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Impacts of meteorological conditions on $PM_{2.5}$ and PM_{10} pollution in Zhengzhou, China

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Abstract. Meteorological conditions play an important role in aerosol pollution. In this study, the relationships between wind, temperature, relative humidity, and aerosol concentrations ($PM_{2.5}$ and PM_{10}) in Zhengzhou from January 2016 to December 2017 were analysed. Backward trajectory model was also used to investigate the relationship between meteorological parameters and regional transport of pollutants. Significant seasonal variations can be observed in the time series of pollutants and wind, temperature and relative humidity. The simulation of backward trajectories indicated that pollutants from southeast is critical to the air quality in Zhengzhou, in addition to local emissions of pollutants. To improve the air quality in Zhengzhou, joint efforts to reduce emissions in both Zhengzhou and its southeast adjacent regions should be considered.

1 Introduction

Zhengzhou is the provincial capital of Henan province and a national central city in the midlands of China. It is a densely populous city and a national integrated transport hub. Zhengzhou is also a centre of railway, aviation, electric power, post and telecommunication and a city with the only national airport economic comprehensive experimental zone. In February 2017, Zhengzhou became the National Central City and also the one of the core cities of the national development strategy "ecological conservation and high-quality development of the Yellow River Basin" in September 2019. With the important status of politics and economic radiation, the economic growth rate in Zhengzhou is rapid and the problem-deteriorating air pollution is heavy. A systematic analysis of aerosol pollutants and meteorological parameters is necessary to the prediction and consideration of mitigating air aerosol pollutants.

Located at the transition region between the middle and lower reaches of the Yellow River and the northeast wing of Funiu Mountains to the Huang Huai plain, the terrain in Zhengzhou is high in the West and low in the East, and four seasons are in distinct features. For a long time in the past, Zhengzhou's economic development has been based on industry, especially heavy industry. There are many coal mines and metallurgical plants in the southwest that have brought economic development while lead to serious pollution to the environment. In addition, the features of terrain of Zhengzhou make the aerosol pollutants in the southwest naturally diffuse to the urban area of Zhengzhou with atmosphere transport. If the diffusion conditions were not good, serious haze would occur in the urban area of Zhengzhou.

Zhengzhou is a coal-fired polluted city, followed by automobile exhaust pollution [1]. In addition, the dust caused by construction and barren areas are important factors developing serious PM_{10} pollution [2] and there is heavy secondary pollution of large particles in urban area [3]. In recent years, due to the orientation of economic construction and industrial development in Zhengzhou, the reasons and source geographical area of heavy pollution have changed [4][5].

Based on the requirement of prevention and control of air pollution in Zhengzhou in the new internal and external industrial environment, it is necessary to investigate the relationship between the meteorological factors and the regional transport of air pollutants [6]. In this study, a systematic analysis and different correlations between meteorological parameters including vector wind, temperature and relative humidity and air pollutants ($PM_{2.5}$ and PM_{10}) in a period which has typical characteristics from January 2016 to December 2017 in Zhengzhou was conducted. Numerical simulation method was also used to provide the relationship between meteorological parameters and regional transport of pollutants [7].

2 Methods and data

The daily concentrations of $PM_{2.5}$ and PM_{10} as well as hourly meteorological parameters between January 2016 and December 2017 were included in the study. There are 9 air quality monitories in Zhengzhou which have been used to measure and record the concentrations of $PM_{2.5}$ and PM_{10} 24 times a day (once an hour in 00-23h universal time) and all operated by China National Environmental Monitoring Centre. The location and distribution were in Table 1 and Figure 1. In terms of

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geographical location, No.1 and No.5 monitoring stations are far away from the monitoring core area which can be used as the background stations for data monitoring. When calculating the concentration of pollutants in the Zhengzhou, the data of the remaining seven monitoring stations were collected.

Table 1. Location of 9 air quality monitoring stations in Zhengzhou.

NO.	latitude (N)	longitude (E)
1	34.9089	113.6228
2	34.7472	113.6374
3	34.7534	113.6449
4	34.7274	113.7493
5	34.8587	113.6795
6	34.7766	113.7451
7	34.7408	113.681
8	34.7287	113.6393
9	34.7712	113.6512

Figure 1. Distribution of air quality monitoring stations in Zhengzhou.

Meteorological parameters including wind speed, wind direction, temperature and relative humidity were selected from China Meteorological Administration. All the meteorological parameters were measured and recorded 24 times per day in the meteorological information comprehensive analysis and processing system with embedded technology to record the data in real-time.

Before calculating the average concentrations and the meteorological parameters in hour from all the sites, a check was conducted to remove problematic data points. If the number of valid data was more than 20 per day, the daily average pollutants concentration and meteorological parameters were calculated as valid daily data, or the daily average data is recorded as invalid recording. The daily average is obtained by arithmetic average of 24-hour data of concentrations of pollutants and meteorological parameters, in which the wind speed is the vector averaging. The correlation between the concentration of pollutants and meteorological parameters was calculated by Spearman-Rank correlation analysis [6].

HYSPLIT (hybrid single particle lagrangian integrated trajectory) model which was developed and maintained by National Oceanic and Atmospheric Administration (NOAA) was introduced to investigate the relationship between large-scale meteorological factors and aerosol pollutants transport path. It was mainly used to simulate the transport and diffusion process of air pollutants in this study [7]. HYSPLIT was used to track the backward trajectory by setting the starting point of the trajectory as the centre of Zhengzhou, and the starting height was 100m. HYSPLIT model calculated the trajectory backtracking at 20 o'clock every day, and each trajectory was tracked for 24 hours to investigate the transport paths of main pollutants outside of the core area.

3 Results and discussions

3.1 Data overview

The days that the concentration of pollutants was exceeding the National Standard Level of Daily Concentration (GradeII), as well as the average, minimum, median and maximum average concentrations of $PM_{2.5}$, PM_{10} were calculated in Table 2, and also the average of vector speed of wind, temperature and relative humidity in Zhengzhou from January 2016 to December 2017. According to the statistical summary, the days that the concentration of pollutants which exceeding the standard in Zhengzhou were 225 (31%) and 248 (34%) respectively, and the daily average concentration of $PM_{2.5}$ and PM_{10} were 73.3 and 145.7 μg / m^3, which were 2.09 and 2.08 times of the data in national standard (35μg/m^3 ,70μg/m^3). The average concentrations of $PM_{2.5}$ and PM_{10} were 73.3 and 145.7, which were very close to the values in national standard (75 μg/m^3 ,150μg/m^3). It was indicated that heavy $PM_{2.5}$ and PM_{10} pollution in Zhengzhou were relatively needed to be considering.

Table 2. Statistical summary of the daily average of meteorological parameters of wind speed (WS, m/s), temperature (T, °C), relative humidity (RH, %) and concentration of pollutants (January 2016-December 2017). Units: μg/m^3 for $PM_{2.5}$ and PM_{10};

	$PM_{2.5}$	PM_{10}	WS	T	RH
Standard Level	75	150	-	-	-
Exceeding the standard	225	248	-	-	-
Total days	731	731	731	731	731
Average	73.3	145.7	1.4	17	55.6
Minimum	12.9	20.8	0.1	-5.2	9.4
Median	55.2	123.2	1.3	17.2	54.9
Maximum	592.4	694.8	5.6	34	99.2

Both the meteorological parameters and the concentration of $PM_{2.5}$ and PM_{10} pollutants have significant seasonal variations, implying that the changes of meteorological conditions are critical to the air quality in Zhengzhou [8]. Figure 2 was used to explain the variations of the average concentrations of aerosol pollutants and meteorological parameters in different seasons in the form of box diagram. It can be observed in the figure that the concentrations of $PM_{2.5}$ and PM_{10} pollutants in winter were much higher and having wider spectrum than that in other seasons, followed by spring and fall, and with low abundances in summer. Successively, similar seasonal variation was observed for two kinds of air pollutants. Compared with other seasons, the wind speed in autumn was generally lower in the maximum value and range span. Relative humidity in summer was the highest, and the range of relative humidity in autumn and winter was wide, bfut the high value of relative humidity in autumn was more than that in winter, and the median value of relative humidity in spring was the lowest. Averages of daily temperature was generally higher in summer than that in spring and autumn, and the lowest in winter.

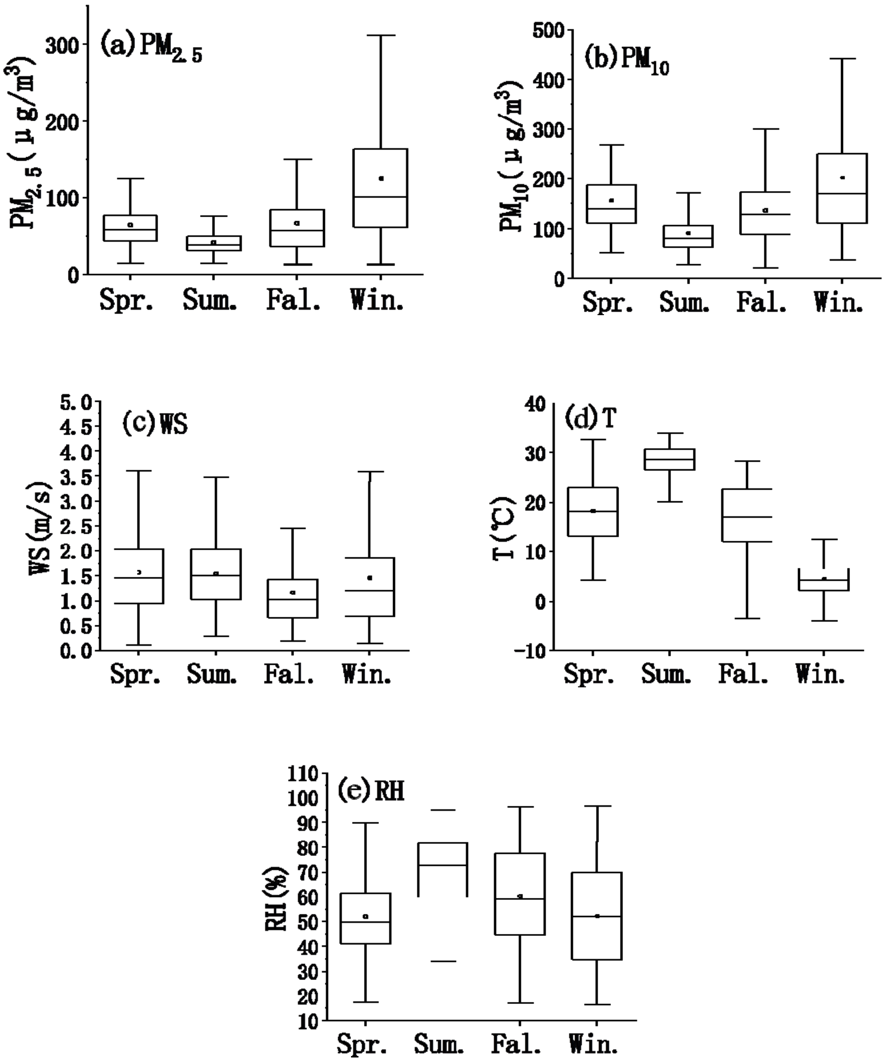

Figure 2. seasonal variations of average concentrations of $PM_{2.5}$, PM_{10} and meteorological parameters

3.2 Correction between meteorological parameters and $PM_{2.5}$ and PM_{10}

As seasonal characteristics were observed in both meteorological parameters and air pollutants, Spearman-Rank correction coefficient shown in Table 3 was quantified for relationship between meteorological factors and pollutants. Ulteriorly, the monthly average in 24 months (from January 2016 to December 2017, 1-24 months) variations of the two pollutants with meteorological parameters including wind speed (WS), temperature (T), humidity (RH) were all calculated in Figure 3.

As the 24 months was classified in seasons (every 12 months in a year with seasonal categories), concentrations of PM2.5 and PM10 were highest in winter when the average of wind speed relatively low, and the aerosol pollution in autumn and winter was significantly worse than in spring and summer. However, in the period of strong wind speed, concentrations of

PM2.5 and PM10 were analysed to a significant negative correlation with wind speed. Except in the case of slight fluctuation in autumn and spring, the concentration of PM2.5 had an obvious negative correlation with temperature, and concentration of PM10 fluctuated more than PM2.5 in the period of relatively stable temperature change.

Although the relative humidity had obvious seasonal variation, the variation was slightly different in different years. In the period of high relative humidity in summer, PM2.5 and PM10 pollutants provided a significant negative correlation with relative humidity. in winter, however, concentrations of PM2.5 and PM10 had a significant upward trend under the condition of high relative humidity, indicating that when aerosol pollution and relative humidity changed with seasons, the correlation between them also changed.

Table 3. Spearman-Rank correlation coefficient between $PM_{2.5}$ and PM_{10} and meteorological parameters in different seasons. The darker colour passed the test of significance.

Meteorology	Season	$PM_{2.5}$	PM_{10}
WS	Spring	**-0.20**	-0.12
	Summer	0.11	0.01
	Fall	-0.11	0.14
	Winter	-0.02	-0.12
T	Spring	-0.13	**-0.24**
	Summer	-0.06	-0.13
	Fall	**-0.42**	**-0.32**
	Winter	-0.02	-0.04
RH	Spring	-0.01	0.10
	Summer	-0.10	-0.10
	Fall	**0.55**	**0.45**
	Winter	**-0.29**	**-0.22**

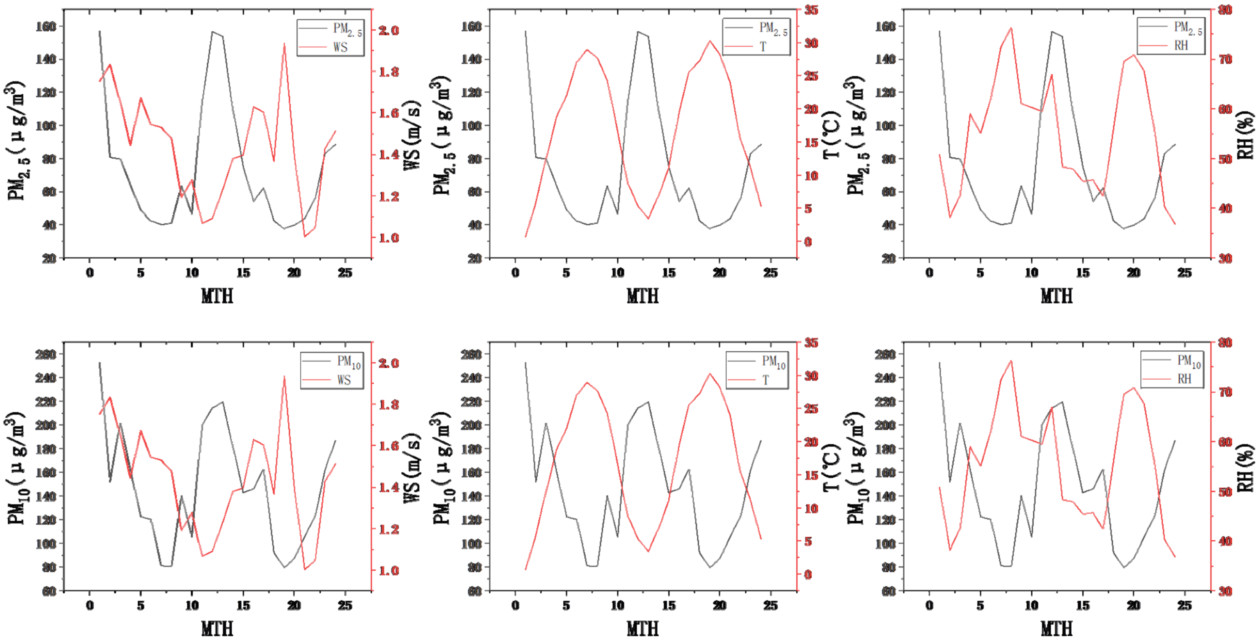

Figure 3. Monthly variations of $PM_{2.5}$ and PM_{10}, and their correlations with wind speed, temperature and relative humidity from January 2016 to December 2017.

3.3 Backward trajectory analysis of pollutants

In order to further studying the relationship between regional air transport and aerosol pollution in Zhengzhou, HYSPLIT backward model was used to analyse and simulate the air transport direction, to investigated the air pollutants from the outside area. The representative transport path of PM2.5 air mass track in winter (the worst polluted period) was analysed by cluster analysis. The pollutant transport with the atmosphere in Zhengzhou area was obtained by comparing with the ground meteorological monitoring data. According to the clustering analysis of HYSPLIT backward trajectory model, there were five representative transport paths of PM2.5 in winter shown as figure 4.

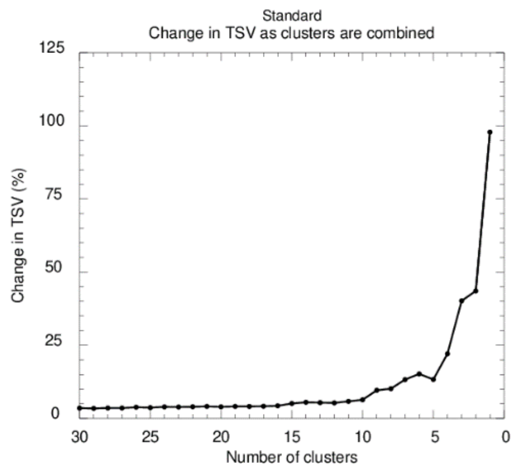

Figure 4. Clustering analysis of backward trajectories.

Backward trajectory analysis of PM2.5 pollutants was calculated in Figure 5, and the concentration of air pollution from northwest direction were significantly lower than the southeast direction by taking core area of Zhengzhou as the calculating centre. It can be indicated that the concentration of air pollution from the transport paths marked as No.1, No.2 and No.3 (in the southeast) accounted for 64% of the total pollution, and the concentration was 2.77 times that of transport paths marked as No.4 and No.5 (in the northwest). The pollutants emitted from southeast adjacent regions were obviously the main source of PM2.5 pollution in the core area in Zhengzhou.

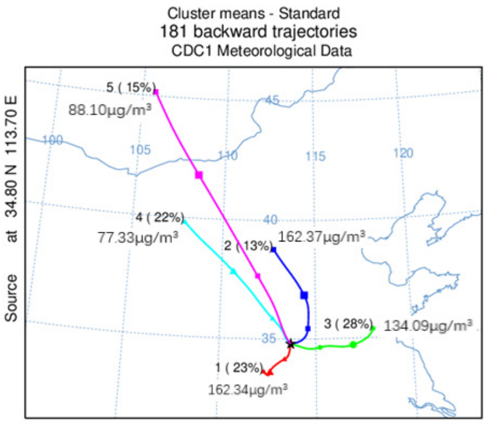

Figure 5. Backward trajectory analysis of PM2.5 in Zhengzhou.

4 Conclusions

Based on the analysis of meteorological parameters, concentrations of PM2.5 and PM10 pollutants in typical period of Zhengzhou area, the relationship between meteorological conditions and air pollution has been recognized, and the impacts of regional air transport on PM2.5 pollution was observed by using numerical simulation method. These studies generated conclusions that the worst air pollution of PM2.5 and PM10 in Zhengzhou mainly occurred in winter, which was characterized by low wind speed and temperature, and high relative humidity. From the further understand, the most obvious correlation between air pollutants and meteorological parameters was the concentration of pollutants and temperature, which indicated a negative correlation trend. Although it also developed a negative correlation trend with wind speed and relative humidity, the short-term fluctuation was also obvious. Thereby, the seasonal variations and the correlation coefficient between temperature and air pollution elucidated that coal burning in winter was still primarily determined to make the worse air pollution. From backward trajectory analysis of PM2.5 in Zhengzhou, the transport paths of pollutants from the southeast outside Zhengzhou was significantly higher than that in the northwest. Most of PM2.5 pollutants were transported by the three transport paths close to the core area. In order to reduce the occurrence of heavy pollution in Zhengzhou, due to the special topography and the unfavourable diffusion conditions， the efforts devoted to reducing the air pollutants from the adjacent southern regions especially the south-easterly should be considered first. Our statistical summary and comparative study indicate the characteristic time-intervals and meteorological conditions of poor air quality in Zhengzhou. With the development of industry, the main direction and paths of aerosol pollutants is changeable, to further understand these relationship and changeable progresses, it requires observation to more parameters like synoptic forcing and planetary boundary layer to investigate the relationships between meteorological conditions and aerosol pollutants, and measures to mitigate the heavy pollution from the changeable allocation of the urban and industrial area in Zhengzhou need to be comprehensively concerned.

References

1. Wenying Gao. Analysis of air pollution in Zhengzhou City from 2001 to 2004. D. Zhengzhou University. (2006)
2. Ruijie Wu. Characteristics of $PM_{2.5}$ and PM_{10} in Zhengzhou. D. Zhengzhou University. (2011)
3. Wending Zhang. Numerical simulation of air pollution in Zhengzhou City and its impact on Regional Transport. D. Zhengzhou University. (2013)
4. Jia Jia, Yi Cong, Qingmin Gao, Lingling Wang, Jingjing Yang, Guohui Zhang. Formation mechanism and source analysis of two heavy pollution periods in winter in a central plains city. J. Environmental Science. Vol.41, NO.12. Dec (2020)
5. Dan Zheng. Variations of black carbon aerosol concentration in four seasons and the impact of wintertime meteorological elements in Zhengzhou. D. Nanjing University of Information Science and Technology. (2020)
6. Hongliang Zhang, Yungang Wang, Jianlin Hu, Qi Ying, Xiaoming Hu. Relationships between meteorological parameters and criteria air pollutants in three megacities in China. Environmental Research 140. 242-254. (2015)
7. Yucong Miao, Yanyu Peng, Jian Li, Gen Zhang. Synoptic Characteristics Associated with Aerosol Pollution during the Same Period of Beijing Olympic and Paralympic Winter Games in History. Acta Scientiarum Naturalium Universitatis Pekinensis, 56(5), 815-823. (2020)
8. Yucong Miao, Shuhua Liu. Linkages between aerosol pollution and planetary boundary layer structure in China. Science of the Total Environment 650, 288-296. (2019)