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Relationship between Meteorological Factors and Diffusion of Atmospheric Pollutants

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In order to explore the influence of meteorological conditions on the diffusion of atmospheric pollutants, this study takes Linfen City, a key national air pollution city, as an example, and uses the daily air pollution concentration data, wind direction and wind speed observation data and the ground weather observation data from 2016 to 2017 in this area to analyze the distribution characteristic and variation law of the main atmospheric pollutants (PM_{10}, $PM_{2.5}$, SO_2, CO, O_3, NO_2). The influence of local meteorological conditions and general atmospheric circulation on the diffusion of atmospheric pollutants is discussed. The results show that the air pollution in Linfen City has obvious seasonal difference. The air quality is better in summer and autumn, and the main pollution is concentrated in heating period. The effect of meteorological factors on air quality index (AQI) is significantly different at different periods. In the non-heating period, there is a good negative correlation between precipitation and $PM_{2.5}$, PM_{10}, SO_2 and NO_2; the relative humidity, air temperature and cloud cover are negatively correlated with most pollution factors. In the heating period, the air temperature, relative humidity and cloud cover are positively correlated with most pollution factors. The wind speed is less correlated with AQI in the non-heating period, and only has a good negative correlation with NO_2. In the heating period, the wind speed is negatively correlated with pollution factors except O_3.

1. Introduction

Along with the development of social economy, people raise higher and higher requirements for living environment, and urban air pollution has gradually become a hot issue which government departments and the public pay close attention to (Fernando et al., 2013; Panday et al., 2012). In recent years, air pollution is serious in Linfen, which has received the social attention for many times and has produced serious influence on the local economic development and people's daily life. Compared with the previous few years, the situation is slightly improved, but it is still very severe. Many studies (He et al., 2016; Zhou and Liang, 2013) have shown that in addition to the level of pollutant emission, air pollution is closely related to meteorological factors and general atmospheric circulation, and the change of general atmospheric circulation is one of the important driving factors for the fluctuation of meteorological factors in some area (Wang and Tian, 2018). The seasonal differences in location and intensity of semi-permanent atmospheric activity centers affect regional air temperature and indirectly affect regional atmospheric environment and climate system (Bandyopadhyay and Chattopadhyay, 2007). Under the background of global warming, air temperature rises, wind speed decreases and rain day increases. The influence of these changes on the diffusion of pollutants is a scientific issue to be studied (Mao, 2018).
The researches on air pollution prediction in many developed countries started in the 1960s. In the early 1960s, air pollution potential forecast was carried out in the United States. Since the 1990s, many provinces in China have carried out a series of studies on the relationship between meteorological conditions and air pollution, and have made relative outstanding achievements. Zhang et al. (2012) studied the effect of the circulation feature on the air quality in Beijing by using the principal component analysis (PCA) method, and pointed out that the circulation feature was the main driving factor for the daily variation of pollutant concentration in Beijing. Wang et al. (2009) used a multivariate linear regression (MLR) model to study the

causes of change in PM_{10} concentration in Beijing during the 2008 Olympic Games, pointing out that 40% of the change was related to meteorological conditions and 16% was related to the control of emission sources. Through observation data of wind direction and wind speed and NCEP / NCAR re-analysis of global atmospheric circulation, Zhou analyzed the variation characteristics of PM10 concentration in autumn in Shanghai and its relationship with wind direction and wind speed. Local meteorological conditions caused by landform that are not conducive to the spread of pollutants are the main cause of severe air pollution in valley cities (Hu et al., 2013). However, the influence of meteorological conditions and pollutant emission in different regions and seasons on urban air quality is different (Roustan et al., 2011). A deep analysis of the influence factors of urban air quality can not only deepen the understanding of the cause of air pollution, but also provide scientific basis for urban air pollution control and its effect evaluation.

For many years, Linfen has been one of the key polluted cities in China. There are few researches on it because of its relatively small area. In order to study the change features of air pollution in Linfen and the influence of climate conditions on the diffusion of pollutants, this study starts with weather, general atmospheric circulation, landform and industrial structure, and uses the daily variation data of air pollutant concentration and the ground meteorological data of Linfen City from 2016 to 2017 to analyze the change trend of Linfen air pollution index and variation characteristics of PM_{10}, $PM_{2.5}$, SO_2 and NO_2 concentrations in the past two years. Then this study explores the influence of meteorological factors on the diffusion of pollutant concentration, providing scientific basis for the prevention and control of air pollution in Linfen.

2. Materials and research methods

2.1 Survey of the research area

Linfen City is located in southwest Shanxi Province with geographical coordinates of N 35°23′-36°57′ and E 110°22′-112°34'. It is located in semi-arid and semi-humid monsoon climate area, belonging to temperate continental climate with distinct four seasons and warm and rain at the same time. Linfen is high in the north and low in the south, and is between Taihang Mountains and Lvliang Mountain. In the middle zone is Chingji Basin in the lower reaches of Fenhe River. The basin profile is long and narrow, and the space is closed, which provides favorable conditions for the development of the thermal inversion layer. The frequency of static wind is not large, which is very unfavorable for the diffusion of atmospheric pollutants and long-distance transportation. The atmospheric environmental capacity is small and easy to form pollution. Industrial engineering is the main industry of the city with coal, electric power, chemical industry, metallurgy, paper, machinery and other coal coke iron resource-based basic industries with high consumption and high pollution accounting for 90% of the city’s industrial economy. Human activities such as energy exploitation and fuel combustion make the environmental pressure of this area huge. Under the double catalysis of natural geographical environment and social and economic environment, the pollution of Linfen City has been very serious.

2.2 Data sources

The air quality monitoring data are the average value of the daily monitoring data of 6 automatic air quality monitoring stations in the whole year 2016 in Linfen City, and AQI selects the average value of the monitoring data. $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2 are 24-hour average values of each pollutant, and O_3 air pollutant concentration is an 8-hour sliding average value. The above data are from the national urban air quality real-time release platform (http: / /106. 37. 208. 233: 20035 /). The meteorological observation data of the same period come from the national basic meteorological station. The meteorological elements in this study mainly include average air temperature, maximum air temperature, minimum air temperature, relative humidity, precipitation, average wind speed and maximum wind speed.

2.3 Main research methods

(1) Evaluation factors: SO_2, NO_2, PM_{10}, CO, O_3 and $PM_{2.5}$.

(2) Evaluation method, AQI is obtained by calculating individual air quality index (IAQI), which reflects the situation of air quality in Linfen City. AQI is a numerical value for quantitatively describing the air quality level, and is a dimensionless number with a value ranging from 0 to 500.

Table 1: Grading technical index of AQI

Category of AQI	Excellent	Good	Mild pollution	Moderate pollution	Severe pollution	Heavily severe pollution
Grade of AQI	Grade I	Grade II	Grade III	Grade IV	Grade V	Grade VI
AQI	0~50	51~100	101~150	151~200	201~300	>300

(3) Multivariate statistical analysis: Normal distribution analysis is carried out by using SPSS software and Pearson correlation. Based on the Environmental Air Quality Standard (GB3095-2012), the air quality of Linfen City from 2016 to 2017 is evaluated.

3. Analysis of result

3.1 Air quality situation

(1) Analysis of the characteristics of air pollution

In 2016, there were many excellent air quality days in Linfen City, with 261 days in the whole year, accounting for 71%. By 2017, the air quality days in Linfen significantly reduced, with a total of 12 days. Moderate and mild pollution days increased significantly, and the proportion of excellent-grade days dropped from 14% to 4%, and the number of mild and moderate pollution days in 2016 was 40 days and 17 days respectively, accounting for 16% of the total number of days in the whole year. The number of severe pollution and heavily severe pollution days accounts for 6% and 7% of the total number of days in the while year. In 2017, compared with 2016, the number of days of mild pollution increased significantly from 11% in 2016 to 36% in 2017, and the number of severe and heavily severe pollution days decreased slightly to 5% compared with the previous year. As a whole, the air pollution in Linfen increased in recent two years.

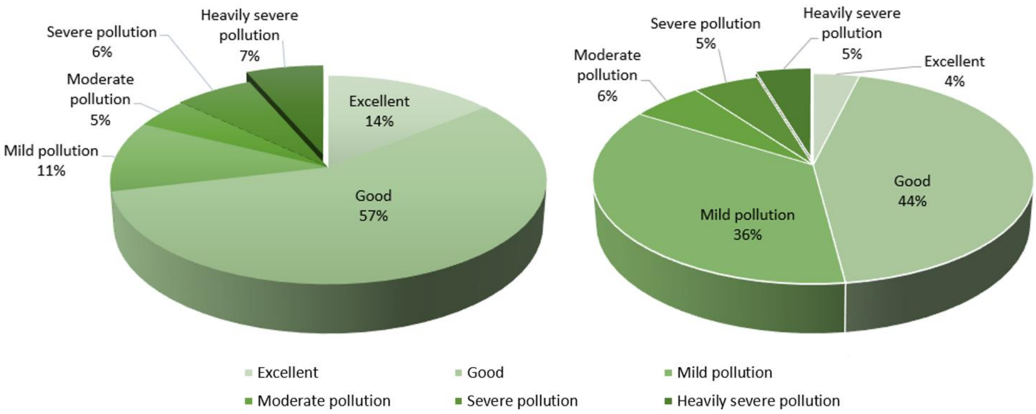

Figure 1: Number of days and proportions of different levels of AQI in Linfen City during 2015-2016

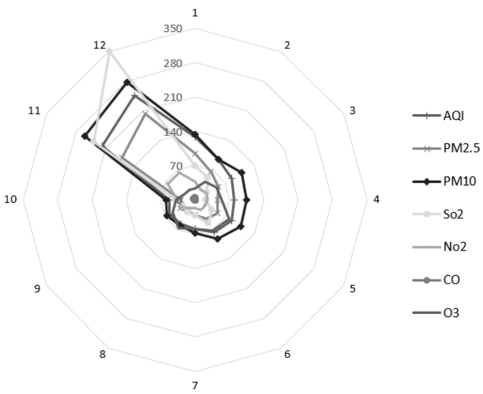

Figure 2: The evolution trend of air pollution of Linfen in 2016

(2) Characteristics of monthly variation of air pollutant concentration

The change trend of concentration of AQI, $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO and O_3 in Linfen City in 2016 is shown in Figure 2 above. The monthly trend of AQI, $PM_{2.5}$ and PM_{10} is basically the same, and reaches peak values in November and December. It can be seen the figure that the seasonality of SO_2 pollution is very obvious, and the high concentration is mainly concentrated in winter. The concentration of SO_2 seriously exceeds the standard in December, and the 24-hour maximum average concentration is 858 μg/m3, which is 4.7 times of Grade II standard. SO_2 exceeds the standard mainly at the end of autumn and winter, and the concentration of other seasons is generally low. From comparing the pollutant conditions of each pollutant in Figure 2, it is also shown that the variation characteristics of pollutants in the year are that the pollutant concentration is relatively low from March to October and the air quality is better in spring, summer and autumn. However, at the end of the autumn and winter from November to February, the concentration of pollutants is high and the air quality is poor, and the concentrations of $PM_{2.5}$, PM_{10} and SO_2 are the most obvious. This may reflect that the pollution situation in Linfen has a certain correlation with the seasonal variation of atmospheric activity or the seasonal evolution of general atmospheric circulation and the winter circulation is more unfavorable to the emission of pollutants.

3.2 Analysis of correlation between meteorological conditions and air pollutant concentration

The following table shows the correlation between air quality and meteorological factors during heating period and non-heating period. It can be seen from the table that the influence degree of meteorological conditions on 6 pollution factors at different times is not consistent and the difference is obvious. Thus, we can't simply summarize that the effect of a certain meteorological parameter on pollution is changeless. The effects of meteorological factors on air quality are discussed below.

Table 2: Correlation coefficients between IAQI and meteorological factors for different pollutants in Linfen

	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
Wind speed	.130	.030	.151*	-.046	-.303**	.077	.187**
Maximum air temperature	-.149*	-.126*	-.078	.177**	-.282**	-.221**	.528**
Minimum air temperature	-.203**	-.246**	-.242**	.134*	-.348**	-.362**	.393**
Precipitation	-.006	-.169**	-.205**	-.197**	-.230**	-.111	-.116
Relative humidity	-.066	-.124	-.284**	-.023	-.052	-.250**	-.401**
Total cloud cover	-.009	.003	.009	-.062	-.025	-.005	-.305**

Table 3: Correlation coefficients between IAQI and meteorological factors for different pollutants in Linfen

	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
Wind speed	-.618**	-.607**	-.612**	-.515**	-.681**	-.608**	.676**
Maximum air temperature	.364**	.332**	.409**	.277**	.445**	.121	-.055
Minimum air temperature	.425**	.403**	.456**	.320**	.498**	.097	-.183*
Precipitation	.018	.024	-.001	-.057	-.028	-.121	-.059
Relative humidity	.247**	.261**	.218*	.124	.201*	.157	-.351**
Total cloud cover	.227*	.225*	.220*	.129	.168	.056	-.212*

(1) Influence of precipitation on diffusion of pollutant concentration

During the non-heating period, precipitation has a good negative correlation with $PM_{2.5}$, PM_{10}, SO_2 and NO_2. Heavy rain is concentrated in this period, which can effectively reduce the concentration of these four pollutants in the air. In the heating period, there is little correlation between precipitation and AQI. The precipitation is generally less in winter. There were only 5 times of rainfall in the heating period in 2016, all of which were drizzle (0-0.9 mm) and light rain (1-9.9 mm). It has been found that the ability of different grades of precipitation to remove different pollutants is obviously different, and this level of precipitation has not only no cleaning effect on some pollutants, but also may increase the concentration of pollutants.

(2) Influence of wind speed on diffusion of pollutant concentration

In the non-heating period, the correlation between the wind speed and AQI is slightly poor, and only has a good negative correlation with NO2. The wind speed has a lag phenomenon to the air purification, especially when the turning weather occurs, as shown in Figure 3 from March 3 to March 17. When the wind speed is great, AQI is small on the next day. On March 9, the average wind speed reaches Grade IV, and the air quality on March 10 is excellent. When the wind speed on March 15 is Grade III, AQI of the next day is only 20, and the air quality is excellent.

In the heating period, the wind speed has a good negative correlation with AQI, $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO, and only has a positive correlation with O_3. The greater the wind speed is, the stronger the air mobility is, that is, the better the atmospheric diffusion condition is, which is more conducive to the diffusion and dilution of pollutants in the atmosphere and plays a significant role in changing air quality.

(3) Influence of air temperature on diffusion of pollutant concentration

During the non-heating period, the air temperature is negatively correlated with AQI and most of the indexes, which is consistent with the seasonal variation of air quality. The air temperature gradually rises from spring to summer and decreases from summer to autumn until winter, and the corresponding air quality gradually improves and reaches the best in summer but deteriorates gradually from summer to autumn, and becomes the worst in winter. In the heating period, the air temperature is positively correlated with AQI, and there is no significant correlation between AQI and air temperature in the continuous polluted weather (for example, November-December 2016). One of the main reasons is the increase of pollutants released by heating coals in winter and unfavorable topographic conditions. Two mountains and a river shape into a basin so that atmospheric pollutants are not easily diffused, and the air temperature is relatively high and the variation range is not large during this period, which is liable to cause haze.

(4) Influence of relative humidity and cloud cover on Diffusion of pollutant concentration

In non-heating period, there is a good negative correlation between relative humidity and PM10, CO and O3, and cloud cover only has a good negative correlation with O_3. During heating period, total cloud cover is positively correlated with AQI, $PM_{2.5}$, PM_{10}, and negatively correlated with O_3.

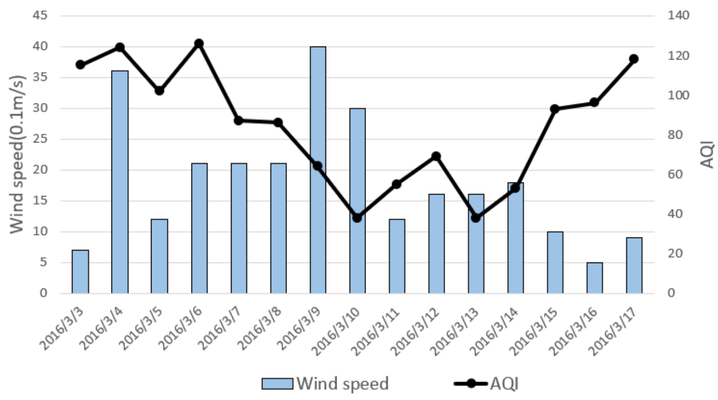

Figure 3: Changes of wind speed and AQI from March 3, 2016 to March 17, 2016

3.3 Influence of landform on diffusion of atmospheric pollutant

Linfen City is located in the middle of the basin, with Taiyue and Lvliang mountains ridging on both east and west sides, like an upright high wall. Such a landform easily generates microclimate, such as landform temperature inversion, valley wind and urban heat island effect. Linfen basin has the special topography in “multi” shape in north-south direction and the dominant wind direction in the whole year is northeaster followed by southwester, which results in strong landform temperature inversion. When the north wind low-altitude air flow enters the basin, it is blocked by the eastern mountain and turns back and wanders in the basin. When the low-altitude air flow of the southwest yellow river canyon and the south enters the basin, it also returns to the basin after being blocked by the mountains. Due to the restriction of landform, the two main air flows form a local wind field in the middle of the basin, so the pollutants in Linfen urban area, suburban area and the mining area will form closed circulation with the specially formed local wind field of valley wind in Linfen City, making it difficult for the pollutants to spread everywhere in the basin. In the urban area, the static wind frequency is as high as 48% and the temperature inversion frequency is as high as 30%, which is not conducive to the vertical diffusion and horizontal transport of pollutants and stays in the basin, and the adverse air pollution diffusion conditions lead to serious air pollution.

4. Conclusions and suggestions

(1) The air quality of Linfen is mainly good and mild pollution. In 2016, the number of days of excellent and good air quality in Linfen was 52 and 209, accounting for 14% and 57% of the whole year. The excellent and good rate was 71%, and the days of severe pollution and heavily severe pollution accounted for 6% and 7% of the total number of days in a year.

(2) $PM_{2.5}$ and PM_{10} are the main pollutants in Linfen City with the largest occurrence days. AQI is basically in line with the monthly change trend of $PM_{2.5}$ and PM_{10}, reaching the peak values in November and December. The change of AQI and the concentrations of SO_2, PM_{10}, NO_2 and other pollutants in Linfen City show remarkable seasonality, which can be divided into heating period (November-March) and non-heating period (April-October). Air pollution during heating period is more serious while air quality is better in summer and autumn. Coal heating is the direct cause of high AQI in winter.

(3) There is significant difference in the meteorological factors affecting AQI between heating and non-heating periods. Among them, the meteorological factors that have significant influence on AQI include wind speed, relative humidity and cloud cover during heating period. The influence of air temperature on AQI during

heating period is reflected by influencing the amount of burnt coal. However, in the non-heating period, temperature, precipitation, wind speed and relative humidity are the major meteorological factors affecting the air quality.

(4) Wind and turbulence have a certain diffusion effect on atmospheric pollutants, but the geographical environment of Linfen City makes wind and turbulence not to effectively exert their diffusion effect. The pollutants in downtown, suburb and mining area will form closed circulation with the specially formed local wind field of valley wind in Linfen City, making it difficult for the pollutants to spread everywhere in the basin and deteriorate the air environment quality in Linfen City.

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