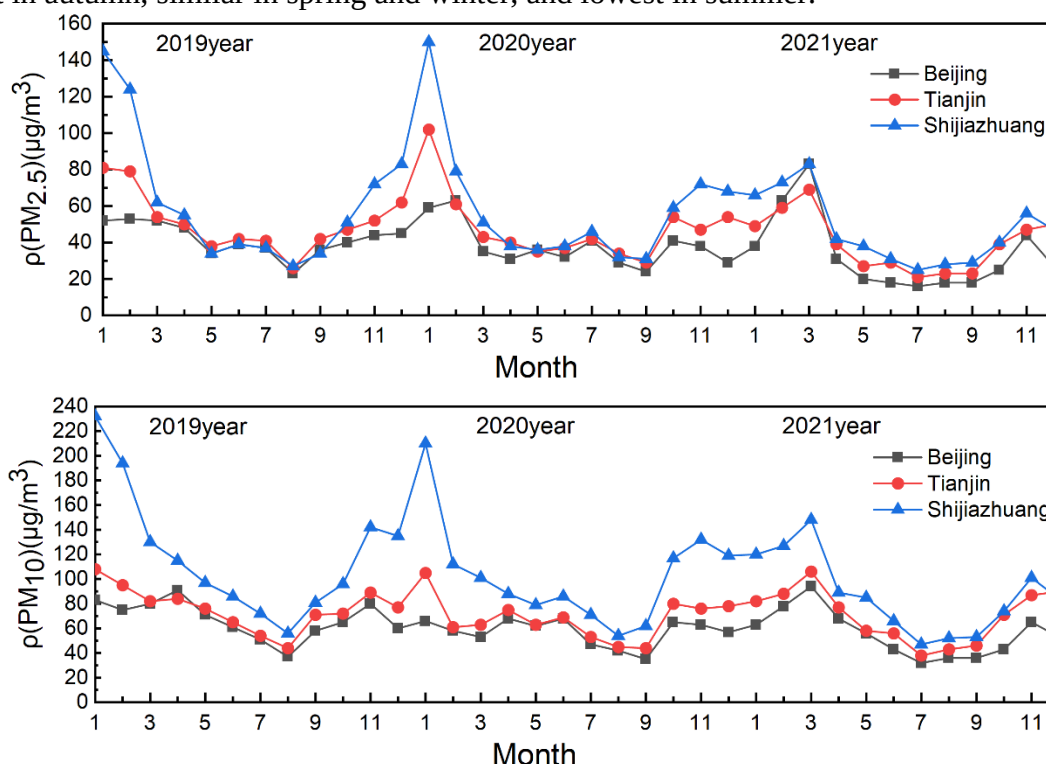


Fig.3 Variation curve of average PM_{10} concentration from 2019 to 2021

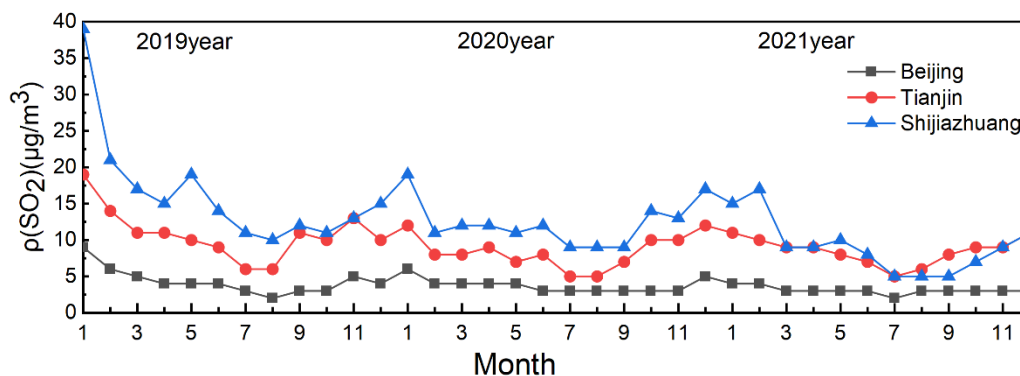


Fig. 4 Variation curve of average SO_2 concentration from 2019 to 2021

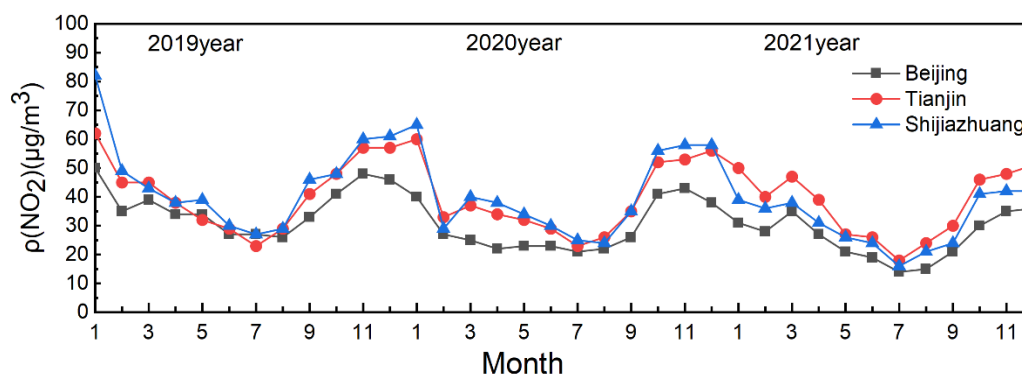


Fig. 5 Variation curve of average NO_2 concentration from 2019 to 2021

3.2. Trends in air pollutants

2.2.1 Comprehensive air pollution index

In this study, the comprehensive air pollution index method was used to apply $PM_{2.5}$, PM_{10} , SO_2 and NO_2 to three typical cities in the Beijing-Tianjin-Hebei region. The pollution indexes of the four pollutants were calculated and summed separately to obtain the comprehensive air pollution index, as shown in Table 3. The results show that from 2019 to 2021 (Beijing-Tianjin-Hebei region), the comprehensive air pollution index is 3.96, 3.42 and 3.06, respectively, showing a decreasing trend year by year.

2.2.2 Air pollution load factor

The air pollution load factors of three typical cities in the Beijing-Tianjin-Hebei region from 2019 to 2021 are shown in Table 3. The average pollution load coefficients of four pollutants, including $PM_{2.5}$, PM_{10} , SO_2 and NO_2 , were 38.18%, 31.64%, 3.84% and 26.34%, respectively, in three years. It can be seen that load factors of $PM_{2.5}$ and PM_{10} are much higher than those of SO_2 and NO_2 , indicating that the air pollutants in the Beijing-Tianjin-Hebei region are based on $PM_{2.5}$ and PM_{10} is the mainstay, of which $PM_{2.5}$ has the largest pollution load, and the impact of PM_{10} , NO_2 and SO_2 on air quality is reduced in turn.

Tab.3 Air pollution load coefficients in the Beijing-Tianjin-Hebei region from 2019 to 2021

city	year	$PM_{2.5}$	PM_{10}	SO_2	NO_2
Beijing	2019	0.38	0.31	0.02	0.29
	2020	0.40	0.30	0.02	0.27
	2021	0.39	0.32	0.02	0.27
	average value	0.39	0.31	0.02	0.28
Tianjin	2019	0.39	0.29	0.05	0.28
	2020	0.40	0.28	0.04	0.28
	2021	0.35	0.31	0.04	0.29
	average value	0.38	0.29	0.04	0.28
Shijiazhuang	2019	0.37	0.35	0.06	0.23
	2020	0.38	0.34	0.05	0.23
	2021	0.38	0.35	0.04	0.23
	average value	0.38	0.35	0.05	0.23

2.2.3 AQI Index Trend

The value of AQI (Air Quality Index) reflects the ambient air quality and pollution level, the higher the value of AQI, the worse the ambient air quality and the more serious the degree of pollution. The AQI index change trend of the three typical cities in the Beijing-Tianjin-Hebei region from 2019 to 2021 is shown in Figure 6, which shows that the AQI change trend of each city is similar to the change trend of each air pollutant. There are significant seasonal distribution characteristics, and they also follow the change law of "high winter and low summer, autumn rise and spring fall". From the annual average size of AQI from 2019 to 2021 in the three typical cities, the annual AQI size is 2019 (100.19), 2020 (90.64), 2021 (81.09), and in 2021, it decreased by 19.06% compared with the average AQI in 2019, indicating that the air pollution in the study area has gradually decreased in the past three years.

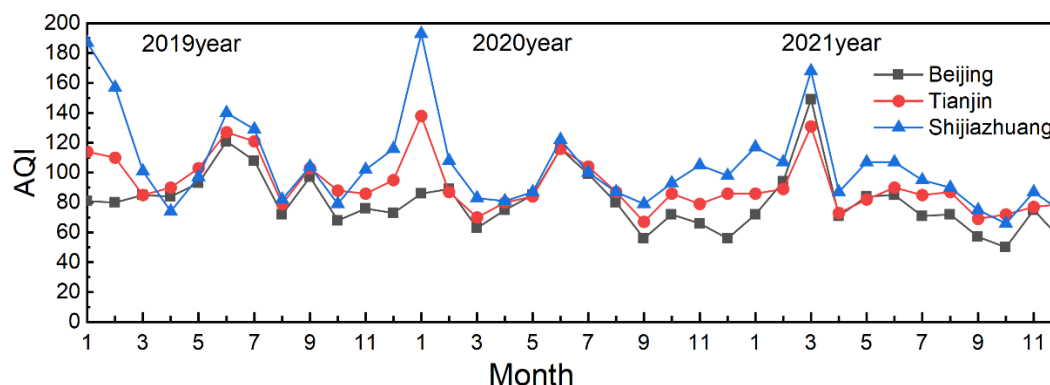


Fig. 6 Monthly AQI average change curve from 2019 to 2021

Scholars have conducted a certain degree of research on the air quality in the Beijing-Tianjin-Hebei region. Li Hui et al^[13] studied the characteristics and influencing factors of air quality in Beijing-Tianjin-Hebei and surrounding areas, and the results showed that PM_{2.5}, PM₁₀, SO₂ and NO₂ in "2+26" cities from 2013 to 2019 and other pollutant concentrations decrease significantly. This is related to the measures in the "Air Pollution Prevention and Control Action Plan" promulgated by the state in 2013 to accelerate the construction of desulfurization, denitrification, dust removal renovation projects in key industries, and accelerate the elimination of old vehicles^[14]. Cheng Xueyan et al^[15] explored the spatio-temporal variation characteristics of air pollution in the Beijing-Tianjin-Hebei region from 2015 to 2018, and the results showed that the main pollutant in the study area was PM_{2.5}, followed by PM₁₀. And the seasonal change trend of each air pollutant concentration basically shows a "U-shaped" distribution of "high autumn and winter, low spring and summer". The above-mentioned scholars' conclusions on the interannual and intra-annual variation trends of atmospheric pollutants in the Beijing-Tianjin-Hebei region and the determination of major pollutants are consistent with this study. However, there are limitations to the comprehensive analysis of a variety of air pollutants. Therefore, this study explores the timing change characteristics of various air pollutants, and comprehensively analyzes various air pollutants in combination with AQI index. This study has certain guiding significance for understanding the long-term air quality changes in the Beijing-Tianjin-Hebei region.

The Beijing-Tianjin-Hebei region has always been a key prevention and control area for air pollution in China. Since 2018, the state has successively issued policies such as the Action Plan for the Comprehensive Control of Air Pollution in the Autumn and Winter of 2018-2019 in Beijing-Tianjin-Hebei and Surrounding Areas, and the Action Plan for the Comprehensive Control of Air Pollution in the Autumn and Winter of 2020-2021 in the Beijing-Tianjin-Hebei and Surrounding Areas and the Fenwei Plain. Local governments have comprehensively promoted clean heating methods such as "coal to gas" and "coal to electricity", reducing the use of loose coal in the heating season from the source, further reducing the proportion of coal in primary energy consumption in the region, and reducing PM_{2.5} and PM₁₀ emissions^[16]. With the implementation of a series of measures to reduce coal burning, the annual average concentration of SO₂ in the Beijing-Tianjin-Hebei region has continued to decrease, among which the average concentration of SO₂ in Beijing in 2021 has dropped to a very low 3.08 µg/m³, which fully supports the remarkable results achieved in coal pollution control in the region. Since 2019, with the gradual transformation of fuel vehicles in the Beijing-Tianjin-Hebei region, the accelerated elimination of old vehicles and the vigorous development of new energy vehicles, the annual average concentration of NO₂ has maintained a steady downward trend, marking that the pollution control of road traffic mobile sources has achieved great results.

So far, although the air quality in the Beijing-Tianjin-Hebei region is in the context of overall improvement, the current reduction of major air pollutants is still lower than the need to basically eliminate the continuous heavy pollution weather in the region^[17]. Under the comprehensive treatment of air pollution by the local government for many years, the Beijing-Tianjin-Hebei region

has begun to enter a tough period of air pollution prevention and control, and the space for reducing pollutant emissions has gradually narrowed, the difficulty of governance has increased, and the relevant contradictions have deepened^[18]. It is recommended that the region carry out a series of comprehensive air pollution control actions in the long term, with a view to achieving the goal of improving air quality in the 14th Five-Year Plan.

4. Conclusions and outlook

4.1. Main Conclusions

Based on the urban air quality data published by the Ministry of Ecology and Environment and the online monitoring and analysis platform of air quality, this study analyzes the time change of air pollutant concentration and the degree of influence of each pollutant on air quality in the Beijing-Tianjin-Hebei region by using the comprehensive pollution index method and the pollution load factor method, and the main conclusions are as follows:

(1) The ambient air quality in the Beijing-Tianjin-Hebei region will improve as a whole from 2019 to 2021. The average concentrations of $PM_{2.5}$, PM_{10} , SO_2 and NO_2 all showed a downward trend, and the concentrations in 2021 decreased by 23.72%, 19.28%, 34.28% and 24.03% respectively compared with 2019. The changes in the air pollution index and the AQI index also show a downward trend year by year.

(2) The seasonal variation of air pollution in the Beijing-Tianjin-Hebei region is significant. From 2019 to 2021, the monthly average change of the concentration of each pollutant was roughly "U" shaped, following the change law of "high winter, low summer, autumn rise and spring descent".

(3) The average pollution load coefficients of four pollutants in the Beijing-Tianjin-Hebei region, including $PM_{2.5}$, PM_{10} , SO_2 and NO_2 , were 38.18%, 31.64%, 3.84% and 26.34%, respectively, from 2019 to 2021. It indicates that the ambient air quality in this area is greatly affected by particulate matter pollution.

4.2. Outlook

(1) This study only uses the static monitoring values of three typical cities of Beijing, Tianjin and Shijiazhuang to represent the entire Beijing-Tianjin-Hebei region. In the future, remote sensing data can be combined with the analysis of the spatio-temporal variation characteristics of air pollutant concentrations in the region.

(2) This study only analyzed four kinds of indicators such as $PM_{2.5}$, PM_{10} , SO_2 and NO_2 among the six conventional air pollutants. In future studies, we can consider supplementing the two indicators of CO and O_3 -8h to conduct a more comprehensive and comprehensive study.

(3) This study only analyzes the time series changes of air pollutants in the Beijing-Tianjin-Hebei region from 2019 to 2021, and the time scale is relatively short. In the future, longer-term pollutant concentration data should be selected for analysis to increase the scientific nature of the research.

(4) It is recommended to set air pollutant concentration limits strictly below the national standard in the Beijing-Tianjin-Hebei region with a view to further improving the air pollution situation in the region.

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