CHARACTERISTICS AND INFLUENCING FACTORS OF THE NEAR-GROUND OZONE CONCENTRATIONS IN CHANGSHA, A TYPICAL CITY IN CENTRAL AND SOUTHERN CHINA

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Abstract. This study aimed to preliminarily explore the distribution characteristics of the ozone (O_3) pollution period in 2021 in Changsha, which is a typical city in central and southern China, and the differences in reasons for ozone and other pollutions were also investigated. The study was based on the hourly environmental monitoring and meteorological data in 2021 provided by the Ecological Environment Monitoring Center and Meteorological Observatory of Hunan Province. The effects of topography, precursors, meteorological conditions, and other factors on the O_3 concentration were analyzed. The results showed that the overall air quality of 14 environmental monitoring stations in Changsha in 2021 was less affected by sulfur dioxide, nitrogen dioxide (NO_2), and carbon monoxide, and principally affected by particulate matter and O_3. Among the 14 environmental monitoring stations, the duration of pollution due to O_3 was in the range of 0–29 days, with a maximum concentration of 252 μg/m^3; the daily O_3 concentrations were in the range of 29–94 μg/m^3, showing "unimodal" trends in general; and the monthly average O_3−8 h (the daily maximum 8-h O_3 concentrations) concentrations were in the range of 44–149 μg/m^3, showing "bimodal" trends in general. Generally speaking, compared with the provincial control sites, the ozone concentration of the national control sites was higher, and the urban areas were higher than the suburbs. The O_3 concentrations were ranked in the following order: summer > autumn > spring > winter, and the urban area was affected to a larger extent by the emission. The concentrations of O_3 and NO_2 varied in opposite trends. The O_3 concentration exhibited a typical "inverted U-shaped" profile, while that of NO_2 substantially exhibited a "U-shaped" profile. The O_3 concentration was significantly positively correlated with the daily average wind speed and ambient temperature but negatively correlated with the wind direction, wind pressure, and humidity. The following conditions promoted the generation of O_3 in Changsha: ambient temperature of around 30°C, relative humidity of around 50%, and wind speed of 0.5–2.0 m/s. These findings are beneficial for the scientific prediction, warning, and control of O_3 pollution in the central and southern regions of China.
Keywords: *Changsha, distribution characteristic, causative factors, meteorological factor, ozone pollution*

Introduction

In the last decades, the rapid development of the economy has significantly deteriorated energy consumption, air pollutant emission, and air pollution worldwide (Li et al., 2013; Wang et al., 2022; Zhao et al., 2013). The troposphere ozone (O_3) has been well recognized to have natural and secondary atmospheric sources. The former is due to the transfer of O_3 from the stratosphere to the troposphere. The latter is attributed

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to the emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) from natural and artificial sources such as coal combustion, automobile exhaust, chemical industry, and petroleum industry. Photochemical reactions occur between NO_x and VOCs to produce O_3 under solar conditions (Feng et al., 2018). O_3 has been the primary atmospheric pollutant in summers, and the sources and precursors have a significantly nonlinear relationship (Dentener et al., 2006; Sillman, 1999). Besides the aforementioned factors, the change in O_3 concentration has also been affected by natural meteorological conditions (Fujita et al., 2016; Li et al., 2021). Concentrated O_3 pollution events are usually related to meteorological factors, such as high temperature, low wind speed, and low relative humidity (RH), and typical atmospheric circulation modes, such as anticyclone and high-pressure systems because these factors enhance the chemical production and accumulation of O_3 in the boundary layer (Shen et al., 2015; Xu et al., 2011; Zhao et al., 2016; Yu et al., 2020). Moreover, the meteorological conditions also alter the O_3 exchange between the stratosphere and the troposphere, thereby affecting the O_3 concentration in the lower troposphere (Li et al., 2013; Lin et al., 2015). O_3 is principally removed from the troposphere through chemical reactions, and the VOCs produced by plants also significantly contribute to near-ground O_3 (Yao et al., 2021). In the last decades, extremely high concentrations of aerosols (particulate matter PM_{10} and $PM_{2.5}$) have been observed in industrialized areas around the world, which had a significant impact on the O_3 concentration through heterogeneous reactions and influencing photolysis rates (Fu et al., 2019). Therefore, the O_3 present in the troposphere is a secondary pollutant and an important greenhouse gas with ultra-strong oxidative toxicity (Wang et al., 2016).

Currently, many studies have reported on the spatiotemporal characteristics, chemical precursor sources, meteorological factors, influence of terrain characteristics, and other influencing factors of O_3 in the ambient pollution of different cities, but have rarely analyzed the changes and differences among multiple stations (Yang et al., 2021; Kong et al., 2022; Quan et al., 2022; Liu et al., 2020; Sun et al., 2016). The central southern region is one of the developed agricultural regions in China, and Changsha is an important new first-tier city. In the last decades, rapid urbanization, industrialization, and agricultural modernization have led to a continuous increase in the number of motor vehicles and the quantity of coal combustion products with high energy consumption in the industry. The pollution problems due to $PM_{2.5}$ and O_3 are prevalent in the entire Hunan Province (Liu et al., 2022). However, the deteriorating trend of O_3 pollution has not been effectively alleviated. Therefore, O_3 pollution in the major cities in the central and southern regions has become a serious concern. In the past, O_3 pollution was mainly distributed in Beijing, Tianjin, Hebei, the Yangtze Delta, and the Pearl River Delta urban regions, and the research on major cities or regions, particularly in Changsha, with their unique geographical and climatic characteristics, was not enough. Therefore, this study aimed to analyze and preliminarily investigate the characteristics of O_3 concentration and the causes of pollution in each pollution period in 2021 in Changsha. The similarities and differences in the characteristics of O_3 pollution in Changsha and other regions as well as the changes in O_3 concentration between stations were analyzed, and the impact of terrain, precursors, and meteorological conditions on O_3 concentration was clarified, to establish scientific scaffolds for the prediction, warning, and control of ozone pollution in this city. The purposes of this study were as follows: (a) Analyze the current situation and problems of O_3 pollution in Changsha and clarify the pollution degrees of the six standard pollutants; (b) investigate the spatiotemporal variation

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characteristics of O_3 concentrations in 14 environmental monitoring stations in Changsha; (c) analyze the relationships between the primary precursors and O_3; and (d) clarify the correlation between changes in O_3 concentration and meteorological factors.

Materials and methods

Overview of the research area

Changsha is located in central China, north of eastern Hunan Province (27°51′—28°41′N, 111°53′—114°15’E), along the lower reaches of the Xiangjiang River, and on the western edge of the Changsha Basin. It spans 230 km from east to west, 88 km from north to south, covering an area of 11,819 km^2. Its population density is high, with a total population of more than 7.9 million. It has a mild subtropical monsoon climate with abundant precipitation. Its rainy season is hot, and all four seasons are well-defined. The annual average temperature is 17.2℃, and the average yearly precipitation amounts to 1361.6 mm (Jia et al., 2017).

The study sourced online atmospheric observation data from 10 national and 4 provincial control air automatic monitoring stations in Changsha. The national control stations (Environmental Protection Bureau in the Gaokai District, Hunan Normal University, Hunan University of Chinese Medicine, Environmental Protection Bureau in the Tianxin District, New Railway Station, Mapoling, Wujialing, Shaping, Environmental Protection Bureau in the Yuhua District, and Environmental Protection Bureau in the Economic Development Zone) were concentrated in the main urban area of the city. In contrast, the provincial control stations (Environmental Protection Bureau in the Ningxiang City, Management Committee in the Economic Development Zone of Wangcheng District, Changsha County Government, and Environmental Protection Bureau in the Liuyang City) were distributed in the suburb. The study period was from January 1, 2021, to December 31, 2021 (*Fig. 1; Table 1*). In this study, the seasons were divided based on the regulations of the China Meteorological Administration (QX/T152-2012): spring (March and May), summer (June and August), autumn (September and November), and winter (December and February). Each administrative region in Changsha had a monitoring station. These locations were selected to reflect the diversity of potential sources of variability of air pollution in Changsha, such as population density (882 people/km^2), transportation environment, industry, and geographical and climatic conditions. Therefore, the data thoroughly reflected the overall O_3 pollution situation in Changsha.

Data source and preliminary processing

The hourly monitoring data of O_3, $PM_{2.5}$, PM_{10}, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) in the 10 national and 4 provincial control stations of Hunan Provincial Ecological Environment Monitoring Center in 2021, as well as the meteorological data and observation data (temperature, pressure, RH, wind speed, and wind direction) of Hunan Provincial Meteorological Station in 2021, were taken as the data source. The missing or abnormal data were fixed by linear interpolation. According to the standards “Environmental Air Quality Standard” (GB 3095-2012) and “Technical Specification for Environmental Air Quality Assessment (Trial)” (HJ 663-2013), the daily maximum 8-h dynamic average concentration value of O_3 (O_3−8 h) and the hourly average concentration value of O_3 (O_3−h) are the common

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O_3 evaluation indicators. The O_3−8 h index was used to assess the O_3 concentration and excessive emissions in this study. Excel and Origin 2021 were used to analyze, process, evaluate, and plot the relevant data.

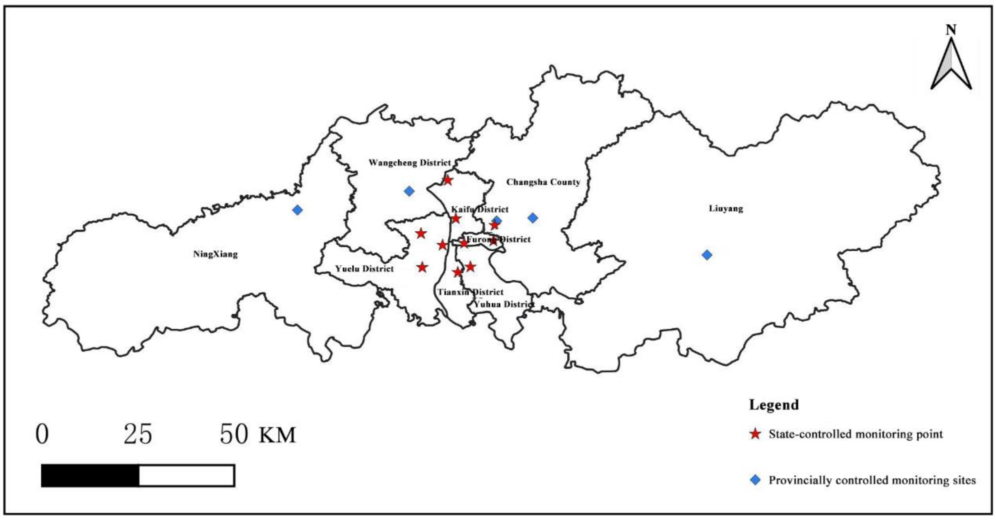

Figure 1. *Spatial distribution of O_3 monitoring stations in Changsha*

Table 1. *Names and abbreviations of 14 monitoring stations in Changsha*

No	Point name	Abbreviation
1	New Railway Station	HCXZ
2	Hunan Normal University	HNSF
3	Shaping	SP
4	Hunan University of Chinese Medicine	HNZYY
5	Environmental Protection Bureau of Economic and Technological Development Zone	JKHB
6	Mapoling	MPL
7	Environmental Protection Bureau of Tianxin District	TXHB
8	Wujialing	WJL
9	Environmental Protection Bureau of Yuhua District	YHHB
10	Environmental Protection Bureau of Gaokai District	GKHB
11	Ningxiang Environmental Protection Bureau	NXHB
12	Management Committee of Wangcheng District Economic Development Zone	WCJK
13	Changsha County Government	CCX
14	Liuyang Environmental Protection Bureau	LYHB

Results and discussion

Current situation of atmospheric environment pollution in Changsha in 2021

According to the quality required by the environmental functional zone defined in Section 4 of the "Environmental Air Quality Standard" (GB 3095-2012) (*Table 2*), the threshold values of level-2 standards for the annual average concentrations of SO_2, NO_2, PM_{10}, and $PM_{2.5}$ in region II were 60, 40, 70, and 35 μg/m^3, respectively. The threshold value of 24-h average CO concentration was 4 mg/m^3. In 2021, the annual average concentrations of SO_2, NO_2, and PM_{10} pollutants at the 14 environmental monitoring

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stations in Changsha did not exceed the threshold values of level-2 standards (*Fig. 2*), but the $PM_{2.5}$ concentrations in most of the stations exceeded the threshold value and were significantly higher than those of the other pollutants. Only the values in Environmental Protection Bureaus in the Ningxiang and Liuyang cities did not exceed the threshold value. The average annual $PM_{2.5}$ concentrations in other monitoring stations were in the range of 37–46 μg/m^3, and the average annual PM_{10} concentration in each station was in the range of 44–59 μg/m^3, which were significantly higher than those of other pollutants. The average annual concentrations of SO_2, NO_2, and CO were relatively low, without exceeding the threshold values of level-2 standards. This indicated that SO_2, NO_2, and CO were not the dominant influencing factors of air quality in Changsha in 2021.

***Table 2.** Concentration limits of basic items of ambient air pollutants*

No	Pollutant item	Meantime	The limit of concentration		Unit
			First-order	Second-order	
1	SO_2	Annual mean	20	60	μg/m^3
		24-h average	50	15	
		1-h average	150	500	
2	NO_2	Annual mean	40	40	
		24-h average	80	80	
		1-h average	200	200	
3	CO	Annual mean	4	4	mg/m^3
		24-h average	10	10	
4	O_3	The daily maximum 8-h average	160	200	μg/m^3
		1-h average	160	200	
5	PM_{10}	Annual mean	40	70	
		24-h average	50	150	
6	$PM_{2.5}$	Annual mean	15	35	
		24-h average	35	75	

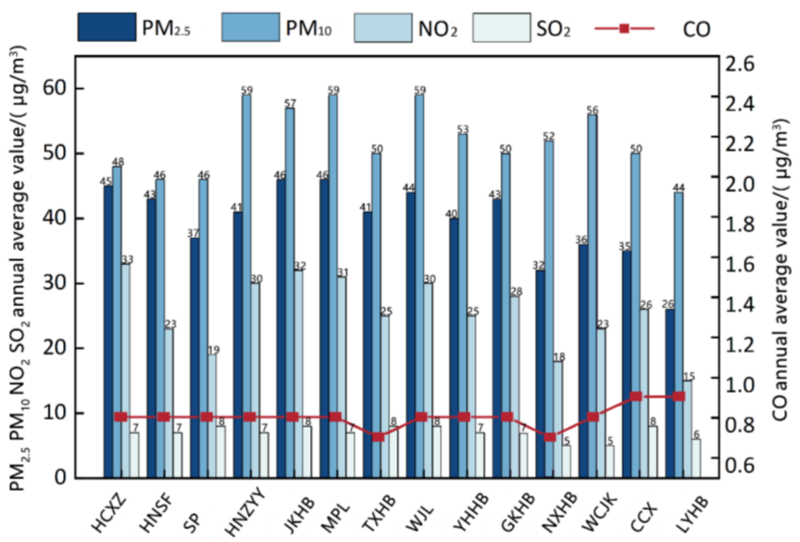

***Figure 2.** Annual mean values of pollutant concentrations in the monitoring stations in Changsha in 2021*

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Additionally, the number of O_3 pollution days in the 14 environmental monitoring stations in Changsha in 2021 was in the range of 0–29 days (*Fig. 3*). The difference among these stations was obvious. Hunan Normal University, Shaping; Environmental Protection Bureau of Economic Development Zone, Mapoling; Environmental Protection Bureau of Tianxin District, Wujialing; and Environmental Protection Bureau of Gaokai District all reported more than 20 pollution days. In contrast, the Environmental Protection Bureaus of Ningxiang and Liuyang reported zero pollution days. The ratios of pollution days in these 14 environmental monitoring stations with $PM_{2.5}$ as the dominant pollutant accounted for 1.9%–13.1%. Notably, urban areas experienced significantly more pollution days than the suburbs. Among these stations, the dominant pollutant in the New Railway Station, Environmental Protection Bureau of Economic and Technological Development Zone, Mapoling, Wujialing, and Environmental Protection Bureau of Gaokai District all recorded over 40 pollution days with $PM_{2.5}$ as the primary pollutant. However, for all these stations, the dominant pollutant did not exceed 10 days. According to the previous analysis results, the seriously polluted stations among the 14 monitoring stations in Changsha were located in the urban area, which might be ascribed to their terrains. The northeast and northwest regions of Changsha are surrounded by mountains, the central terrain is relatively flat, and hillocks are distributed in most of the urban region. These special terrains led to the concentration of particulate matter in the urban area with poor diffusion performance. The volatile organic compounds in each monitoring site were mainly alkanes, followed by aromatic hydrocarbons and olefins. The main sources of hydrocarbon compounds in Changsha urban site were liquefied petroleum gas, motor vehicle exhaust emissions, and organic solvents. VOCs, as the precursors of O_3 and secondary organic aerosol (SOA), are important in the formation of air pollution (Fu et al., 2021; Hui et al., 2019). Therefore, particulate pollution was more serious in the urban region than in the suburbs. Additionally, the rising trend of O_3 pollution was not effectively alleviated, indicating that Changsha was affected by both ozone and particulate matter in 2021. In contrast, only 8 days of particulate matter pollution took place in the provincial control station of Liuyang Environmental Protection Bureau, and the excess of O_3 concentration was not observed.

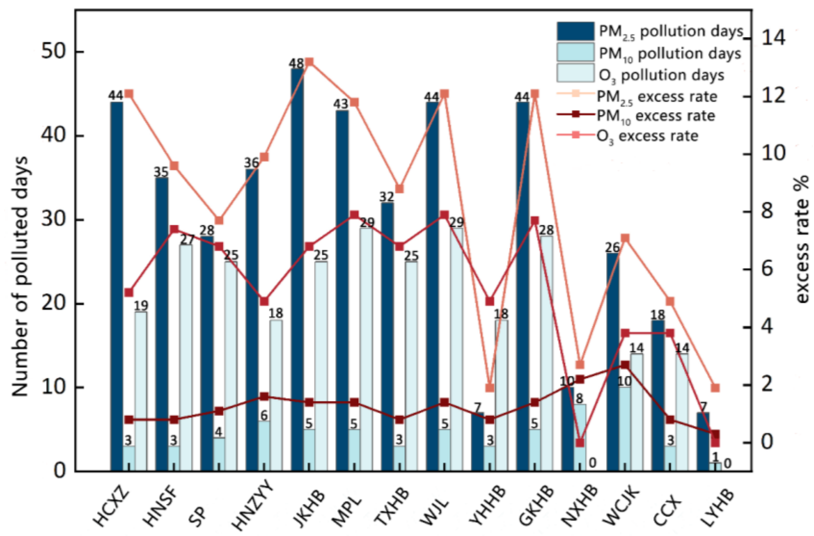

***Figure 3.** Days of pollution and ratios of pollution days in the monitoring stations in Changsha in 2021*

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Temporal variation characteristics of O_3 in the monitoring stations in Changsha in 2021

Daily variation characteristics

The daily variation characteristics of hourly O_3 concentrations in these 14 environmental monitoring stations in Changsha in 2021 are depicted in *Figure 4*. The hourly O_3 concentrations represent the arithmetic mean values of O_3 concentrations within 1 h in each monitoring station. Generally speaking, the data showed an obvious "unimodal" trend, with daytime concentrations much higher than nighttime concentrations. The daily concentrations were in the range of 29–94 μg/m^3, and the daily O_3 concentrations varied by following these three stages. In the first stage, O_3 accumulated, when the tropospheric temperature was low without the solar radiation. The titration effect of NO was weak due to the low lighting intensity. From 8:00 to 10:00, the concentration of O_3 commenced to dramatically increase, and this was the O_3 generation stage. Subsequently, as the lighting further intensified, the photochemical reaction rate to give O_3 improved and the rate reached a maximum between 14:00 and 17:00. The changes in the O_3 concentrations of these stations were different. The O_3 concentration changes in the provincial control monitoring stations were much more obvious than those in the national control monitoring stations. The daily variation characteristics of O_3 concentrations were obvious in the national control stations, including Hunan Normal University, Shaping; Environmental Protection Bureau of the Economic Development Zone, Mapoling; and Wujialing. The O_3 concentrations in the provincial control stations were ranked in the following order: Ningxiang Environmental Protection Bureau > Wangcheng District Economic Development Zone Management Committee > Changsha County Government > Liuyang Environmental Protection Bureau. The lowest O_3 concentration in Liuyang Environmental Protection Bureau was possibly because of its special geographical location, mountainous and superior natural environment, and relatively weak pollution from traffic and other emission sources. This result was substantially consistent with the analysis results of daily O_3 concentration variation trends in Zhaoqing and Guangzhou Cities observed by Weng et al. (2021) and Huang et al. (2018).

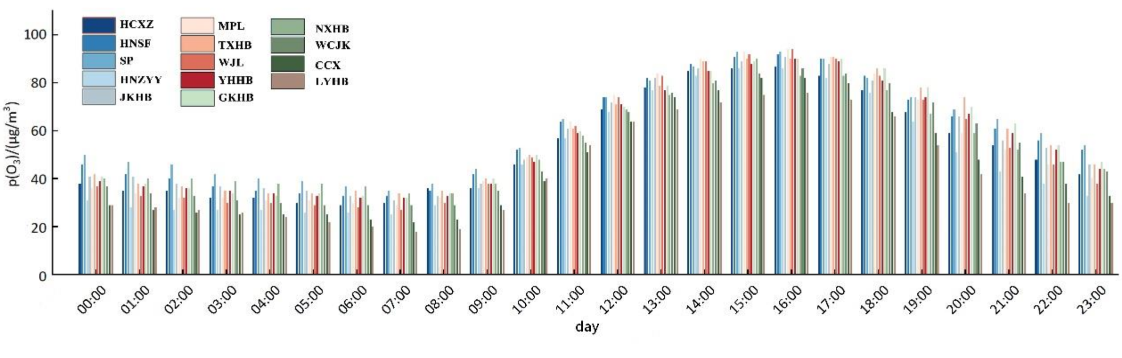

Figure 4. *Variations in hourly O_3 concentrations in the monitoring stations in Changsha in 2021*

Monthly and seasonal variation characteristics of O_3−8 h values

The monthly variation characteristics of O_3−8 h values in the 14 environmental monitoring stations in Changsha in 2021 are illustrated in *Figure 5*, where the O_3−8 h

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values represent the arithmetic mean values of the daily maximum 8-h O_3 concentrations. The monthly average O_3−8 h concentrations in Changsha in 2021 were in the range of 44–149 μg/m^3, and the O_3−8 h data showed a “bimodal” pattern over time. The first peak occurred in March to June, with a maximum of 127 μg/m^3. Although the O_3−8 h values slightly decreased from June to August, the profiles generally showed an upward trend. The second peak occurred from August to September, with a maximum of 149 μg/m^3. The possible reason for the two peaks was that the higher temperature during the day was conducive to the formation of ozone. From October, the solar ultraviolet radiation gradually weakened, the temperature gradually declined, and the cold-air outbreaks commenced. In this stage, the $PM_{2.5}$ emissions reached their maximum, and the concentrated $PM_{2.5}$ weakened the near-ground photochemical reaction rate to generate O_3, resulting in the low O_3−8 h values, which occurred in January, February, March, and December. In detail, the O_3−8 h values in all the stations in different months exhibited certain spatiotemporal characteristics. The O_3 concentrations were higher in the national control monitoring stations than in the provincial control monitoring stations. The O_3 concentration reached a maximum of 149 μg/m^3 in the Mapoling station in September, whereas it reached a maximum of 101 μg/m^3 in the Ningxiang Environmental Protection Bureau station. The difference was 48 μg/m^3. Based on the data of *Table 3* and *Figure 5*, the number of days with O_3 as the dominant pollutant in each station in the months with high O_3 concentrations was relatively large, and the ratios of days with O_3 as the dominant pollutant were the highest in September. Except for the Ningxiang and Liuyang Environmental Protection Bureaus, the other monitoring stations had 14–29 days with O_3 as the dominant pollutant. From November to March of the next year, the number of days with O_3 as the dominant pollutant was small, even zero, indicating that the high concentration of O_3 at a specific site was controlled by various factors such as terrain, primary emissions, photochemical reactions, and so forth. The formation mechanism of O_3 was more complex than that of other pollutants (Fu et al., 2021; Li et al., 2017).

Table 3. *The number of ozone pollutant days in each month of Changsha monitoring site in 2021*

Station name	January	February	March	April	May	June	July	August	September	October	November	December
HCXZ	−	−	−	1	1	5	2	3	7	−	−	−
HNSF	−	−	−	−	2	6	2	3	14	−	−	−
SP	−	−	−	1	2	6	2	3	11	−	−	−
HNZYY	−	−	−	−	2	6	1	2	7	−	−	−
JKHB	−	−	−	1	1	6	3	3	11	−	−	−
MPL	−	−	−	−	3	6	4	4	12	−	−	−
TXHB	−	−	1	−	1	5	1	3	12	−	1	1
WJL	−	−	−	1	2	8	3	3	11	−	−	1
YHHB	1	−	−	−		4	1	3	9	−	−	−
GKHB	−	−	−	1	2	7	4	3	9	2	−	−
NXHB	−	−	−	−	−	−	−	−	−	−	−	−
WCJK	−	−	−	−	3	4	1	1	5	−	−	−
CCX	−	−	−	−	−	3	2	2	4	3	−	−
LYHB	−	−	−	−	−	−	−	−	−	−	−	−

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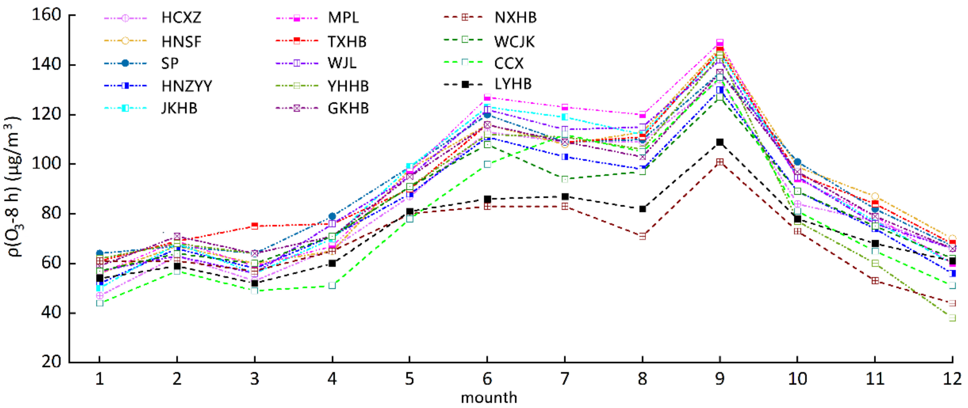

Figure 5. *Variations in O_3−8 h values in the monitoring stations in Changsha in 2021 in different months*

Figure 6 depicts the seasonal variation characteristics of O_3−8 h values in the 14 environmental monitoring stations in Changsha in 2021. The seasonal concentration value in this study stood for the arithmetic mean concentration value of the daily average maximum 8-h dynamic O_3 concentration within a quarter. In 2021, the O_3 concentrations in the 14 monitoring stations in Changsha were higher in summer and autumn compared with spring and winter, and the maximum values occurred in summer, which were in the range of 79–123 μg/m^3. The low values in winter were in the range of 50–66 μg/m^3. The O_3 concentrations were in the order of summer > autumn > spring > winter. Similarly, the seasonal variations in O_3 concentrations were more obvious in the national control stations than in the provincial control stations. The O_3 concentration reached a maximum of 123 μg/m^3 in the National Control Station, Mapoling, while it reached a maximum of 104 μg/m^3 in Hunan University of Chinese Medicine. The difference was 19 μg/m^3. The O_3 concentrations in the provincial control stations in the summer were ranked in the following order: Ningxiang Environmental Protection Bureau (106 μg/m^3) > Changsha County Government (100 μg/m^3) > Wangcheng District Economic Development Zone Management Committee (85 μg/m^3) > Liuyang Environmental Protection Bureau (79 μg/m^3). Generally speaking, the monthly and seasonal variation trends of O_3 were similar to those of most other cities, which were principally consistent with the analysis results of monthly and seasonal changes of O_3 concentrations in Zhengzhou and Chenzhou observed by Liu et al. (2022) and Zhou et al. (2022). In this study, the O_3−8 h values showed opposite seasonal variation trends compared with $PM_{2.5}$, PM_{10}, and NO_2 possibly because the boundary layer was higher in summer and autumn, promoting the downward transport of O_3 from the stratosphere to the near-ground space (Mao et al., 2020).

Relationship between O_3 and the precursor NO_2 in each monitoring station in Changsha

According to the analysis results earlier, various factors, such as solar radiation, terrain, and primary emissions, controlled and affected the O_3 concentrations in the monitoring stations. Similarly, the precursors (NO_2, VOCs, and so on) were also important influencing factors. The daily variations in O_3 and NO_2 concentrations in the 14 monitoring stations in Changsha in 2021 are illustrated in *Figure 7*. The NO_2 concentrations in all the stations fluctuated. The NO_2 concentrations commenced to rise in the early morning, which was the early rush hour. The increase in automobile exhaust emissions of urban vehicles was an important reason for the elevated NO_2 concentrations.

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From 9:00 to 17:00, the quantity of NO_2 emissions reduced. The surface temperature continued to rise and the solar radiation continued to strengthen when NO_2 was continuously consumed to generate O_3. After 19:00, the NO_2 concentration commenced to gradually increase and reached its maximum at around 10:00. This trend continued until the next early morning. Then, the concentration declined gradually. After 17:00, solar radiation barely existed, and late rush hour took place in the city. In addition, the evening activities, such as barbecues and night snacks, were launched due to the rich and colorful night activities in Changsha, being the provincial capital city of Human province. The NO_2 concentration commenced to rise again, which was due to urban transportation, meteorological conditions, and emission sources (Fu et al., 2021). Obviously, the O_3 and NO_2 concentrations show opposite variation trends in this figure. The O_3 concentration exhibited a typical “inverted U-shaped” profile, whereas that of NO_2 principally showed a “U-shaped” profile. The variations in NO_2 concentrations were more evident in the national control stations than in the provincial control stations. Therefore, the relationship between O_3 concentration and the concentration of precursor NO_2 was analyzed from the perspective of principles of variations of photochemical reactions (Wang et al., 2017). The O_3 in the Earth’s atmosphere is finally generated from the combination reaction of atomic oxygen (O_3P) and molecular oxygen (O_2), and the O_3P is principally generated from the photolysis of NO_2 in the troposphere, promoting the formation of O_3. Once O_3 is formed, it easily reacts with NO to generate NO_2 again. If other chemicals are not involved, recycling reactions occur. However, the troposphere contains other oxidants, especially free radicals (HO_2 and RO_2), which can effectively convert NO into NO_2, leading to the accumulation of O_3. An effective “NO_x cycle” is established in the entire reaction process, and O_3 is generated without the consumption of NO_x. The entire reaction process of O_3 is extremely complex. If the NO level is high, usually in polluted urban areas, the production of O_3 is inhibited, and the “NO_x titration state” takes place (Tan et al., 2019). Although the quantity of NO*x* emissions continues to decrease, the research results based on observations and emissions suggest that certain locations in the major urban areas in China may still be in the state of VOC−NO_x combustion emissions or O_3 generation restricted by NO_x during certain periods (Tan et al., 2018). Obtaining other precursors was difficult in this study, and the contributions of photochemical interactions of various precursors to the generation of O_3 should be analyzed in the future. This study emphasized that reducing O_3 pollution via concerted control of VOC−NO_x was necessary.

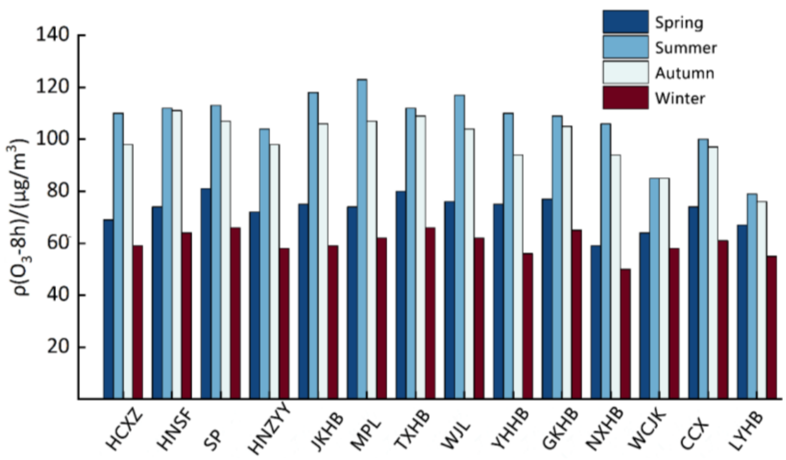

Figure 6. *Variations in O_3−8 h values in the monitoring stations in Changsha in 2021 in different seasons*

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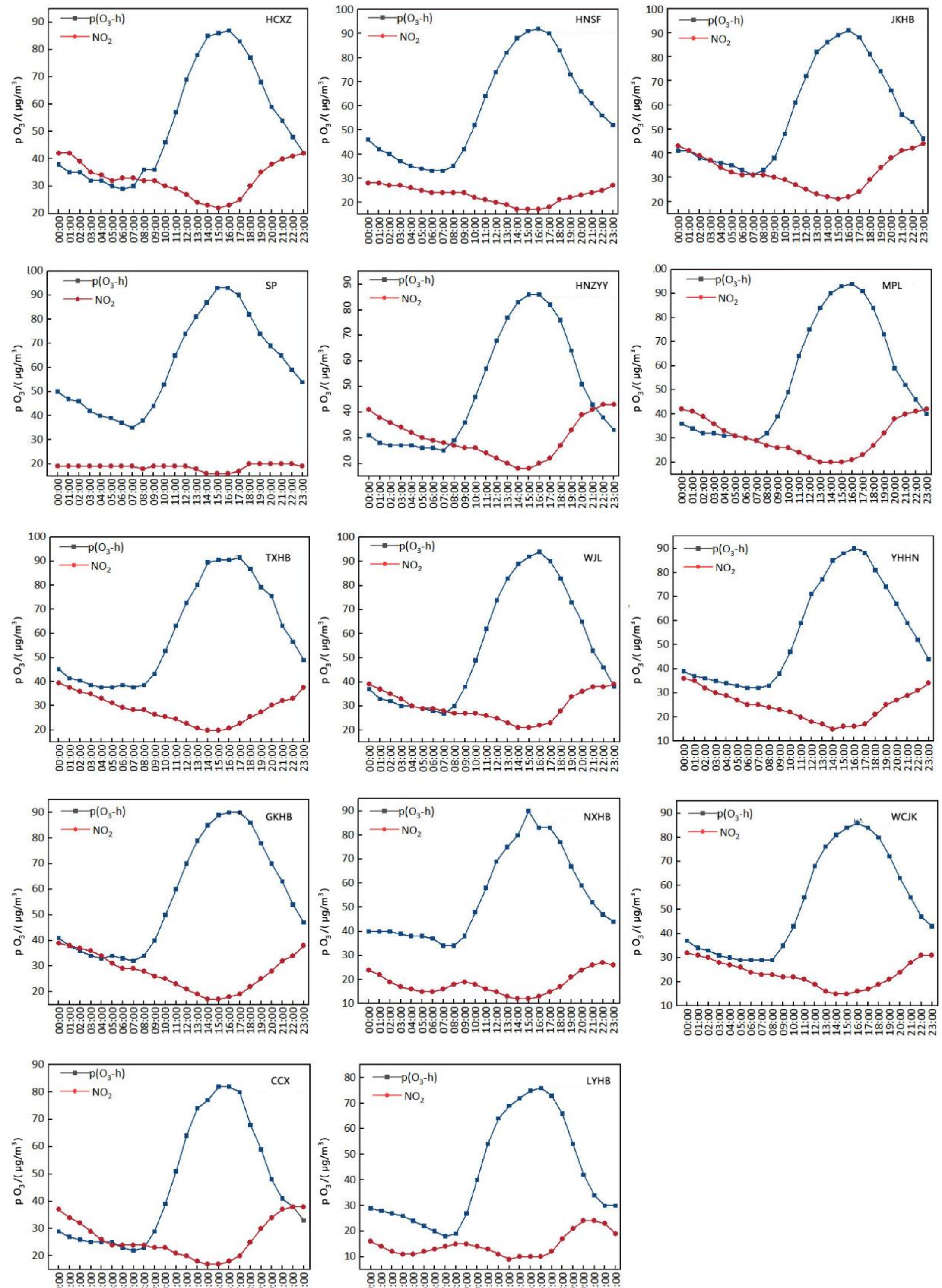

***Figure 7.** Daily variations in O_3 and NO_2 concentrations in the monitoring stations in Changsha in 2021*

Analysis of the relationship between O_3−8 h and meteorological factors

Studies reported that an increase in O_3 concentration at a city scale was related to artificial sources (industrial emissions, automobile exhaust, solvent application, biomass

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combustion, fuel evaporation, and so on), emissions from biological sources (plant), as well as atmospheric transport capacity, dry and wet deposition of gases and aerosols, chemical reactions, and natural emission rates determined by meteorological conditions (Mozaffar et al., 2021). Wu et al. (2017) reported that the high-temperature and low-humidity conditions were favorable to the occurrence of O_3 pollution events in Chengdu. Deng et al. (2021) analyzed the relationship between O_3 concentration in Wuyishan City and meteorological conditions and reported that the O_3 concentration was significantly positively correlated with ultraviolet radiation and atmospheric temperature. At a wind speed of ≤ 2.0 m/s, the frequency of excessive O_3−8 h values also increased. Bai et al. (2022) analyzed the average mass concentration of O_3−8 h in Tianjin and found that the concentration of O_3 was relatively high under the conditions of daily maximum temperature >30℃, RH of 20%–70%, southwest or southeast wind speed of 1−2.5 m/s, and daytime boundary-layer height < 1400 m. Based on these studies, this study preliminarily explored the relationship between the O_3 concentration and meteorological factors in the environmental monitoring stations in Changsha. The correlations between O_3−8 h and wind speed, wind direction, atmospheric pressure, atmospheric temperature, and humidity are shown in *Figure 8*. The correlation coefficients between O_3 concentration and meteorological factors were not consistent. The O_3 concentration was significantly positively correlated with daily average wind speed and atmospheric temperature and extremely correlated with atmospheric temperature, with a correlation coefficient of 0.65. The O_3−8 h value was negatively correlated with the wind direction, atmospheric pressure, and humidity and significantly negatively correlated with the wind direction and RH. The correlation coefficient between O_3−8 h value and RH was as low as −0.48. Therefore, the impact of temperature, humidity, and wind speed on O_3−8 h in Changsha was analyzed. The national control monitoring station Environmental Protection Bureau in the Tianxin District and the provincial control monitoring station Environmental Protection Bureau in Liuyang City were selected because one was located in the urban area and the other in the suburb. The difference between the two stations was obvious, and hence the contrast was strong. The meteorological data of the two stations was intact without missing values.

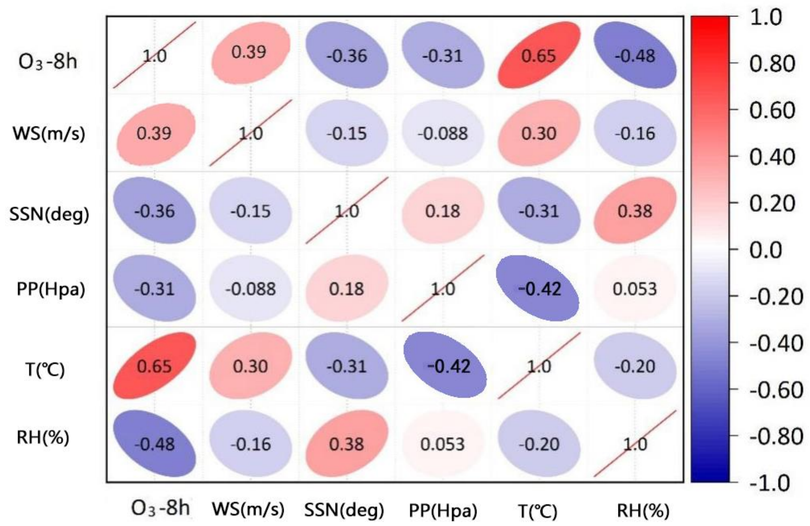

Figure 8. *Correlations between O_3-8 h value and meteorological factors. WS-Wind speed; SSN-wind direction; PP-atmospheric pressure; T-atmospheric temperature, and RH-humidity*

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Analysis of the relationships between O_3−8 h and atmospheric temperature, humidity, and wind speed

The O_3−8 h value gradually increased with the increase in temperature (*T*). At $T < 10$°C, the O_3 concentration reached a minimum of only 52 μg/m^3, and the ratio of pollution days based on O_3−8 h was 0 (*Table 4*). At $10 < T < 20$°C, the O_3 concentration was still low. At $T > 30$°C, the O_3−8 h value increased from 71 to 116 μg/m^3, an increase of 45 μg/m^3. The ratio of pollution days reached 12.9%. However, the RH had the opposite effect on the O_3−8 h value compared with the atmospheric temperature. The higher the RH, the lower the O_3−8 h value. Under the condition of RH > 90%, the O_3 concentration was merely 49 μg/m^3. Moreover, under the condition of RH > 70%, the ratio of pollution days based on O_3−8 h was 0. Under the condition of 50% < RH ≤ 70%, the O_3−8 h value was 98 μg/m^3, with a low ratio of pollution days of only 3.4%. Under the condition of RH ≤ 50%, the O_3 concentration increased from a minimum of 49 μg/m^3 to 109 μg/m^3, an increase of 60 μg/m^3. The ratio of pollution days based on O_3−8 h reached 14.2%. The effects of wind speed and RH on the O_3−8 h value were similar. Namely, the increase in the wind speed inhibited the generation of O_3, while a low wind speed promoted the generation of O_3−8 h, indicating that the conditions of high temperature, low humidity, and low wind speed contributed to the pollution due to concentrated O_3. In detail, the conditions of an atmospheric temperature of around 30°C, RH of around 50%, and wind speed of 0.5−2 m/s were favorable to the generation of O_3 in Changsha.

Table 4. *Relationships between the daily average atmospheric temperature, wind speed, humidity, and O_3−8 h in the monitoring stations in Changsha in 2021*

Daily average atmospheric temperature (*T*/°C)	**O_3−8 h (μg·m^{-3})**	**Ratio of pollution days based on O_3−8 h/%**	**Daily average relative humidity (RH/%)**	**O_3−8 h (μg·m^{-3})**	**Ratio of pollution days based on O_3−8 h/%**	**Daily average wind speed (F/m/s)**	**O_3−8 h (μg·m^{-3})**	**Ratio of pollution days based on O_3−8 h/%**
$T \leq 10$	52	0	RH ≤ 50	109	14.2%	F ≤ 1	77	1.4%
$10 < T \leq 20$	71	1%	50 < RH ≤ 70	98	3.4%	1 < F ≤ 2	89	3.2%
$20 < T \leq 30$	95	2.4%	70 < RH ≤ 90	74	0	2 < F ≤ 3	88	4.1%
$T > 30$	116	12.9%	RH > 90	49	0	F > 3	0	0

The scatter plots and fit results of the O_3−8 h values, atmospheric temperature, RH, and wind speed are shown in *Figure 9*. The O_3−8 h values were positively correlated with the temperature and wind speed while negatively correlated with the RH. The O_3−8 h values obviously increased with the increase in temperature. The daily maximum temperature was directly related to the solar radiant intensity and radiation duration. At a higher temperature, the quantity of O_3 produced by the photochemical reactions increased. The fit results of O_3−8 h against RH showed that the fit was good if the RH of the urban region was in the range of 40%–80% or the RH of the suburb was in the range of 60%–80%. The increase in humidity would reduce the quantity of O_3 generated. However, the fit was good if the wind speed in the urban stations was in the range of 0.5–2.0 m/s, or the wind speed in the suburban stations was in the range of 0.5–1.5 m/s. These findings, together with the conclusions from various studies, disclosed the importance of meteorological factors in determining the interannual variation in O_3 concentration in summer. In addition, meteorological factors are also crucial in evaluating the effectiveness of emission control measures. The meteorological conditions such as temperature and humidity alter the distribution efficiency of chemical reactions and dry

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deposition, thus regulating the production and loss of O_3 (Wang et al., 2020). Previous studies have shown that the concentrated O_3 is usually formed under the conditions of long sunshine hours, low wind speed, and low RH, which are favorable to the photochemical reactions of O_3 and the accumulation of O_3 precursors. The wind direction is also essential because it can affect the transportation of pollutants, thereby forming concentrated O_3 in the wind direction (Huang et al., 2019). Therefore, the meteorological and environmental departments should focus on the crucial impact of meteorological factors on the short-term changes in O_3 concentration.

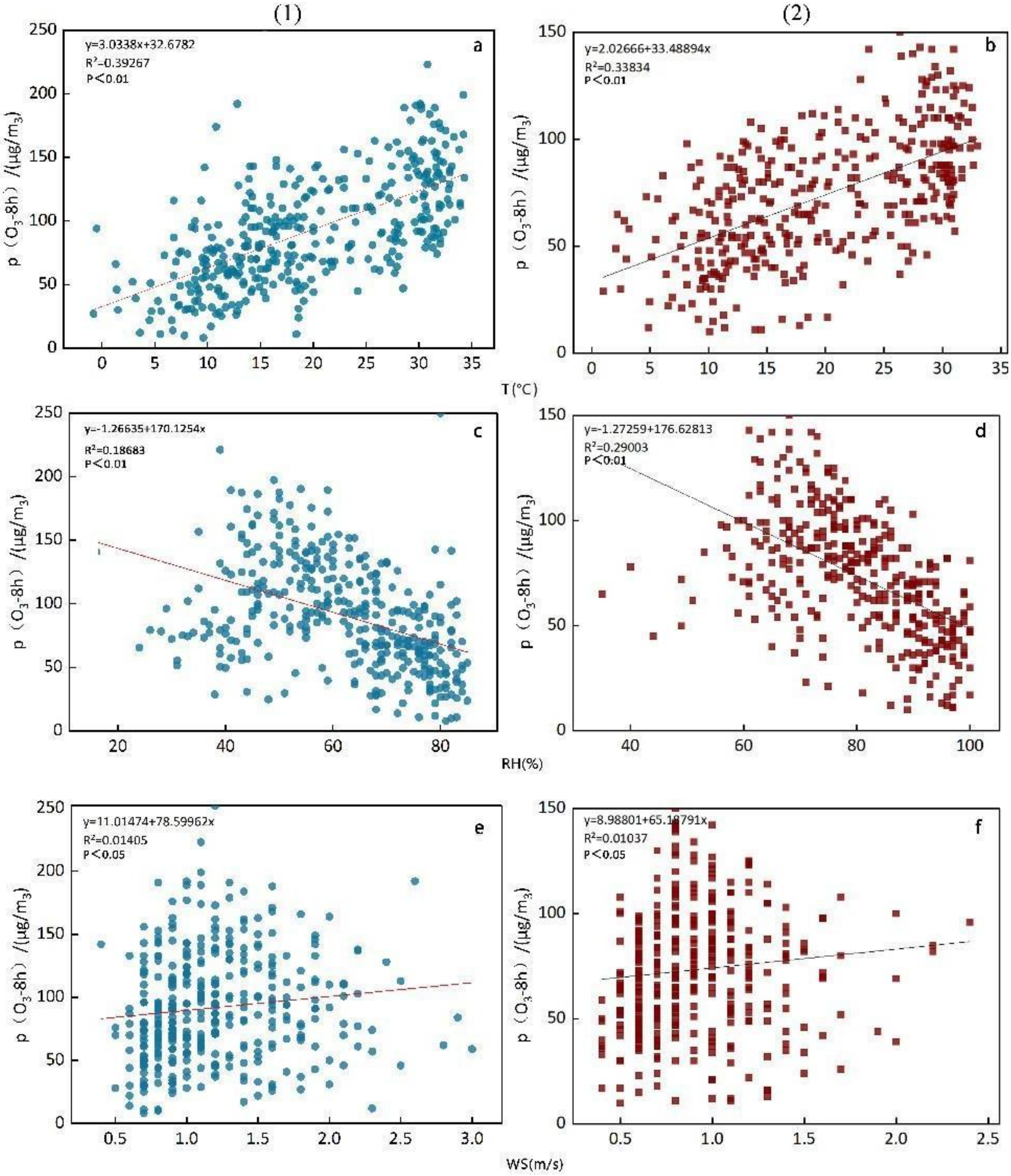

Figure 9. *Scatter plots and fit results of the O_3 concentrations and meteorological factors. (1) Environmental Protection Bureau in the Tianxin District, and (2) Environmental Protection Bureau in the Liuyang City. T-Atmospheric temperature; RH-Relative humidity; WS-Wind speed*

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Discussion

During 2021, the air quality of 14 environmental monitoring stations in Changsha was less affected by sulfur dioxide, nitrogen dioxide (NO_2), and carbon monoxide. Particulate matter and O_3 were the main factors affecting air quality. Analysis revealed that the increasing trend of ozone concentration in Changsha was primarily attributed to the rapid rise in emissions of ozone precursors such as volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Overall, industrial emissions and traffic exhaust were the main contributors to this issue. Changsha’s numerous factories and enterprises had a noticeable impact on air quality due to their emissions of waste gas and particulate matter. Furthermore, the substantial increase in the city’s car population has led to motor vehicle exhaust emissions becoming a significant factor in air pollution, exacerbating the air quality problem.

In addition, the short-term impact of seasonal meteorological effects on ozone concentration varied greatly. Changsha is located in the subtropical monsoon climate zone, which is conducive to the formation of ozone, leading to ozone-induced pollution events and further aggravating air pollution problems. At the same time, previous studies had shown that high temperature and low humidity were favorable meteorological conditions for photochemical reaction and ozone generation (Shen et al., 2015; Zhao et al., 2016). The results of this study also further proved that the influence of temperature and humidity on ozone concentration was relatively stable on the scale of diurnal variation and step change, and other meteorological factors (such as wind speed and air pressure) also had a great influence on ozone concentration. Chen et al. (2019) showed that the one-way influence mechanism of meteorology on ozone concentration in Beijing was relatively simple. In summer, high temperatures and low humidity were shown to be favorable conditions for ozone production, which is usually considered to be the main reason for the highest ozone concentration in summer. The results of this study also showed that the summer ozone concentration in Changsha was relatively less affected by meteorological factors. Therefore, the rapid increase of ozone precursors such as VOCs and NO_x in summer was the main reason for the increase of ozone concentration. VOCs and NO_x were mainly anthropogenic and natural source emissions (Dentener et al., 2006; Feng et al., 2018). Wang et al. (2018) used remote sensing images to monitor long-term biogenic emissions and found that warming had led to a significant increase in biogenic emissions in Beijing in recent years. Therefore, climate warming may be a major driving factor for the increase of ozone pollution events in China. At present, a large number of scholars have found that the use of meteorological means such as artificial rainfall and high-rise building sprinklers (Yu, 2014) reduced short-term ozone pollution and alleviated urban heat islands.

However, compared with other first-tier cities (such as Beijing, Shanghai, and Guangzhou), Changsha’s air pollution level had its unique characteristics compared with other large cities and regions. Changsha’s air pollution level was at an upper-middle level in the country. Compared with other small and medium-sized cities, Changsha had higher industrial activities and traffic density, resulting in larger emissions of pollutants such as particulate matter and ozone. This situation made Changsha face more complex challenges in improving air quality. To this end, the government needed to strengthen the management and supervision of industrial enterprises’ emissions, ensure that their emissions met national standards, and encourage enterprises to promote cleaner production technologies. In the meanwhile, established a sound monitoring system, regularly release emission data and environmental quality status, and promote enterprises to fulfill their environmental responsibilities. Furthermore, the construction of convenient bicycle lanes and walking systems to encourage non-motorized travel to reduce motor vehicle exhaust emissions, as well as the strengthening of the management and protection of green space to ensure it continued to play the role of purifying air, were potential solutions to reduce ozone pollution events.

Conclusions

The following conclusions were drawn from this study:

(a) SO_2, NO_2, and CO had little effect on air quality, while O_3 and particulate matter exceeded the standard pollution days significantly more than in suburban sites.

(b) The monthly and daily average concentrations and seasonal variations of O_3 concentration were different at different sites. The O_3 concentration in urban sites was significantly higher than that in suburbs.

(c) The concentration of O_3 and NO_2 showed an opposite trend. At the same time, under the influence of meteorological factors, the formation of O_3 in Changsha was promoted under certain conditions (about 30°C atmospheric temperature, about 50% relative humidity, and 0.5-2 m/s wind speed).

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REFERENCES

[1] Bai, Y., Li, Y., Guo, R., Kong, J., Liu, B. (2022): Analysis of the impact of meteorological factors on the ozone concentration in Tianjin. – Environmental Impact Assessment 44(02): 14-9.

[2] Chen, Z. Y., Zhuang, Y., Xie, X. M., Chen, D. L., Cheng, N. L., Yang, L., Li, R. Y. (2019): Understanding long-term variations of meteorological influences on ground ozone concentrations in Beijing During 2006-2016. – Environmental Pollution 245: 29-37.

[3] Deng, H. Y., Chen, L. X., Yu, Y. J., Wang, H. (2021): Analysis of the ozone distribution characteristics and relationship between ozone distribution and meteorological factors in Wuyishan City. – Ecology and Environmental Sciences 30(07): 1428-35.

[4] Dentener, F., Stevenson, D., Ellingsen, K., Van, N. T., Schultz, M., Amann, M., Atherton, C., Bell, N., Bergmann, D., Bey, I., Bouwman, L., Butler, T., Cofala, J., Collins, B., Drevet, J., Doherty, R., Eickhout, B., Eskes, H., Fiore, A., Gauss, M., Hauglustaine, D., Horowitz, L., Isaksen, I. S. A., Josse, B., Lawrence, M., Krol, M., Lamarque, J. F., Montanaro, V., Müller, J. F., Peuch, V. H., Pitari, G., Pyle, J., Rast, S., Rodriguez, J., Sanderson, M., Savage, N. H., Shindell, D., Strahan, S., Szopa, S., Sudo, K., Van Dingenen, R., Wild, O., Zeng, G. (2006): The global atmospheric environment for the next generation. – Environmental Science & Technology 40(11): 3586-94.

[5] Feng, Z. Z., Li, P., Yuan, X. Y., Gao, F., Jiang, L. J., Dai, L. L. (2018): Research progress on the ecological and environmental effects of surface ozone in China. – Acta Ecologica Sinica 38(05): 1530-41.

[6] Fu, S., Guo, M., Fan, L., Deng, Q., Han, D., Wei, Y., Luo, J., Qin, G., Cheng, J. (2021): Ozone pollution mitigation in Guangxi (south China) driven by meteorology and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_15911609

anthropogenic emissions during the COVID-19 lockdown. – Environmental Pollution 272: 115927.
[7] Fu, Y., Liao, H., Yang, Y. (2019): Interannual and decadal changes in tropospheric ozone in China and the associated chemistry-climate interactions: a review. – Advances in Atmospheric Sciences 36(9): 975-93.
[8] Fujita, E. M., Campbell, D. E., Stockwell, W. R., Saunders, E., Fitzgerald, R., Perea, R. (2016): Projected ozone trends and changes in the ozone-precursor relationship in the South Coast Air Basin in response to varying reductions of precursor emissions – J Air Waste Manag Assoc 66(2): 201-14.
[9] Huang, J., Liao, B. T., Wu, D., Wang, C. L., Lan, J., Shen, Z. Q., Tang, J., Liang, G. X. (2018): Analysis of the characteristics of near-ground ozone concentration and meteorological effects in Guangzhou. – Acta Scientiae Circumstantiae 38(01): 23-31.
[10] Huang, X. G., Zhao, J. B., Cao, J. J., Song, Y. Y. (2019): Spatiotemporal variation characteristics and driving factors of O_3 concentrations in Chinese cities. – Environmental Science 40(03): 1120-31.
[11] Hui, L., Liu, X., Tan, Q., Feng, M., An, J. L., Qu, Y., Zhang, Y. H., Cheng, N. L. (2019): VOC characteristics, sources and contributions to SOA formation during haze events in Wuhan, Central China. – Science of the Total Environment 650: 2624-39.
[12] Jia, H. Y., Li, M., Chen, B. F., Wang, J. K., Zhang, Y. F., Chen, N. L. (2017): Analysis of the characteristics of ozone concentration in urban area of Changsha. – Environmental Science & Technology 40(2): 168-173.
[13] Kong, X. R., Chen, M., Chen, H. R., Pan, F., Pang, K., Ma, C. Y., Zhang, Q. (2022): Variation characteristics of the near-ground ozone concentration in Lanzhou City and analysis of its influencing factors in 2018-2019. – Environmental Engineering 40(07): 69-75 + 152.
[14] Li, Y., Yin, S., Yu, S., Li, Y. S., Yu, S. J., Bai, L., Wang, X. D., Lu, X., Ma, S. L. (2021): Characteristics of ozone pollution and the sensitivity to precursors during early summer in central plain, China. – Journal of Environmental Sciences 99: 354-368.
[15] Li, Z., Gu, X., Wang, L. S., Li, D. H., Xie, Y. S., Li, K. T., Dubovik, O., Schuster, G., Goloub, P., Zhang, Y., Li, L. H. X., Ma, Y. Z., Xu, H. (2013): Aerosol physical and chemical properties retrieved from ground-based remote sensing measurements during heavy haze days in Beijing winter. – Atmospheric Chemistry and Physics 13(20): 10171-83.
[16] Lin, M., Fiore, A. M., Horowitz, L. W., Langford, A. O., Oltmans, S. J., Tarasick, D., Rieder, H. E. (2015): Climate variability modulates western US ozone air quality in spring via deep stratospheric intrusions. – Nature Communications 6(1): 1-11.
[17] Liu, C. W., Lian, X. B., Huang, J. P. (2020): Research progress on the spatiotemporal distribution and causes of ozone pollution in China. – Journal of Arid Meteorology 38(03): 355-61.
[18] Liu, C., Dong, J. L., Tian, L., Kong, H. J. (2022): Analysis of the ozone concentration characteristics and meteorological factors in Zhengzhou City in 2017. – Meteorological and Environmental Sciences 45(04): 33-38.
[19] Liu, Y. Y., Yang, L. F., Xie, D. P., Zeng, R. Y. Z., Huang, Z. J., Yang, J., Zhao, P., Han, J. L., Jia, W. C., Yuan, Z. B. (2022): Analysis of the principal characteristics of ozone pollution in Hunan Province and identification of dominant control factors of long-term variation trend. – Environmental Science 43(03): 1246-55.
[20] Mao, J., Wang, L. L., Lu, C. H., Liu, J. D., Li, M. G., Tang, G. Q., Ji, D. S., Zhang, N., Wang, Y. S. (2020): Meteorological mechanism for a large-scale persistent severe ozone pollution event over eastern China in 2017. – Journal of Environmental Sciences 92: 187-99.
[21] Meng, Li., Liu, H., Geng, G. N., Hong, C. P., Liu, F., Yu, Song., Tong, D., Zheng, B., Cui, Y. H., Man, Y. R., Zhang, Q., He, K. B. (2017): Anthropogenic emission inventories in China: a review. – National Science Review 4(6): 834-66.

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DOI: http://dx.doi.org/10.15666/aeer/2202_15911609

[22] Mozaffar, A., Zhang, Y. L., Lin, Y. C., Xie, F., Fan, M. Y., Cao, F. (2021): Measurement report: high contributions of halocarbon and aromatic compounds to atmospheric volatile organic compounds in an industrial area. – Atmospheric Chemistry and Physics 21(23): 18087-99.
[23] Quan, S., Liu, M. H., Chen, B. X., Huang, Y. H., Ma, Q. X., Han, Y. (2022): Characteristics of the near-ground O_3 pollution in Henan Province and the relationship between O_3 and meteorological factors. – Research of Environmental Sciences 35(12): 2666-2676.
[24] Shen, L., Mickley, L., Tai, A. (2015): Influence of synoptic patterns on surface ozone variability over the eastern United States from 1980 to 2012. – Atmospheric Chemistry and Physics 15(19): 10925-38.
[25] Sillman, S. (1999): The relation between ozone, NOx and hydrocarbons in urban and polluted rural environments. – Pergamon 12.
[26] Sun, L., Xue, L., Wang, T., Gao, J., Ding, A. J., Cooper, O., Lin, M. Y., Xu, P. J., Wang, Z., Wang, X. F., Wen, L., Zhu, Y. H., Chen, T. S., Yang, L. X., Wang, Y., Chen, J. M., Wang, W. X. (2016): Significant increase of summertime ozone at Mount Tai in Central Eastern China. – Atmospheric Chemistry and Physics 16(16): 10637-50.
[27] Tan, Z., Lu, K., Jiang, M. Q., Su, R., Dong, H. B., Zeng, L. M., Xie, S. D., Tan, Q. W., Zhang, Y. H. (2018): Exploring ozone pollution in Chengdu, southwestern China: a case study from radical chemistry to O_3-VOC-NOx sensitivity. – Science of the Total Environment 636: 775-86.
[28] Tan, Z. F., Lu, K. D., Jiang, M. Q., Su, R., Wang, H. L., Lou, S. R., Fu, Q. Y., Zhai, C. Z., Tan, Q. W., Yue, D. L., Chen, D. H., Wang, Z. S., Xie, S. D., Zeng, L. M., Zhang, Y. H. (2019): Daytime atmospheric oxidation capacity in four Chinese megacities during the photochemically polluted season: a case study based on box model simulation. – Atmospheric Chemistry and Physics 19(6): 3493-513.
[29] Wang, H., Wu, Q., Liu, H., Wang, Y., Cheng, H., Wang, R., Wang, L., Xiao, H., Yang, X. (2018): Sensitivity of biogenic volatile organic compound emissions to leaf area index and land cover in Beijing. – Atmospheric Chemistry and Physics 18: 9583-9596.
[30] Wang, M., Chen, W.T., Zhang, L., Qin, W., Zhang, Y., Zhang, X. Z., Xie, X. (2020): Ozone pollution characteristics and sensitivity analysis using an observation-based model in Nanjing, Yangtze River Delta Region of China. – Journal of Environmental Sciences 93: 13-22.
[31] Wang, T., Xue, L. K., Brimblecombe, P., Lam, Y. F., Li, L., Zhang, L. (2016): Ozone pollution in China: a review of concentrations, meteorological influences, chemical precursors, and effects. – Science of the Total Environment 1582-96.
[32] Wang, T., Xue, L. K., Feng, Z. Z., Dai, J. N., Zhang, Y. N., Tan, Y. (2022): Ground-level ozone pollution in China: a synthesis of recent findings on influencing factors and impacts. – Environmental Research Letters 17(6).
[33] Weng, J. F., Liang, X. Y., Deng, K. Q., Zhou, H. D., Lian, Q. M., Peng, D. (2021): Analysis of $PM_{2.5}$ and O_3 pollution characteristics and potential source areas in Zhaoqing City in different seasons. – Research of Environmental Sciences 34(06): 1306-1317.
[34] Wu, K., Kang, P., Wang, Z. S., Gu, S., Tie, X., Zhang, Y., Wen, X. H., Wang, S. H., Chen, Y. Z., Wang, Y., Chen, D. (2017): Study on the characteristics of ozone pollution and meteorological causes in Chengdu. – Acta Scientiae Circumstantiae 37(11): 4241-52.
[35] Xu, W. Y., Zhao, C. S., Ran, L., Deng, Z. Z., Liu, P. F., Ma, N., Lin, W. L., Xu, X. B., Yan, P. Z., He, X., Yu, J., Liang, W., Chen, L. (2011): Characteristics of pollutants and their correlation to meteorological conditions at a suburban site in the North China Plain. – Atmospheric Chemistry and Physics 11(9): 4353-69.
[36] Yang, M. Y., Wang, Y. W., Zhang, D., Xing, L. F. (2021): Preliminary analysis of the spatiotemporal distribution characteristics and pollution causes of ozone in Chongqing. – Acta Scientiae Circumstantiae 41(12): 5026-5037.

[37] Yao, Q., Ma, Z. Q., Hao, T. Y., Fam, W. T., Yan, X., Tang, Y. X., Cai, Z. Y., Han, S. Q. (2021): Spatiotemporal distribution characteristics and background concentration estimation of ozone in the Beijing-Tianjin-Hebei region. – Chinese Environmental Science 41(11): 4999 5008.
[38] Yu, S. (2014): Water spray geoengineering to clean air pollution for mitigating haze in China's cities. – Environmental Chemistry Letters 12: 109-116.
[39] Yu, Y. J., Meng, X. Y., Wang, Z., Zhou, W., Yu, H. X. (2020): Discussion on the trend and causes of urban ozone pollution in the Beijing-Tianjin-Hebei region. – Environmental Science 41(01): 106-14.
[40] Zhao, W., Fan, S. J., Guo, H., Gao, B., Sun, J. R., Chen, L. G. (2016): Assessing the impact of local meteorological variables on surface ozone in Hong Kong during 2000–2015 using quantile and multiple line regression models. – Atmospheric Environment 144: 182-93.
[41] Zhao, X. J., Zhao, P. X., Xu, J., Meng, W., Pu, W. W., Dong, F., He, D., Shi, Q. F. (2013): Analysis of a winter regional haze event and its formation mechanism in the North China Plain. – Atmospheric Chemistry and Physics 13(11): 5685-96.
[42] Zhou, Q. Y., Zeng, P. P., Yuan, T., Chen, W. (2022): Analysis of the atmospheric ozone pollution characteristics and meteorological conditions in Chenzhou urban region. – Proceedings of the Science and Technology Annual Conference of Chinese Society for Environmental Sciences in 2022(I): 275-283.

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