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Analysis of Ozone Pollution Characteristics, Meteorological Effects, and Transport Sources in Zhuzhou, China

Bei Yan [1,†], Jia Luo [2,†,‡], Min Zhang [2,‡], Yi Zhang [2,‡], Tongjue Xiao [3], Lu Wang [4], Bo Liu [2,‡], Yunjuan Han [2,‡], Gongxiu He [1], Lili Yang [1,*] and Zhihong Huang [5,*]

1 Forestry College, Central South University of Forestry and Technology, Changsha 410004, China; 18874747370@163.com (B.Y.); hegongxiu@163.com (G.H.)
2 Hunan Academy of Forestry, Changsha 410004, China; jialuo220525@sina.com (J.L.); zhm9981@126.com (M.Z.); 13786160433@163.com (Y.Z.); hnlkylb@sina.com (B.L.); hh2023juan@sina.com (Y.H.)
3 Ecology and Environment Monitoring Centre of Hunan, Changsha 410014, China; xxt_110@163.com
4 Hunan Meteorological Observatory, Changsha 410018, China; wahahalulu@163.com
5 Hunan Bamianshan National Nature Reserve Management Bureau, Chenzhou 423501, China
* Correspondence: znl_yll@163.com (L.Y.); hzh_2024@126.com (Z.H.)
† These authors contributed equally to this work and share first authorship.
‡ Represents the first unit in parallel.

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Abstract: Based on the hourly surface ozone (O_3) observations and meteorological data from Zhuzhou in 2021, the pollution characteristics and influencing factors of O_3 in Zhuzhou were investigated in the study. In addition, the Potential Source Contribution Function (PSCF) and Concentration Weighted Trajectory (CWT) analysis methods were employed to analyze the transmission paths and potential pollution sources of O_3 pollution in Zhuzhou. The results showed that the total number of days with O_3 exceeding the standard at all monitoring stations in Zhuzhou was 142 days in 2021. The overall air quality was less affected by SO_2, NO_2, and CO, and the trend of O_3 pollution was still increasing. The concentrations of O_3, CO, and NO_2 varied significantly in different months, and the variation of O_3 exhibited a "double-peak" pattern, with the peak value occurring in September. The O_3 concentration in urban areas was significantly higher than that in suburban areas. Meteorological conditions had a significant impact on the degree of O_3 pollution in Zhuzhou. The average wind speed in Zhuzhou throughout the year was 1.7 m/s, and the prevailing wind direction in summer was southeast, with a frequency of 16%. O_3 pollution was mainly transported by short-distance airflow during the over-standard periods in 2021, accounting for 37.64%. The main source of O_3 pollutant was from Jiangxi Province in the east, with the shortest distance of regional transport and the highest O_3 concentration. In addition, transportation from central Guangdong Province, western Jiangxi Province, and central Hubei Province also had a significant impact.

Keywords: O_3; Zhuzhou; meteorological impact; potential source contribution (PSCF); concentration weight (CWT); pollution characteristics

1. Introduction

Urban air pollution has a significant impact on the environment, human health, and plant physiology and ecology [1]. Ozone (O_3) is a typical secondary pollutant formed by photochemical reactions of its precursors (NO_x and VOCs) under ultraviolet radiation [2,3]. O_3 is not only a greenhouse gas that affects climate change but also affects the oxidative capacity of the atmosphere, threatens urban air quality, and harms human health and plant growth [4,5]. In many cities in China, researchers conducted fumigation experiments using open-top boxes (OTCs) with different O_3 concentrations and found that tree biomass, net photosynthetic rate, and transpiration rate significantly decreased with increasing O_3 concentrations [6,7]. Additionally, tree root biomass, fine root production, and turnover rate decreased [8]. Therefore, high O_3 concentrations lead to a decrease in agricultural and forestry yields, resulting in a decrease in economic production [9]. Previous studies have shown that surface O_3 concentrations in many cities in the central and southern regions have been increasing year by year [10,11], and it is important to strengthen regional O_3 pollution control. In addition to the levels influenced by precursors, meteorological factors and weather systems also play an important role in the formation, dilution, and transport of O_3 [12,13]. Weather with strong solar radiation, high atmospheric temperature, and low relative humidity are key meteorological factors that promote the formation of O_3 photochemical reactions [14]. Aerosols can significantly affect photochemical processes and interact with O_3 [15].

Currently, domestic and foreign scholars have analyzed the variation characteristics of O_3 in different time periods from the sources of pollutants, pollution processes, and spatiotemporal characteristics, and they have conducted relevant studies on the sources and transmission characteristics of air pollution in different cities using backward trajectory clustering analysis, potential source contribution factor analysis, and concentration weighting analysis [16,17]. Ozone is the primary pollutant in the local area, but currently, there is almost no research on the spatiotemporal changes and influencing factors of ozone in Zhuzhou. In this study, the relationship between meteorological factors such as temperature, relative humidity, wind speed, and O_3 concentrations in Zhuzhou in 2021 was analyzed, and the main sources and distribution of O_3 pollution in Zhuzhou during the pollution period were investigated. The research results can provide data support and a theoretical basis for future urban development and air quality improvement in Zhuzhou.

2. Study Methods

2.1. Study Area

Zhuzhou City is located in the eastern part of Hunan Province, downstream of Xiangjiang River. The total area of Zhuzhou was 11,262 square kilometers, located between 26°03′05″ and 28°01′07″ N and 112°57′30″ and 114°07′15″ E. The city of Zhuzhou is situated at the western foot of the Luoxiao Mountains on the incline section from the Nanling Mountains to the Jianghan Plain. The mountains are mainly concentrated in the southeast of the city, while the plains are distributed along both banks of the Xiangjiang River. Zhuzhou is an old industrial base in China. In 2022, the city's GDP reached 361.68 billion yuan, ranking fifth in Hunan Province. The energy consumption has reached 3.3698 million tons of standard coal, and economic development has also put forward higher requirements for air quality.

2.2. Data Sources

The O_3, $PM_{2.5}$, PM_{10}, NO_2 and CO hourly monitoring data used in this study were obtained from seven national monitoring sites (Dajing Scenic Area, Zhuye Hospital, Cite Monitoring Station, Railway Station, Tiantai Villa, City No. 4 Middle School, Yuntian Middle School) and five regional monitoring sites (Strainer District Water Company, You County Environmental Protection Bureau, Chaling County Monitoring Station, Yanling County Land and Resources Bureau, Liling City Environmental Protection Bureau) at the Hunan Ecological Environment Center. The data time period was from January to December 2021. All pollutant data were sourced from the Ecology and Environment Monitoring Centre of Huanan, and meteorological data were obtained from hourly monitoring data provided by the Hunan Provincial Meteorological Station (Figure 1). The meteorological data used for the backward trajectory clustering analysis were sourced from the Global Data Assimilation System (GDAS) information provided by the National Centers for Environmental Prediction (NCEP), with a spatial horizontal resolution of $1° \times 1°$. According to the Ambient Air Quality Standards (GB 3095-2012) [18] and the Technical Specification for Ambient Air Quality Evaluation (for Trial Implementation) (HJ 663-2013) [19], the arithmetic mean of six environmental monitoring data from 12 monitoring points was used to represent the average concentration in Zhuzhou. The missing or abnormal data with the same linear interpolation was used to supplement the collection process.

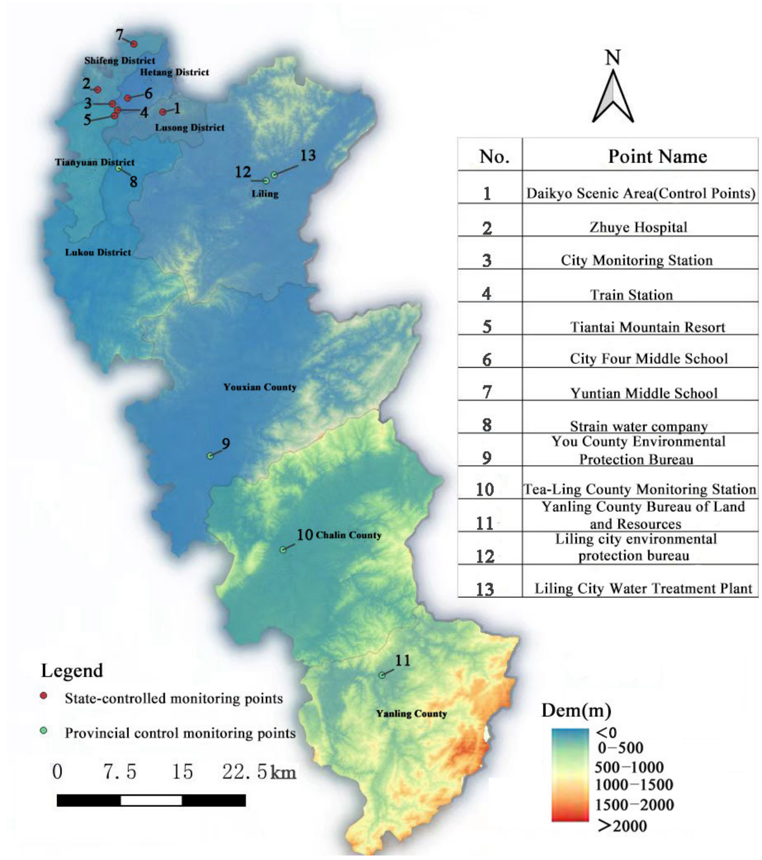

Figure 1. Distribution of O_3 monitoring stations in Zhuzhou.

2.3. Research Method

The TrajStat tracking (1.4.9) software within the Meteoinfo software (2.2.1) was selected for the backward trajectory analysis and potential source analysis of O_3. The backward trajectory analysis of the Zhuzhou urban area (27.82° N, 113.13° E) was used as the starting point, and the backward trajectory of the air mass arriving at the Zhuzhou urban area hour by hour during the O_3 exceedance days was calculated in September 2021. The trajectory was delayed for 48 h, and the simulated study height was 500 m.

Cluster analysis is an analysis method that groups each class of trajectories based on the spatial similarity of trajectories on the basis of backward trajectories and selects optimal results. The systematic clustering method was used to analyze all backward trajectories. It classifies all trajectories and first merges the two closest trajectories into the same class, and so on, until all trajectories are merged into one optimal result [20]. The length of the line represents the transmission distance between regions, and the shorter the line, the shorter the transmission distance.

The potential source contribution function (PSCF) model was applied to describe and account for the potential sources of O_3. The PSCF function is defined as the conditional probability that the value of an element corresponding to an air mass passing through the ijth grid reaches a set starting point and exceeds a set cut-off threshold. A larger PSCF value corresponding to each grid indicates a greater contribution of the grid point to the pollutant mass concentration at the starting point [21].

The Concentration-weighed trajectory (CWT) analysis method was also used in this study. By calculating the concentration of each trajectory weight, it reflects the pollution level of different trajectories and thus quantitatively discerns the pollution contribution of the grid corresponding to the potential source area.

Variance and Pearson correlation analyses were performed using SPSS software (17.0).

The national standards for air quality in China are shown in Table 1.

Table 1. The national standards for air quality in China.

Pollutant Name	Average Time	Concentration Limit (μg/m^3)	
		First-Class	Second-Class
O_3	O_3 daily maximum 8 h average	100	160
	hourly average	160	200
NO_2	annually average	40	40
	24 h average	80	80
	hourly average	200	200
PM_{10}	annually average	40	70
	24 h average	50	150
$PM_{2.5}$	annually average	15	35
	24 h average	35	75

3. Results and Discussion

3.1. O_3 Pollution Change Characteristics

3.1.1. General Environmental Pollution Situation

In 2021, the annual average concentrations of SO_2, NO_2, CO, and PM_{10} pollutants at 12 environmental monitoring stations in Zhuzhou did not exceed the limits of the secondary standards for ambient air pollutants. However, the $PM_{2.5}$ levels at national monitoring stations exceeded the secondary standards and were significantly higher than all other pollutants. The regional stations did not exceed the $PM_{2.5}$ secondary standards, with an annual average of 33 μg/m^3 at Dajing Scenic Area, Yuntian Middle School, and the City Monitoring Station.

The annual average concentrations of $PM_{2.5}$ at Yuntian Middle School, the City Monitoring Station, the Railway Station, and Zhuye Hospital all exceeded 40 μg/m^3, and the annual average concentrations of PM_{10} at each site ranged from 28 to 60 μg/m^3. In addition, the total number of days that O_3 exceeded the standard in 2021 was 142. The total number of days of O_3 pollution at the national sites, Yuntian Middle School, the city Monitoring Station, the Railway Station, and Zhuye Hospital was 20. O_3 pollution occurred at Dajing Scenic Area for only 3 days, and there was very little O_3 pollution at the regional monitoring sites. The Chaling County monitoring station only experienced 2 days of O_3 pollution (Table 2). The annual average concentrations of SO_2, NO_2, and CO were relatively low, with only 3 days of NO_2 exceeded the standard limit at the Railway Station, while other stations did not exceed the secondary concentration limits of the ambient air quality standards. This indicates that, in 2021, SO_2, NO_2, and CO were not the main factors affecting air quality in Zhuzhou.

Table 2. Statistics of the number of days of pollutants exceeding the standard at each station in Zhuzhou in 2021.

Site Name	O_3 Exceeded the Standard Days/d	$PM_{2.5}$ Exceeded the Standard Days/d	PM_{10} Exceeded the Standard Days/d	NO_2 Exceeded the Standard Days/d
Yuntian Middle School	20	36	7	--
Daikyo Scenic Area	3	25	6	--
Train Station	20	38	13	3
City Monitoring Station	20	41	12	--
City Four Middle School	16	38	9	--
Tiantai Mountain Resort	19	39	9	--
Zhuye Hospital	20	29	9	--
Tea-Ling County Monitoring Station	2	6	4	--
Liling city environmental protection bureau	5	7	2	--
Strain water company	4	17	6	--
Yanling County Bureau of Land and Resources	7	3	1	--
You County Environmental Protection Bureau	6	15	6	--

3.1.2. O_3 Pollution Monthly Change Characteristics

The monthly average concentration changes of pollutants in 2021 are presented in Figure 2. O_3, CO, and NO_2 concentrations differ significantly in different months. O_3 is essentially distributed in a bimodal pattern, and the change characteristics of national and provincial control sites are relatively similar. O_3 concentration gradually increases in spring, with peak O_3 appearing in September. The highest O_3 concentration was 148 $\mu g/m^3$ at the municipal monitoring station of the national control site and 128 $\mu g/m^3$ at the Strain Water Company of the regional site. The seasonal change in O_3 concentration is characterized as follows: summer > autumn > spring > winter. Overall, O_3 pollution mainly occurs in summer, with higher concentrations in autumn and summer and lower concentrations in winter. Meanwhile, the variation in O_3 concentration is closely related to meteorological conditions.

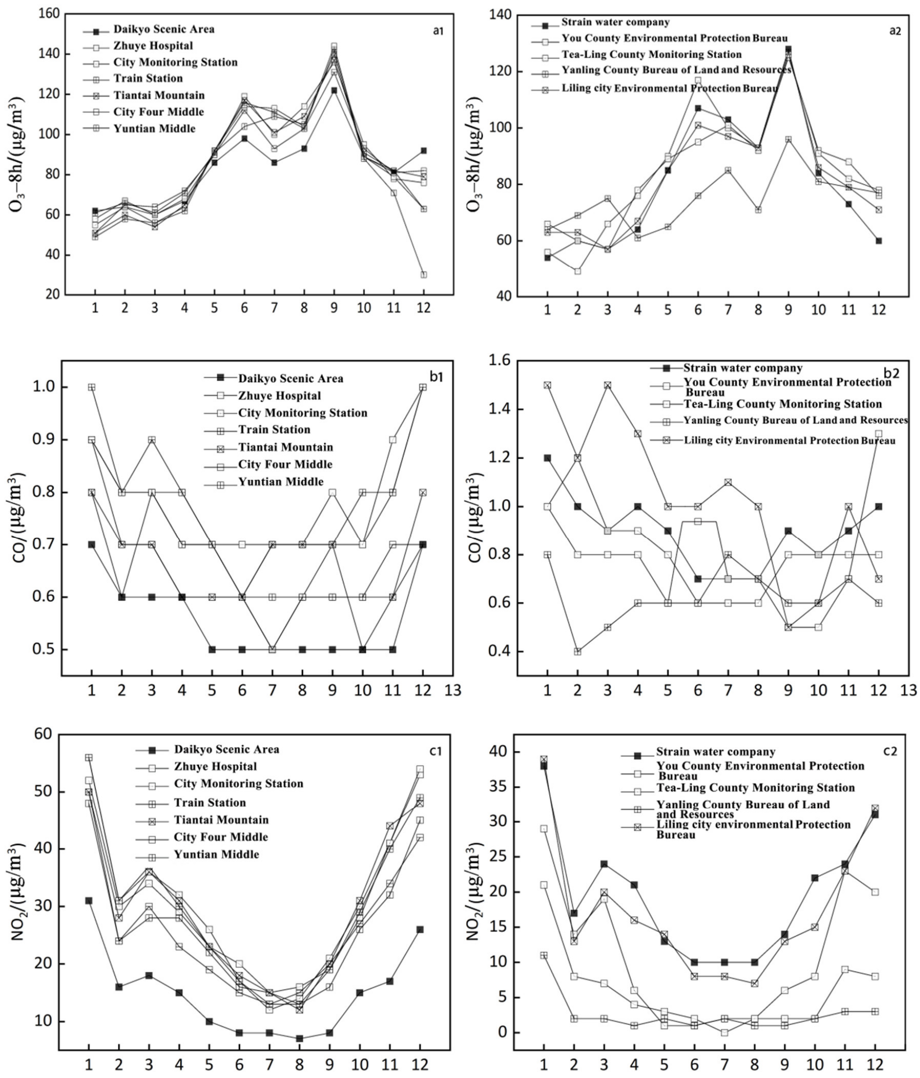

Figure 2. The monthly variations of O_3 (**a**), CO (**b**), and NO_2 (**c**) concentrations at typical stations of Zhuzhou City during 2021.

In contrast to O_3, the monthly changes in CO and NO_2 show a weak "V"-shaped distribution of "low in summer and high in winter". The CO concentration at the national sites is slightly lower than that at the regional sites, while the NO_2 concentration at the national sites is significantly higher than that at the regional sites. It can be presumed that national sites in urban areas are more significantly influenced by various emission sources.

This phenomenon occurs mainly because concentrations in summer are lower due to consumption as an O_3 precursor, while the high concentrations in winter are due to greater consumption of fossil fuels and the tendency to have an inverse thermosphere and stable atmospheric boundary layer in winter [22], which limit the convective diffusion of several pollutants. The photochemical reaction process can be explained by Equations (1)–(3) [23]. The main process is the oxidation of NO by atmospheric oxidants to produce NO_2 and the photolysis of NO_2 to produce O_3. Temperature and solar radiation play important roles in the formation and transport of O_3 [12].

$$NO + O_3 \rightarrow NO_2 + O_2 \tag{1}$$

$$NO_2 + hv \rightarrow NO + O \tag{2}$$

$$O + O_2 \rightarrow O_3 \tag{3}$$

3.1.3. O_3 Pollution Daily Variation Characteristics

The daily variation in O_3 is illustrated in Figure 3, and both the national sites and regional sites showed a single peak type of O_3 concentration between 12:00 and 18:00 on a daily basis. The highest daily variation was observed at the national site Railway Station, and the lowest was observed at Dajing Scenic Area. The highest daily variation at the regional sites was observed at Youxian Environmental Protection Bureau, and the lowest was observed at Yanling County Land and Resources Bureau.

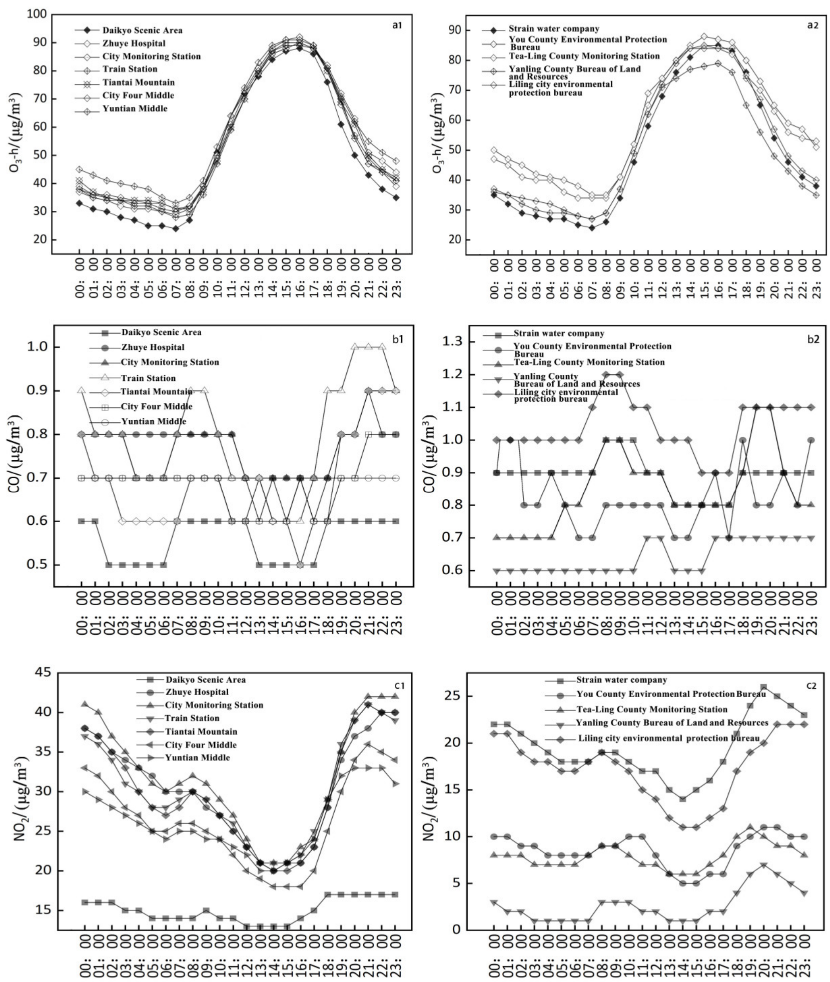

Figure 3. The daily variations in O_3 (**a**), CO (**b**), and NO_2 (**c**) concentrations at typical stations of Zhuzhou City during 2021.

Temperature was the most important factor affecting the monthly and daily variation in O_3. Previous studies have shown that the higher the temperature, the higher the O_3 concentration usually, which was particularly evident in daily variations. In this study, the highest O_3 concentrations during the day at the national and regional sites were observed in the afternoon, corresponding to the period of highest air temperature, and gradually decreased with lower nighttime air temperatures. This pattern was generally consistent with the daily variation in solar radiation. The daily variation in O_3 concentrations at the national control sites was more significant than that at the regional sites. The lowest O_3 concentrations were observed between 6:00 a.m. and 8:00 a.m.

The hourly concentrations of CO and NO_2 were higher, and high values of NO_2 corresponded to low values of O_3. During this time, the production of O_3 was inhibited and led to a "NO_x titration state" in polluted urban areas under conditions of elevated NO levels [24]. As temperature rose continuously after sunrise, the photochemical reaction rate accelerated, and hourly O_3 concentrations rose continuously after sunrise, reaching a peak in the afternoon from 14:00 to 17:00. During this peak period, the high values of NO_2 and CO corresponded to low values of O_3, which was basically consistent with the daily variation characteristics of O_3 in the Pearl River Delta region, previously studied by scholars [11].

3.2. Relationship between O_3 Pollution and Meteorological Conditions

The concentration of O_3-8 h is negatively correlated with NO_2, NO_x, NO, air pressure, and relative humidity at the Tiantai Mountain Villa National Monitoring Station, with correlation coefficients of −0.27, −0.24, −0.16, −0.16, and −0.4, respectively. It is positively correlated with wind direction and temperature, with correlation coefficients of 0.11 and 0.51, respectively. At the Yanling County Provincial Monitoring Station, it is negatively correlated with NO_2, NO_x, NO, wind speed, wind direction, air pressure, and relative humidity, with correlation coefficients of −0.45, −0.39, −0.11, −0.15, −0.46, −0.37, and −0.52, respectively. It is significantly positively correlated with temperature, with a correlation coefficient of 0.59. Based on this analysis, it can be concluded that national monitoring stations are more significantly affected by NO_2, NO_x, relative humidity, and temperature, indicating a close relationship between O_3 and NO_2, and the accumulation and decomposition of NO_2 have a significant impact on the formation of O_3. O_3 pollution is a secondary pollution, and its precursor is mainly NO_x and VOCs, with nitrogen oxides mainly coming from human activities such as automobile exhaust, coal and petroleum combustion, and VOCs having two sources: natural and anthropogenic. Natural sources include volatile organic compounds released by plants, which can lead to high O_3 concentrations in areas with dense vegetation. Anthropogenic sources include various VOCs emitted from human production activities, such as coal-based chemicals and petrochemicals.

Fuel coating manufacturing and solvent manufacturing [25] are sources of artificially emitted VOCs, which are the main cause of urban photochemical pollution [26]. Based on the analysis of the Tiantai Mountain Villa National Monitoring Station and the Yanling County Provincial Monitoring Station, it can be seen that the provincial monitoring station is more significantly affected by wind direction, wind speed, and air pressure, indicating that wind direction and human activities have a significant impact on O_3 concentration changes. At the same time, there is an extremely significant correlation between O_3-8 h and temperature. When the southeast and south winds prevail in Zhuzhou in summer, it is easy to cause high O_3 pollution, and it is speculated that pollution transmission may occur in the southwest and northwest of Guangdong Province, the northwest of Jiangxi Province, and the central part of Hubei Province.

Currently, the prevention and control of O_3 pollution in Zhuzhou City mainly focuses on monitoring, early warning, and controlling precursor emissions. As ozone is a difficult-to-detect pollutant, monitoring and early warning play a very important social role. It is also necessary to effectively control the emissions of VOCs and nitrogen oxides, for example, by using clean energy, controlling the number of motor vehicles, improving industrial processes, and promoting clean production. With further proof of the relationship between O_3 and NO_x and VOCs, effective preventive and control measures should be studied and implemented to verify the reduction of NO_x and VOCs emissions and the regional transport of O_3. The prevention and control of O_3 pollution needs to develop from local control to regional joint prevention and control.

3.2.1. Temperature and Relative Humidity

Temperature was influenced by the intensity of solar radiation, and the higher the temperature, the more favorable it was to O_3 generation. As shown in Table 3, O_3-8 h concentrations at both national and regional monitoring stations showed an increasing trend with the increase in temperature, and national control monitoring stations were more significantly affected by temperature. The O_3-8 h concentration was significantly and positively correlated with temperature, and when $20 < T \leq 30$ °C, the O_3 concentration was 72 μg/m^3. When T was around 30 °C, the O_3-8 h concentration was 82–88 μg/m^3, representing an increase of 16 μg/m^3, and the O_3 concentration exceeded the standard easily when temperatures were around 30 °C in national control sites. However, the effect of this change was not very significant in regional monitoring sites.

Table 3. Daily average temperature and relative humidity at monitoring stations in Zhuzhou city in 2021. O_3-8 h relationship.

Daily Average Air Temperature (T/°C)	O_3-8 h (μg/m^3)	O_3-8 h Exceedance Rate %	Daily Average Relative Humidity (RH/%)	O_3-8 h (μg/m^3)	O_3-8 h Exceedance Rate %
$T \leq 10$	58	0	$RH \leq 50$	64	0
$10 < T \leq 20$	72	2%	$50 < RH \leq 70$	91	2.5%
$20 < T \leq 30$	82	3.2%	$70 < RH \leq 90$	68	1.8%
$T > 30$	88	1.0%	$RH > 90$	59	0

While relative humidity and O_3-8 h were significantly negatively correlated, the national control site Tiantai Mountain Resort had a better fit when relative humidity was between 60–80% and O_3-8 h concentration, and the regional site Yanling County Bureau of Land Resources had a better fit when relative humidity was around 60–70%. This was mainly because the increase in relative humidity made the O_3-8 h concentration reach the ground. The main reason for this may be that the increase in relative humidity reduced solar radiation reaching the ground and slowed down the photochemical reactions, and high temperature and low humidity favored an increase in O_3 concentration. This was consistent with the previous analysis of temperature and humidity by scholars [27].

3.2.2. Wind Speed

Wind speed had a significant effect on the intensity of stability within the atmospheric boundary layer, and O_3 was significantly influenced by wind speed [28]. The distribution of 2 min wind speed and wind frequency by season was provided in Figure 4. Throughout the year, the overall mean wind speed in Zhuzhou was 1.7 m/s, with the highest mean wind speed in summer (1.9 m/s), followed by autumn (1.8 m/s) and spring (1.6 m/s), and the lowest in winter (1.5 m/s). Northwest wind prevailed in spring with a wind frequency of 17%, southeast wind prevailed in summer with a wind frequency of 16%, northwest and northeast wind prevailed in autumn, and then northwest wind prevailed in winter with a wind frequency of 18%.

O_3-8 h was negatively correlated with wind speed, and the O_3-8 h concentration increased significantly when the wind speed at the national site, Tiantai Hills, was 1.0~2 m/s and increased significantly when the wind speed was greater than 2 m/s; the O_3-8 h concentration decreased significantly. This means that the greater the wind speed, the lower the corresponding O_3-8 h concentration. The highest O_3-8 h concentration was found at the regional site when the wind speed was between 1.0 and 1.5 m/s, and the exact change between the national control site and the regional site was not very significant.

The pollution sources emitted by cars, factories, etc., enter the atmosphere and react with primary pollutants such as hydrocarbons, forming photochemical smog over cities, and nitrogen oxides (NO_x) under the action of sunlight, generating ozone. This may be because the accumulation of pollutants could not be diluted and diffused in a short period of time, and O_3 and its precursors may be transported across the region [29]. At the same time, taking into account the topography and site distribution characteristics of Zhuzhou, it was presumed that there may be transmission channels for O_3 in the northeast, southeast, and northwest directions of Zhuzhou.

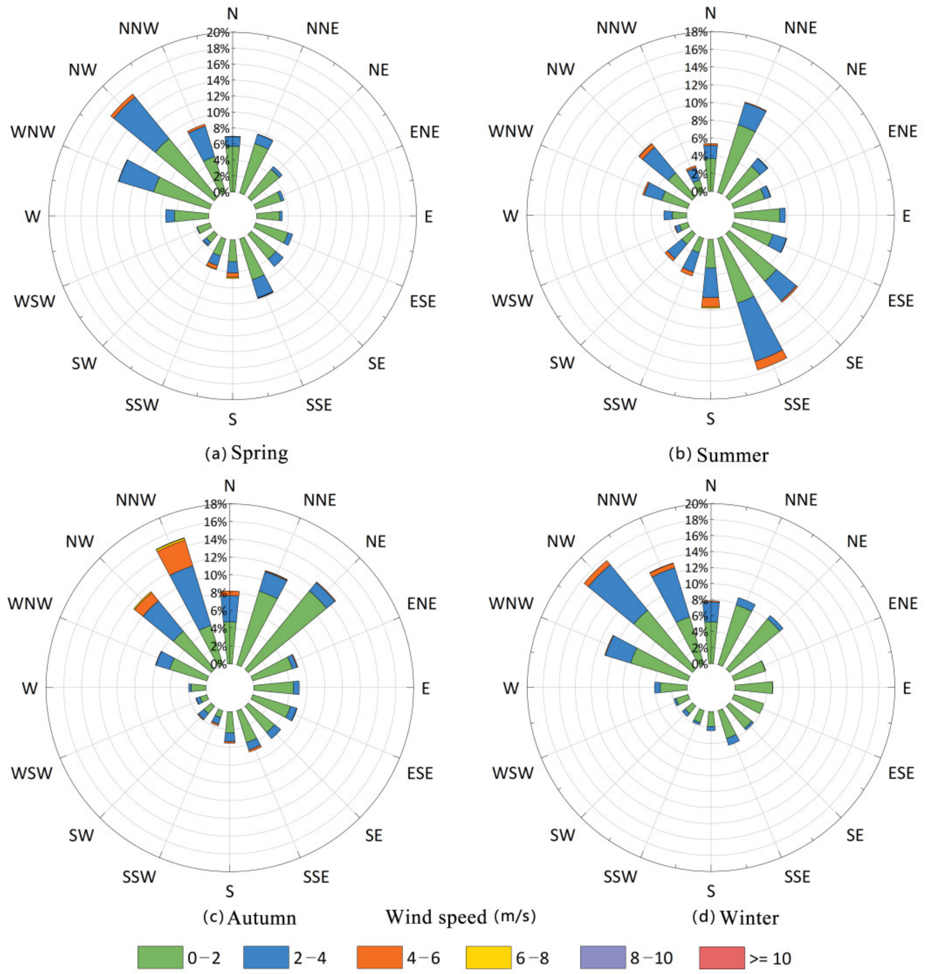

Figure 4. Frequency distribution of seasonal wind speed and wind direction in Zhuzhou.

3.3. O_3 Transport Pathway and Potential Source Analysis

O_3 pollution was influenced by temperature, relative humidity, NO_x, wind direction, wind speed, and was also related to local emissions and regional transport, as well as photochemical reactions carried out by O_3 precursors during transport [23]. To clarify the transport channels of O_3 in Zhuzhou City, the city monitoring station sites with the highest number of O_3 exceedance days in 2021 were selected for transport analysis and cluster analysis of the days polluted by O_3 in September using a backward trajectory model. The results are shown in Figure 5, where the air masses on the O_3 pollution day in Zhuzhou were mainly distributed in the northeast, northwest, and southeast directions.

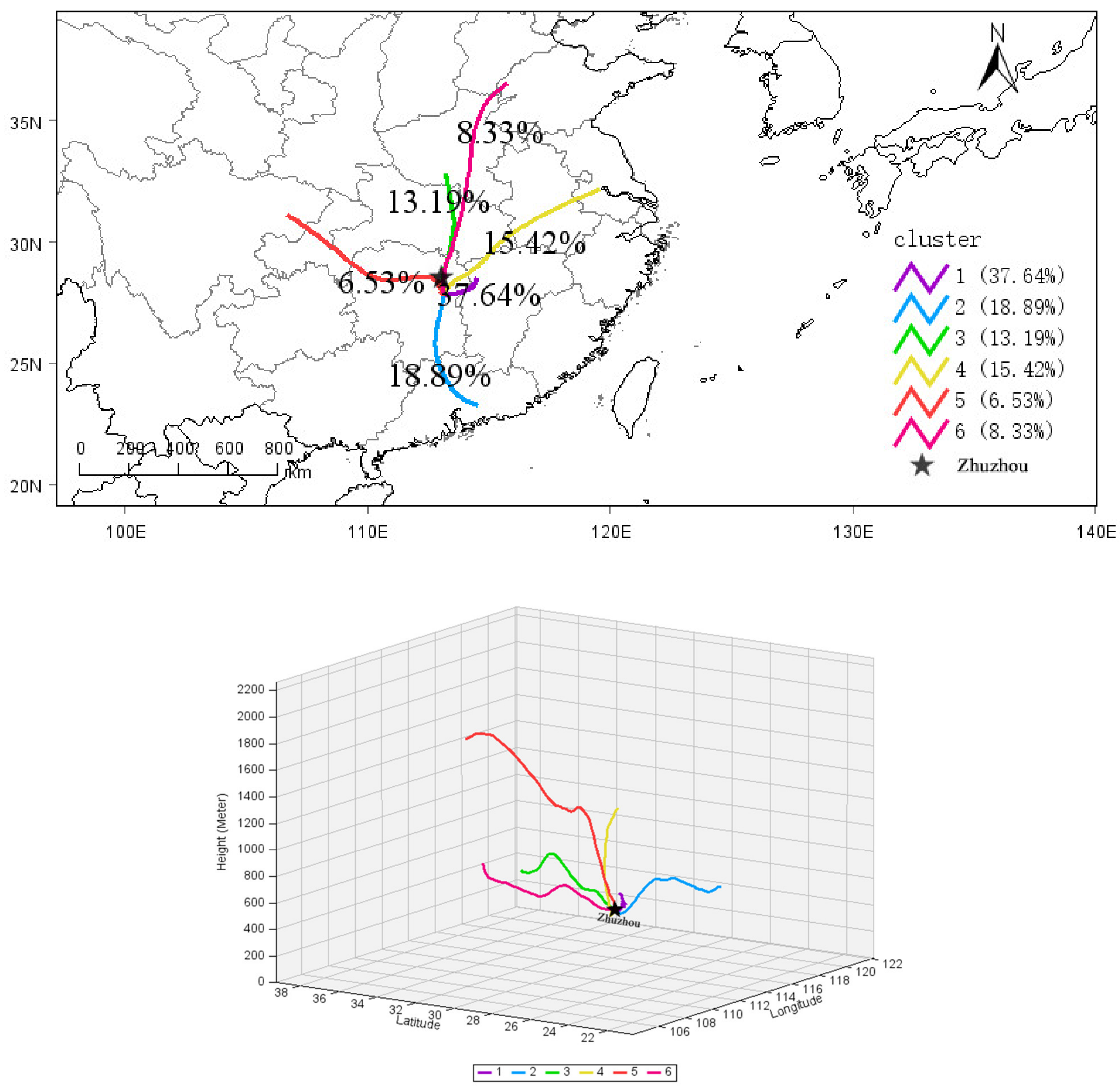

Figure 5. Cluster analysis chart of air flow backward trajectory and air flow trajectory operation altimeter in September.

Track 1 (37.64%) mainly originated from Jiangxi Province in the due east direction, with the shortest regional transmission distance but the highest exceedance frequency and the highest O_3 concentration, mainly from near the ground. Track 2 (18.89%) came from the southeast direction via Qingyuan, Guangzhou, and Huizhou in Guangdong, with a shorter transmission distance of air masses. Track 3 (13.19%) came from Hubei Province in the due north direction via Jingzhou, Xiantao. Trajectory 4 (15.42%) came from the northeast direction via Hunan, Jiangxi, Hubei, Anhui, and Jiangsu, with a long transmission distance. Trajectory 5 (6.53%) came from the northwest direction via the north side of Hunan Province, central Chongqing, with a long regional transmission distance but with a low frequency of O_3 exceedances, running at heights up to 1400 m. Trajectory 6 (8.33%), with air masses mainly via the eastern part of Hubei Province, central part of Henan Province, and western part of Hebei Province, had the longest regional transmission distance and lower average O_3 concentration.

The potential source areas of O_3 in Zhuzhou City are mainly distributed in the eastern part of Hunan Province, the western part of Jiangxi Province, the central part of Hubei Province, and the northern part of Guangdong Province. These regions have high PSCF values (>0.9) and are the main potential source areas of O_3 in Zhuzhou. In addition, Guangdong Qingyuan City, Guangzhou City, Huizhou City, Anqing City, and Hefei City in Anhui Province, Luohe City, Xuchang City, and Zhengzhou City in Henan Province also have high PSCF values (>0.6), indicating that their influence on Zhuzhou cannot be ignored.

From the results of concentration-weighted trajectory (CWT) analysis (Figure 6), areas significantly contributing to O_3 concentration in Zhuzhou during exceedance days are widely distributed and show regional contiguous distribution characteristics. They mainly span the central part of Guangdong Province, the western part of Jiangxi Province, and the central part of Hubei Province, which basically cover the high-value areas of PSCF. Overall, the results obtained from CWT and PSCF analyses are consistent, indicating that O_3 pollution in Zhuzhou is not only affected by local emissions and biogenic sources but also significantly influenced by regional transport, mainly from the central part of Guangdong Province, the western part of Jiangxi Province, and the central part of Hubei Province.

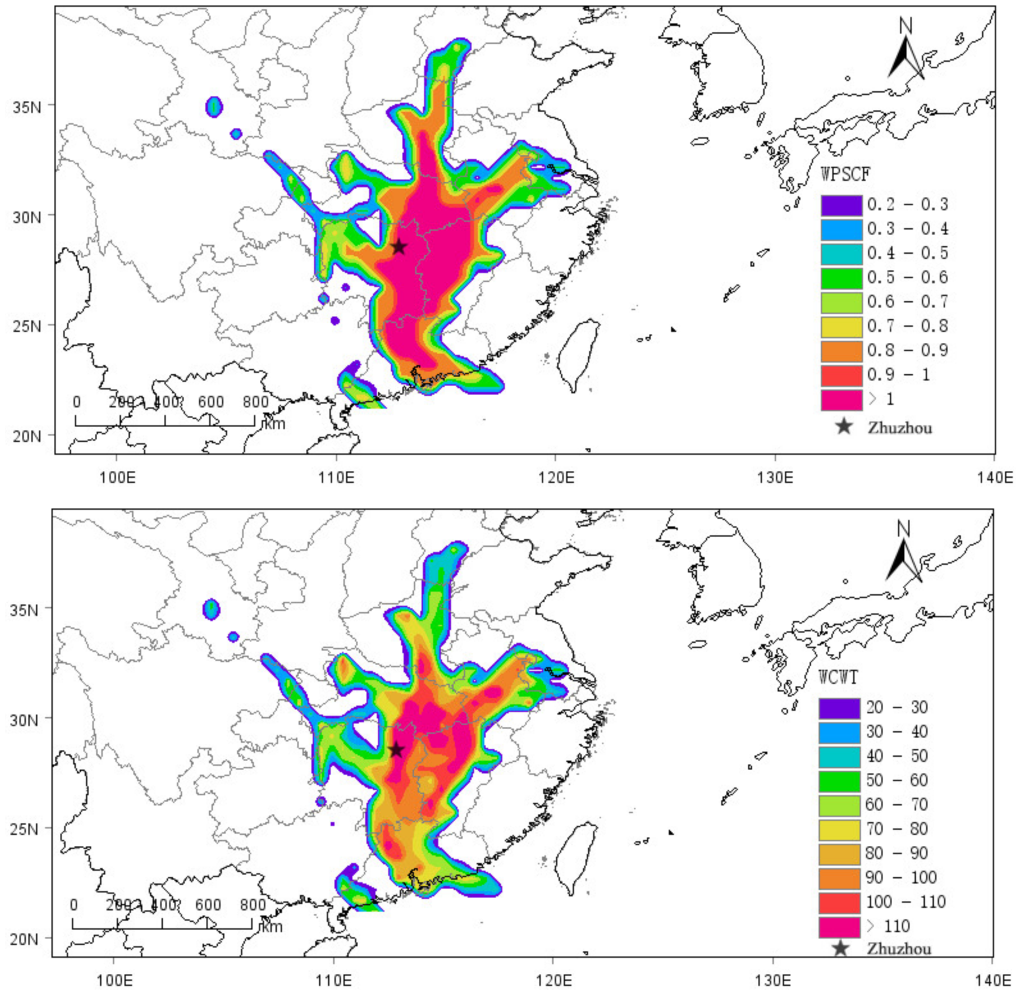

Figure 6. Weighted potential source contribution function and weighted concentration weight distribution of O_3 in September.

Zhuzhou is located at the western foot of the Luoxiao Mountains, blocking the cold air flowing southward from the north–south trend of the Nanling Mountains to the Jianghan Plain. The terrain in the north-central region is characterized by alternating ridges and valleys, while the urban area has a flat topography. The southeastern part of Zhuzhou is all mountainous, making it difficult for pollution to spread. Pollution from the southeastern coast rises to high altitudes with warm and humid airflow, avoiding the barrier effect of the mountains and forming a superimposed pollution in Zhuzhou's urban area. Therefore, meteorological and environmental departments should strengthen regional joint prevention and control while strictly controlling local source emissions.

4. Conclusions

(1) The total number of days in which O_3 exceeded the standard at each station in Zhuzhou in 2021 was 142 days, and the O_3 concentration at national control monitoring stations was significantly higher than that at regional monitoring stations. The monthly variation characteristics of CO and NO_2 show a weak "V" distribution of "low in summer and high in winter", while the monthly variation of O_3 shows a "double peak" pattern. The peak of O_3 appears in September, and the seasonal variation of O_3 concentration is as follows: summer > autumn > spring > winter.

(2) The concentration of O_3 shows a "single peak" pattern between 12:00 and 18:00, and the most important influencing factor for monthly and daily changes is temperature. The higher the temperature, the higher the O_3 concentration, and it reaches its peak in the day from 14:00 to 17:00 in the afternoon.

(3) Meteorological conditions have a significant impact on the level of O_3 pollution in Zhuzhou. When the temperature is around 30 °C, the highest concentration of O_3-8 h is 88 $\mu g/m^3$; There is a significant negative correlation between relative humidity and O_3-8 h.

(4) The sources of O_3 pollution in Zhuzhou are local emissions and the impact of transportation from other places. Analysis of backward trajectory shows that in 2021, O_3 pollution was mainly caused by short-distance transportation airflow during the exceeding dates, accounting for 37.64%. The main source of O_3 pollutants was from the due east in Jiangxi Province, which had the shortest regional transmission distance and the highest O_3 concentration. At the same time, it is also greatly affected by regional transportation, with significant transmission effects in central Guangdong Province, western Jiangxi Province, and central Hubei Province.

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