The University of
Nottingham

UNITED KINGDOM • CHINA , MALAYSIA

MRes in Environmental Engineering

Analysis and research on the change of ozone concentration in the near-surface atmosphere during the new crown epidemic in Zhejiang Province

By

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Thesis submitted to the University of Nottingham for the degree of Master by Research

June 2022

Abstract

With the rapid development of China's economy, ozone pollution has become increasingly serious in many cities and regions. It has become an important air pollutant second only to particulate pollutants. It is a research hotspot in the field of atmospheric environmental chemistry. China has implemented strict control measures, residents' travel and production activities have been strictly restricted, and the intensity of anthropogenic pollutant emissions has dropped to the lowest level in history favorable opportunity.

This study selects Zhejiang Province, relatively developed in the Yangtze River Delta region, as a specific research object. Based on the National Urban Air Quality Real-time Release Platform of China Environmental Monitoring Station monitoring data, 11 major cities in Zhejiang Province(Hangzhou, Jiaxing, Ningbo, Wenzhou, Wenling, Huzhou, Shaoxing, Jinhua, Quzhou, Lishui, and Taizhou) are systematically explored before and after the outbreak of the COVID-19 . The temporal and spatial changes of the near-surface ozone concentration and the number of days exceeding the standard characteristics (including interannual, seasonal, monthly, weekly, and intraday variations). The results show that after the outbreak, the ozone concentration changes at representative sites in cities at the same latitude are consistent with those before the outbreak and still show a gradual increase from west to east. But cities in the same longitude no longer show a decreasing trend from north to south. For the characteristics of the time change, after the outbreak, the difference in ozone concentration between seasons decreased, and the ozone concentration in winter increase, and the peak of ozone concentration appeared on Tuesday or Friday, no longer showing the "weekend effect". At the same time, the ozone concentration increases from 0:00 to 9:00 compared with the data before the outbreak,

In addition, this paper further selects Jinhua City, a representative city in central Zhejiang Province, to explore the influence factors of ozone concentration before and after the outbreak, including meteorological and pollution factors. The results show that for meteorological factors, before and after the outbreak, ozone concentration is positively correlated with temperature but negatively correlated with relative humidity. After the outbreak, the correlation between ozone concentration and temperature decreased than before, while the correlation between ozone concentration and relative humidity increase slightly. For polluting gases, before and after the outbreak, the monthly trend of ozone concentration is negatively correlated with the concentrations of NO_2, SO_2, $PM_{2.5}$, and PM_{10}. After the outbreak, the concentrations of $PM_{2.5}$, PM_{10}, and ozone have been on an upward trend until March. the ozone concentration has increase compared with the data before outbreak, but SO_2 and NO_2 have decreased significantly. Therefore, when formulating the ozone control measures in Zhejiang Province, the control of the emission of pollution factors should be strengthened.

Keywords: Zhejiang Province; ozone concentration; COVID-19

Acknowledgment

The road is a long way away, and I will have to go up and down to find it. Even though I am hesitant to give up, I am grateful to have arrived here.

First and foremost, please accept my gratitude to my Supervisor Jun He. Students are mostly considered to be careless with their studies. The supervisor's careful guidance is inextricably linked to the topic selection, design, development, and writing of this thesis. His pragmatic scientific spirit and practical scientific research attitude brought me into the academic hall and intoxicated it. My supervisor is generous and rigorous in his studies. His words and deeds in work, research, and life are a rare treasure in my future life. At the same time, thanks to the University of Nottingham Ningbo China for the massive data support.

The successful completion of the thesis is inseparable from the full support of every team member. I want to thank the professional brothers for their advice and help in my experimental operation and thesis ideas. I want to thank the teachers and class-fellows who worked diligently and studied hard in the team during the study period. I have benefited greatly from getting along with you in work, study, and life.

I want to thank my parents and family from the bottom of my heart for all the help and support they have given me for a long time. Because of them, I can feel the warmth of home anytime and anywhere.

I want to take this opportunity to thank everyone who has helped me along the way, both those I have thanked directly and those I haven't. Finally, I would like to express my heartfelt thanks to all the reviewers and experts who participated in defense of this thesis.

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Chapter One Introduction

1.1 Research background and significance

With the continuous acceleration of urbanization, industrialization, and regional economic integration in my country, the number of motor vehicles, energy use, and population has rapidly expanded, the high-density emission of pollutants, and the mutual transmission of pollutants between different cities and regions. All kinds of atmospheric pollution problems have become increasingly prominent, especially the compound air pollution with fine particulate matter ($PM_{2.5}$) and ozone (O3) as the main pollutants. $PM_{2.5}$ is widely concerned by the people of China as early as 2010. It has always plagued and affected people's lives as the primary pollutant. But compared with $PM_{2.5}$, ozone pollution is most easily overlooked, and it is also one of the most harmful air pollutions. At present, the pollution formed by the combination of particulate matter and ozone is a prominent form of air pollution in China. Due to the weak visibility of ozone pollution, it is easy to be ignored (Aneja et al., 2004), and the formation principle of ozone is complex, making it difficult to control. Therefore, Even though various localities take measures to reduce the $PM_{2.5}$ concentration year by year, the ozone concentration is increasing year by year, becoming another important pollutant that affects the national ambient air quality after $PM_{2.5}$ (Liu Xin, 2020).

Ozone, a blue gas with a fishy smell, plays a very important role in the chemistry of Earth's atmosphere. Most of the ozone on Earth is concentrated in the stratosphere, which absorbs most of the ultraviolet radiation from sunlight, protecting humans, animals, and plants from short-wave ultraviolet rays. However, a small part of ozone exists in the troposphere because of its strong oxidative activity. It strongly irritates the eyes and respiratory tract when the environmental concentration is high and seriously endangers human health. In addition, ozone is a greenhouse gas, which also has an important impact on climate change and air quality (Aneja et al., 2004), so it has become one of the research hotspots of environmental scholars in various countries in recent years. To cope with the increasing air pollution problem and improve air quality, the government has also successively issued a series of laws, regulations, and action plans. The emission of primary pollutants has been greatly reduced, but the ozone concentration has not fallen but risen, and ozone pollution has intensified.

In January 2020, the novel coronavirus (COVID-2019) epidemic spread across the country, causing serious impacts on the economy, industrial production, and social life. China has taken stringent measures, including the closing of restaurants, shopping malls, and schools, as well as imposing restrictions on public transportation, to halt the progression of the new crown epidemic and protect human health (such as planes, trains, buses, etc. and even private cars), reducing people's social interaction and non-essential business. Anthropogenic sources such as transportation emissions and industrial sources are major contributors to urban air pollutants (Lelieveld et al., 2015). Strict control measures include blocking traffic routes, restricting non-essential activities of the population, closing factories, schools, etc. (Zhao Xue et al., 2021). These measures have dramatically changed people's way of life, minimizing the large number of motor vehicles used for daily activities in cities. During the epidemic prevention and control period, the number of motor vehicles in large cities has dropped sharply, which has brought anthropogenic emissions of volatile organic compounds (VOCs) under control. Lockdowns during the COVID-19 pandemic reduced anthropogenic air pollutant emissions and thus provided a favorable opportunity to assess the impact of anthropogenic sources on air quality in urban agglomerations (Ki and Task Force -NCO, 2020; Rasool et al., 2020).

Zhejiang Province is located in the economically developed Yangtze River Delta region. The province with the highest economic and industrial activities is the largest energy consumer and has the most pollution in China (Zhang et al., 2022). In recent years, Zhejiang's economy has continued to develop, and the city's status has been continuously improved. At the same time, the problem of urban photochemical pollution represented by ozone has become increasingly prominent. This study investigated the gaseous pollution of eleven major cities in Zhejiang Province (Hangzhou, Jiaxing, Ningbo, Wenzhou, Wenling, Huzhou, Shaoxing, Jinhua, Quzhou, Lishui, and Taizhou) from January 1, 2019, to December 31, 2020. The continuous observation data of pollutants (ozone, nitrogen dioxide, sulfur dioxide, $PM_{2.5}$, and PM_{10}) and meteorological parameters (temperature, humidity) are analyzed to explore the temporal and spatial distribution and variation characteristics of ozone concentration in the lower troposphere in different cities before and after the outbreak. Jinhua City, the central city of Zhejiang Province, is selected to study the impact of various pollution factors and meteorological elements on ozone concentration and further analyze the changes in ozone generation before and after the closure of the city, and provide theoretical support for formulating and improving ozone control policies.

1.2 Research status

1.2.1 Sources and hazards of ozone

There are two main sources of tropospheric ozone: natural and anthropogenic. Natural sources include stratospheric input and tropospheric photochemical reactions. Many studies have shown that the stratosphere can transport ozone to the troposphere under certain atmospheric conditions, resulting in a local increase in ozone concentration. Photochemical reaction refers to the part generated from the reaction of naturally occurring nitrogen oxides (NOx) (soil, lightning, and stratospheric transport) and biologically emitted VOCs and generates ozone components through photochemical reactions. The source of tropospheric ozone in anthropogenic sources is the main cause of ozone pollution. In terms of chemical definition, ozone pollution is a secondary reaction formed by a series of photochemical reactions of oxygen in the atmosphere, NOx emitted from motor vehicle exhaust, industrial waste gas, etc., and volatile organic compounds (VOCs) under the condition of solar ultraviolet radiation Pollution (An Junlin et al., 2009). Among them, NOx mainly refers to NO and NO_2. Human activities mainly cause the increase in ozone content, and the main generation source is anthropogenic VOCs. Among the anthropogenic VOCs emissions, industrial sources, such as waste gas from heavy petrochemical production (including petroleum distillation, pyrolysis integration, and material synthesis), coal-fired power generation, and other biomass combustion are the main sources of emissions, accounting for up to 55%, and Ozone generation contributed significantly; followed by traffic sources and living sources. Among them, automobiles are an important source of pollution in urban areas. The exhaust gas of automobiles is rich in NO and VOCs, accounting for about 20% respectively, and contributes greatly to ozone generation. However, this point reflects different generative characteristics in other regions (Wu Kai et al., 2017).

Ozone is a light blue gas mainly present in the stratosphere of the atmosphere. The ozone layer can block ultraviolet radiation and protect humans from ultraviolet rays (Yan Jiapeng, 2015). Ozone pollution occurs when the ozone concentration in the air near the ground is higher than 120 μg/m3. When the hourly concentration of ozone exceeds 260 μg/m3, people begin to feel uncomfortable, such as sore throat, dizziness, headache, and vision loss, which lead to an increase in the incidence of respiratory and cardiovascular diseases (Yang Guiying, 2010; Liao Zhiheng and Fan Shaojia). , 2015). Numerous studies have also confirmed that elevated ozone concentration inhibits plant growth, resulting in poor crop quality and reduced yield (Feng et al., 2014; Mao Bing et al., 2016; Feng Zhaozhong et al., 2018). The increase of ozone concentration will affect the main nutrients contained in soybean and then affect the quality of soybean (Wang Chunyu et al., 2019); in the research on the effect of ozone concentration on Dongguan rice and Beijing winter wheat, it is shown that the increase of atmospheric ozone concentration, Dongguan rice yield The relative decrease of 2.7%, and the relative reduction in winter wheat yield in Beijing by 12.85% (Geng Chunmei et al., 2014); Avnery (Avnery et al., 2011) and others believe that the increase of ozone concentration makes the global wheat, corn, soybean, and other major crops decline. The drop is as high as 15%. When the hourly ozone concentration exceeds 320 μg/m3, plants will dry up or even die. In addition, ozone pollution mainly affects plants' normal growth by affecting plants' photosynthesis and may also affect the ecological environment (Kou Taiji et al., 2009). Some studies also show that high ozone concentrations will also have a certain impact on the climate. For example, Zhou Renjun et al. (Zhou Renjun and Chen Yuejuan, 2007) have shown that the total amount of ozone on the Qinghai-Tibet Plateau from May to July is significantly related to the temperature in summer and winter in my country, and the next spring. Negative correlation and positive correlation with precipitation. It can be seen that the harm of ozone concentration changes to human health, ecological environment, and economic development cannot be underestimated.

1.2.2 Research status of ozone pollution

1.2.2.1 Ozone concentration monitoring

At present, the means of obtaining ozone concentration are mainly through site monitoring and remote sensing monitoring. The ground monitoring site has the characteristics of real-time monitoring, short data monitoring time interval, and long-term continuous observation. To solve the ozone pollution problem and strengthen the monitoring of the temporal and spatial distribution of ground ozone, the ground monitoring of ozone in my country started in 2008, from the initial six pilot cities to the routine monitoring of 1497 national control points in more than 300 cities, which provides the basic conditions for the research on the temporal and spatial distribution characteristics of ozone pollution in my country. The research on ozone pollution's temporal and spatial distribution characteristics is carried out on national, regional, and city scales.

On the national scale, by analyzing the ozone pollution situation of 338 cities in my country in 2016 and combining the topography and meteorological conditions of each city, my country is divided into ten ozone pollution control areas according to the ozone pollution situation (Ma Pengfei et al. ., 2021). Analysis of ozone in 338 cities in my country over three years from 2015 to 2017 is carried out using spatial interpolation of ground-monitoring station data. 2020. At the provincial, regional, and key urban agglomeration scales, the time-based analysis of ground-level ozone in four regions of the Northwestern Mediterranean Basin from 1994 to 2001, including coastal, mountainous, terrestrial and urban areas, showed that the ozone concentration in coastal areas decreased by 22% , the mountain area increase by 14%, and there is no significant change in inland and the urban regions (Rojas and Venegas, 2013). The analysis of ozone concentration in Beijing and its surrounding areas showed that meteorology is the main factor leading to the spatial variation of ozone in this area (Tang et al., 2012), after dividing Sichuan Province into five major regions, in the exploration of the temporal and spatial distribution of ozone concentration and pollution in the different areas from 2015 to 2016, the temporal and spatial distribution of ozone has obvious regional differences (Li Polan et al., 2018). The more commonly used methods for investigating the temporal variation and spatial heterogeneity of ozone concentration including the use of statistical methods and geographic detectors, or through the Moran index, Kriging interpolation and hot-spot analysis methods. (Peng Chao et al. al., 2018; Huang Xiaogang et al., 2019)

1.2.2.2 Spatial and temporal characteristics of ozone pollution

In recent years, economic activities in the Yangtze River Delta region have developed rapidly, and the ozone concentration in urban air has been increasing yearly (Shanyuanyuan et al., 2016b; Chen Chao et al., 2019). Many scholars have analyzed the characteristics of ozone pollution in Zhejiang and its relationship with meteorological conditions to analyze the ozone generation mechanism, change elements, meteorological conditions, and control strategies that affect ozone concentration in this region. Research on the temporal and spatial characteristics of ozone pollution in the Yangtze River Delta region shows that the highest ozone concentration will occur in the year in late spring and early summer, and there are also high ozone events in September (Wang Huixiang et al., 2003).

Among the studies on the spatiotemporal distribution of urban ozone, a study investigating the differences in the weekend effect of ozone between urban and rural areas in southern Italy showed an overall decrease in total ground-level ozone over the weekend (Schipa et al., 2009). In exploring ozone pollution and spatiotemporal characteristics in Xuchang City from 2014 to 2016, ozone pollution showed an increasing trend with time (Wang Aiqin et al., 2017). The analysis of the spatiotemporal characteristics of annual ozone concentration showed that the ozone concentration in Xuzhou is high in summer and low in winter (Shang Jing, 2018). Another study explored the spatial distribution of ozone by using passive measurement methods to monitor ozone concentrations in industrial cities in Turkey (Pekey and Ozaslan, 2013).

In addition, many domestic studies have investigated the sources and concentrations of volatile organic compounds in the ambient air during special periods of human ozone emission (such as the Spring Festival and other major events). The research on the concentration of volatile organic compounds during the Spring Festival in Beijing showed that the concentration of volatile organic compounds decreased by about 60% during the Spring Festival and pointed out that fireworks and firecrackers during the Spring Festival are important sources of acetonitrile, aromatic hydrocarbons, CO, SO_2, and NOx, emphasizing the control of fireworks and firecrackers and the importance of discharge (Li et al., 2019). The research on the changes in the concentration of volatile organic compounds, the potential and sources of ozone generation during the Beijing Olympics showed that automobile exhaust and solvent volatilization are the two major sources of volatile organic compounds, and aromatic hydrocarbons have the greatest potential for ozone generation in the atmosphere in Beijing. Compounds accounted for 47%, followed by alkenes with 40%, and alkanes with the lowest 13% (Wu Fangkun et al., 2010). During the above major events, local pollutant reduction efforts are strong, but the impact of pollutant migration in surrounding areas could not be ignored (Jia Haiying et al., 2017).

1.2.2.3 Factors Affecting Ozone Pollution

Atmospheric ozone generation and pollution concentrations are influenced by a combination of local sources (photochemical reaction generation and removal), regional transport (input and output), and stratospheric ozone intrusion. The photochemical reaction substances that generate ozone are based on precursors (mainly NOx and VOCs). The necessary conditions include sufficient solar radiation and air temperature, while wind, precipitation, and relative humidity play a role in the transmission, removal, and deposition of ozone concentration.

In addition to local photochemical reactions affecting the level of near-surface ozone concentrations, weather systems, and meteorological conditions are also closely related to ozone concentrations (Aneja et al., 2004; Geng et al., 2009). Most scholars conduct correlation analysis on ozone concentration from two perspectives of local and overall meteorological conditions. In the exploration of the influence of meteorological elements on ozone concentration in Beijing, by comparing the size of the same meteorological component on the day when the ozone concentration reaches the standard and the day when the ozone concentration exceeds the standard, it is concluded that the wind speed and pressure levels on an exceeding day are lower than those on the meeting day. The temperature and humidity levels on an exceeding day are lower than the standard day. The conclusion is higher than the target date (Wang Zhanshan et al., 2018). In the research on the annual average ozone concentration in Nanjing, the correlation analysis results of meteorological elements at different levels of ozone concentration show that the correlation between ozone concentration and temperature is the best at the normal level, and the relationship between ozone concentration and humidity and wind speed is the second level exceeding the standard. Relevance is the best. The correlation analysis results of ozone concentration and meteorological elements such as temperature, humidity, and wind in Xi'an from January to April 2013 show that the ozone concentration is the highest when the temperature is high, low humidity, and the wind direction is southeasterly and southerly (Liu Song et al., 2017). In addition, in the correlation analysis of the average ozone concentration in my country from 2014 to 2017 and meteorological factors such as temperature, humidity, and 24-h precipitation, ozone concentration is positively correlated with temperature, and negatively correlated with humidity and precipitation in the past 24 hours (Liu Yulian et al., 2018). More studies have shown that the ozone concentration is inseparable from the pressure, and ozone mainly occurs in the type of weather controlled by high pressure (Zhu Yuxiu and Xu Jialiu, 1994; Hong Shengmao et al., 2009). The ozone concentration is significantly higher on sunny days with few clouds than on cloudy and rainy days (Shan et al., 2010). In addition, meteorological factors such as temperature, relative humidity, wind direction, and wind speed affect the near-surface ozone concentration (Ding Guoan et al., 1995; Tan Jianguo et al., 2007; Sun Guojin et al., 2020).

Precursor concentration level is one of the important factors affecting ozone generation. Overseas studies on ozone precursor-related issues are earlier. In 1953, Haggen-Smit proposed that the precursors of near-ground ozone formation are NOx and VOCs. Ozone precursors can affect ozone generation, but the relationship between the two is complex and easily influenced by other environmental factors, showing a nonlinear relationship. In some cases, controlling a single precursor will not significantly reduce ozone concentration but may aggravate ozone pollution (Miranda et al., 2005; Chen et al., 2020). Emissions of large amounts of NOx and SO_2 in the Asia-Pacific coastal areas can significantly increase regional ozone concentrations (Akimoto and Narita, 1994). The in-depth advancement of domestic industrialization and urbanization has increase the emission of anthropogenic VOCs and NOx, resulting in a continuous increase in ozone concentration in urban areas and frequent occurrence of ozone pollution incidents. The change in ozone concentration in China from 2013 to 2019 showed that the massive emission of VOCs is one of the important reasons for the continuous increase in ozone concentration (Li et al., 2020). The observation of ozone concentration in the northern mountainous area of Beijing over six weeks in summer found that the massive emission of VOCs and NOx led to an increase in the level of ozone concentration in Beijing, and NOx played an important role in ozone generation in Beijing (Wang et al., 2006). In the VOCs observations carried out in the cities and suburbs of the Pearl River Delta, it is found that ethylene, toluene, and m/para-xylene are the main precursors of ozone generation in the Pearl River Delta region and contributed greatly to ozone generation (Zhang et al., 2022).

The presence of particulate matter in the atmosphere can reduce the photolysis rate of ozone precursors, thereby affecting ozone production in the atmosphere. A study of near-surface photochemical pollution in Mexico found that the presence of aerosols reduced the rate of NO_2 photolysis, resulting in a 20% reduction in ozone concentrations (Castro et al., 2001). In a study in the summer of 2011 in North China, it is found that the presence of aerosols resulted in a decrease in ozone photolysis rate, OH radicals, and boundary layer ozone concentrations (Li et al., 2020). When exploring the effect of atmospheric particulate matter on ozone in Nanjing, it is found that $PM_{2.5}$ can affect ozone concentration by changing the photolysis rate and heterogeneous reactions of ozone (Guo et al., 2018). Typically, the resulting photolysis rate effect results in a greater ozone reduction when particle concentrations are higher, whereas heterogeneous reactions dominate at low concentrations. Furthermore, in typical VOC-sensitive regions, the ozone concentration can even be increase by heterogeneous reactions. By simulating the sensitivity of NOx and VOCs in summer anthropogenic emissions in my country, it can be seen that the emissions of precursors have a relatively weaker effect on ozone than changes in $PM_{2.5}$ concentration (Irei et al., 2016). In exploring the ozone concentration exceeding the standard in each city of Beijing-Tianjin-Hebei through the filtering method, there is a 90.4% probability that changes in pollutant emissions cause the increasing ozone pollution. Pollutants can be divided into two aspects, one is the decrease in particulate matter concentration (contributing 27.3%), and the other is the increase in precursor concentration (contributing 63.1%); the impact of meteorological conditions on ozone pollution is only 9.6% probability (Yu Yijun et al., 2020). It can be seen that the reduction of particulate matter concentration has the most important contribution to the increase of ozone concentration in the Beijing-Tianjin-Hebei region, which means that we need to further reduce the emission of precursors such as NOx and VOCs to offset the reduction of $PM_{2.5}$. And cause the reverse effect of ozone increase.

1.2.2.4 Ozone Sensitivity Analysis

Currently, the research methods for the sensitivity of near-ground ozone mainly include the sensitivity test method, source tracer method, and indicator. The sensitivity test method determines the sensitivity of the precursor by adjusting the model's input parameters and outputting the change of ozone concentration under different emission scenarios. Wang Xuesong et al. (Wang Xuesong et al., 2009) used the source tracing method combining an air quality model and ozone source identification technology to analyze the source of ozone concentration in the Beijing area. A specific threshold determines the ratio of certain intermediates or products in the photochemical reaction to determine the required control precursors in the region (Wu Lin et al., 2017). However, H2O2 and HN ozone are not easy to monitor, and data are difficult to obtain. The indicators received based on the ozone monitoring instrument (OMI) satellite data have the advantages of good temporal and spatial continuity, wide monitoring range, and little human interference and have been widely used in ozone sensitivity analysis research. OMI satellite data are used in a study to explore the ozone sensitivity of Beijing-Tianjin-Hebei and surrounding areas in summer from June to September 2005 to 2016 (Wu Weiling et al., 2018). The temporal and spatial variation characteristics of ozone sensitivity of different land-use types in the Pearl River Delta from 2005 to 2016 are explored through OMI satellite data and MODIS land cover classification products. Between the edge of the Pearl River Delta and the first two control areas: the developed area is mainly a VOCs/co-controlled area, the more developed area is primarily the same control area, and the less developed area is the Nq control area (Zhuang Liyue et al., 2019). When exploring the spatial distribution characteristics of ozone control areas in the central and eastern regions of my country from 2005 to 2014, the OMI satellite data is also used. It is found that the major cities in Shandong, Yujin, Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta belong to VOC control areas. The surrounding towns belong to the collaborative Control area, and the other regions belong to the NOx control area (Shan et al., 2016a).

1.2.2.5 The impact of COVID-19 on ozone concentration

During the COVID-19 pandemic, motor vehicle traffic, industrial operations, building construction, and shopping malls have all been significantly reduced due to the implementation of social distancing policies. Human and industrial activities are reduced to a minimum, and the discharge of primary pollutants is greatly reduced. Comparing the concentration changes of air pollutants before and after the "partial blockade" in Rio de Janeiro, Brazil, it is found that CO and NO_2 decreased significantly, by 30.3-48.5% and 16.8-53.8%, respectively. And PM_{10} concentrations only dropped in the first few weeks of the partial lockdown. In contrast, ozone concentrations increase by 67% compared to pre-lockdown (Dantas et al., 2020). Similarly, in São Paulo (Li et al., 2020), Barcelona (Mahato et al., 2020), London (Sharma et al., 2020), and many cities in India (Sicard et al., 2020; Tobias et al., 2020b) observed similar trends. In addition, after analyzing the ozone concentrations in four southern European cities (Nice, Rome, Valencia, and Turin) and Wuhan, China, during the lockdown period in 2017-2020, it is found that during the lockdown period in 2020, Nice, Rome, Turin, Valencia The ozone concentration in Wuhan and Wuhan increase by 24%, 14%, 27%, 2.4%, and 36% respectively, of which the increase in ozone in Wuhan is the largest. It is inferred that the increase in ozone concentration is mainly due to the sharp drop in NOx emissions, resulting in a reduction in NO titration depletion of ozone (Sicard et al., 2020).

In addition, studies have shown that although $PM_{2.5}$ in the Yangtze River Delta region decreased during the epidemic blockade, it still maintained a high level, with high background pollution and residues (Li et al., 2019). The concentration of $PM_{2.5}$ in Wuhan has decreased significantly, but its chemical composition and sources have a complex nonlinear response to air pollution control measures, requiring regional joint control (Zhang et al., 2022). After the epidemic prevention and control, HONO in the Shijiazhuang area decreased by about 31%, NO by 62%, and NO_2 by about 36% (Liu Xinjun et al., 2022). Wang Shenbo et al. (2020) showed that apart from ozone, PM2. 5 and NO decreased significantly in Henan Province under the influence of the Spring Festival and the epidemic, but the concentrations are still high. During the epidemic, all air pollutants except ozone in Beijing-Tianjin-Hebei are generally in a downward trend, and controlling industrial emissions is still the key to air pollution control (Zhu Yifan et al., 2021). The above studies all show that the heavily polluted weather has not disappeared due to the reduction of anthropogenic emissions.VOCs are important precursors of ozone and $PM_{2.5}$, and the emission reduction of VOCs will be the key to realizing the coordinated control of ozone and $PM_{2.5}$ in my country (Zhang et al., 2022). The pollution characteristics and source changes of VOCs before and after the epidemic prevention and control in the Nanjing urban area are studied. It is found that the volume fraction of VOCs decreased significantly after the epidemic prevention and control began, and the contribution of the chemical industry and motor vehicle pollution sources to VOCs decreased significantly (Tian Kaiwen et al., 2022). The research on the change characteristics, ozone generation potential, and source analysis of VOCs during the epidemic prevention and control period in Jiyuan City shows that the volume fraction of VOCs during the epidemic prevention and control period has increase compared with that before the epidemic prevention and control period. The contribution rate of TVOCs in Jiyuan City has been greatly reduced. Still, the contribution of ethanol and chlorine-containing substances from disinfectants to TVOCs in Jiyuan City has increase significantly (Wang Hongguo et al., 2021).

1.3 Research purpose and content

1.3.1 Research purpose

Based on the sorting and summary of previous research work, this research relies on representative sites of 11 cities in Zhejiang Province (Hangzhou, Jiaxing, Ningbo, Wenzhou, Wenling, Huzhou, Shaoxing, Jinhua, Quzhou, Lishui, and Taizhou) January 2019- The monitoring data in December 2020 is divided into two stages: "before the outbreak" (2019) and "after the outbreak" (2020). From the data perspective, the ozone in typical cities in Zhejiang Province before and after the outbreak is explored from the two dimensions of time and space. The distribution characteristics of pollution, and Jinhua City, a city in central Zhejiang Province, is selected as a representative to explore further the influencing factors of ozone concentration and its correlation with precursors and meteorological factors and analyze the possible causes of ozone pollution during the epidemic. In epidemiological emergencies, formulating effective control strategies for air pollutants provides scientific guidance and technical support to provide reference and a basis for environmental management and decision-making.

1.3.2 Research content

The specific research contents of this paper are set as follows:

(1) Spatial and temporal characteristics of ozone pollution in Zhejiang Province before and after the outbreak of COVID-19

Statistical analysis of the hourly ozone concentration of 11 typical cities in Zhejiang Province from January 1, 2019, to December 31, 2020, is conducted to explore the same longitude (from north to south) and latitude (from west to east) in Zhejiang Province before and after the new crown epidemic.) represents the interannual, seasonal, monthly, weekly, and intraday variation characteristics of ozone concentration at urban sites.

(2) Analysis of the influencing factors of ozone pollution

Taking Jinhua City, a city in central Zhejiang Province, as a distinct research area by analyzing the change characteristics of meteorological factors such as temperature, relative humidity, and pollution factors such as PM2. Analyze the effects and possible mechanisms of meteorological factors and polluting gases on ozone concentration.

Chapter 2 Data and Methods

2.1 Introduction to observation sites

The observation site in this study is located in Zhejiang Province, and the regional locations of Zhejiang Province are 118° 01'E~123° 10'E, 27° 02'N~31° 11'N, as shown in Figure 1. Zhejiang is one of the country's most economically developed and populous provinces. The straight-line distance from east to west and north to south in Zhejiang is about 450 kilometers, with a land area of 105,500 square kilometers, including 11 prefecture-level cities and 20 county-level cities, with a resident population of more than 64.57 million and a GDP of more than 6,461.3 billion yuan. Zhejiang Province has a complex topography and naturally slopes from the southwest to the northeast. Except for the east, which is adjacent to the East China Sea, the rest are surrounded by cities. The province's interior consists of eight major water systems and several plains, hills, basins, and mountains. Zhejiang Province is located in the mid-subtropical zone with a suitable climate. The average annual temperature is between 15 and 18 degrees. The subtropical climate is humid, with four distinct seasons, mild temperatures throughout the year, increase rainfall, and relatively good air quality.

According to the survey at the end of 2019, Zhejiang Province has ten meteorological radar observation stations, 15 satellite cloud image-receiving stations, and 3,082 regional automatic meteorological observation stations, which can collect and analyze climate phenomenon data in the province extensively and accurately. According to statistics: In 2019, the average number of haze days in Zhejiang Province is about 37 days, an increase of 15 days over the previous year; the average annual concentration of $PM_{2.5}$ The ambient air quality of the 11 districted cities is 31 micrograms/m3, which is higher than the previous year. A decrease of 3.1%; among the 58 cities above the county level, the percentage of days with good air quality is between 76.7% and 98.1%, with an average of 88.6%, down 0.4 percentage points from the previous year; the percentage of days with good air quality is 77.3 % to 100%, with an average of 94.0%, a decrease of 0.2% from the previous year.

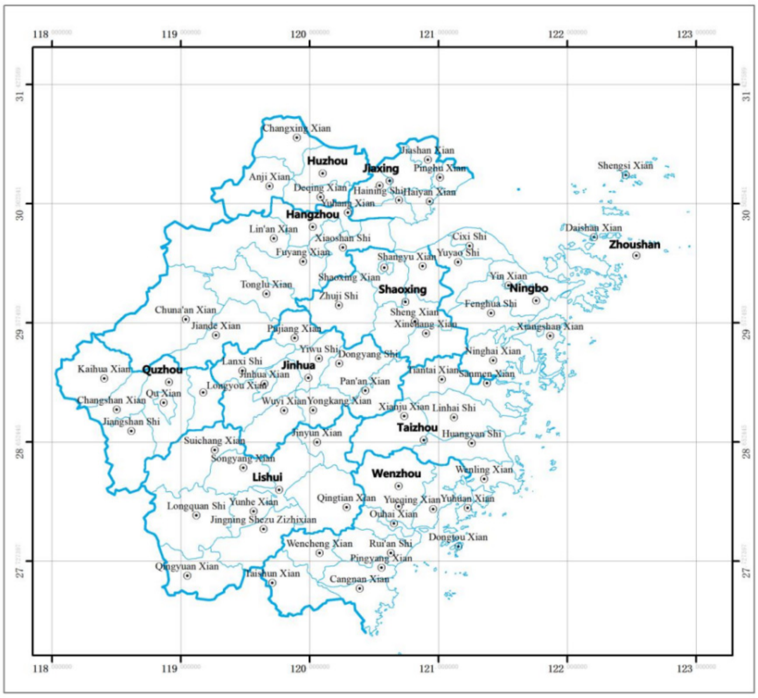

Figure 1 Geographical distribution map of major cities in Zhejiang Province

All the city sites involved in this paper (Table 1), including four cities in the northern part of Zhejiang Province (Huzhou, Jiaxing, Shaoxing, and Hangzhou), four cities in the southern part (Quzhou, Lishui, Wenzhou, and Wenling) and from west to east four cities (Quzhou, Jinhua, Taizhou, and Ningbo). Since the site involves 11 cities, this paper selects the atmospheric background station in Hangzhou to focus on the introduction to better convey the site information. Air quality monitoring stations in other regions operate similarly to this station.

Hangzhou Meteorological Monitoring Station is located in the southern suburbs of Hangzhou. It can more accurately collect atmospheric data in urban areas at the West Lake Viewing Area and Hangzhou metropolitan area, eliminating the influence of human factors. The monitoring station of the weather monitoring center The air quality monitoring station is located at an altitude of about 41.7 meters. The atmospheric composition sampling point is located on the large platform on the third floor of the courtyard. PTFE tubing is used to collect gas samples. The air quality monitoring station is surrounded by mountains in the west, adjacent to West Lake, and mountains in the south. The urban construction group in the center of Hangzhou, mainly residential areas and traffic sections, is separated by the Qiantang River. The north and east sides of the air quality monitoring station are separated by the river, avoiding the industrial pollution source caused by the factory construction.

Table 1. Location of air quality station, period of data collection

Station	Latitute	Longitude	Background	Sampling Duration
Huzhou	3053	11998	Urban	Jan 2019-Dec 2020
Jiaxing	3079	12074	Urban	Jan 2019-Dec 2020
Saoxing	3005	12049	Urban	Jan 2019-Dec 2020
Hangzhou	3027	12006	Urban	Jan 2019-Dec 2020
Jinhua	2891	11981	Urban	Jan 2019-Dec 2020
Quzhou	2858	11857	Urban	Jan 2019-Dec 2020
Lishui	2846	11993	Urban	Jan 2019-Dec 2020
Taizhou	2865	12142	Urban	Jan 2019-Dec 2020
Ningbo	2920	12193	Urban	Jan 2019-Dec 2020
Wenzhou	2779	12009	Urban	Jan 2019-Dec 2020
Wenling	2836	12107	Urban	Jan 2019-Dec 2020

2.2 Data sources

The near-ground ozone data used in this paper comes from the national urban air quality real-time release platform of the China Environmental Monitoring Station. Air quality data types include $PM_{2.5}$, PM_{10}, SO_2, NO_2, ozone, CO, and Air Quality Index (AQI). The data used in this paper are $PM_{2.5}$, PM_{10}, SO_2, NO_2, and ozone data, which are hourly data monitored in real-time. This paper's Chinese surface meteorological data comes from the National Climatic Data Center, a National Oceanic and Atmospheric Administration subsidiary.

If the ozone mass concentration exceeds the standard value, refers to the Ministry of Environmental Protection standard HJ633-2012 "Ambient Air Quality Index (AQI) Technical Regulations" and "Ambient Air Quality Standard" (GB3095-2012). Data quality control for selecting outliers according to the Ambient Air Quality Monitoring Specification. In addition, when classifying and analyzing the data, the lack of hourly and average data due to power outages, instrument maintenance, calibration, etc., during the observation period is eliminated to ensure accuracy and reference values. In addition, records and erroneous data related to instrument failures must be deleted. The data acquisition system saves and records raw data every minute to provide raw data for subsequent research. Finally, according to the validity of the Ambient Air Quality Standards in pollutant statistics, it takes at least 45 minutes per hour. Average concentration values are at least 20 hours per day, hourly arithmetic averages are calculated using 5-minute average data, and daily arithmetic averages are calculated using hourly data.

When analyzing the problem of ozone concentration, O_3 concentration is an evaluation index of pollution degree according to the provisions of the national "Ambient Air Quality Standard" (GB30952012) (the primary standard is 100 μg/m3). Since the raw monitoring data is long-term, with at least 14 hours per day, the arithmetic means data of the valid daily mean is defined as the main analysis. After synthesizing various field information, this paper determines that the effective daily average of ozone is the maximum 8-hour moving average. SPSS 19.0 (IBM Inc., Chicago, IL, US) software is used for data processing and analysis, and Sigmaplot 14.0 is used for plotting.

Chapter 3 Results

3.1 Temporal and spatial variation characteristics of ozone concentration

To explore the spatial distribution characteristics of ozone concentration in Zhejiang Province before and after the outbreak of the new crown epidemic, we selected representative sites in the north (Huzhou, Jiaxing, Shaoxing, Hangzhou) and usual sites in the south (Quzhou, Lishui, Wenzhou, Wenling) with the same longitude, respectively. And the representative stations (Quzhou, Jinhua, Taizhou, Ningbo) from west to east at the same latitude are studied.

3.1.1 Interannual Variation of Ozone Concentration

First, by analyzing the inter-annual spatial changes in ozone concentration at each representative site before and after the outbreak (Fig. 2), it is found that before the outbreak, the inter-annual changes in ozone concentration in cities in Zhejiang Province decreased sequentially from north to south, and sequentially from west to east. Increase. After the outbreak, towns at the same latitude still showed a trend of increasing interannual ozone concentration from west to east. From the longitude perspective, the ozone concentration changes in Hangzhou and Taizhou are different. After the outbreak, the inter-annual average ozone concentration in Hangzhou is the lowest among the 11 cities (52.18 µg/m3), while the ozone concentration in Taizhou is the highest (69.29 µg/m3).

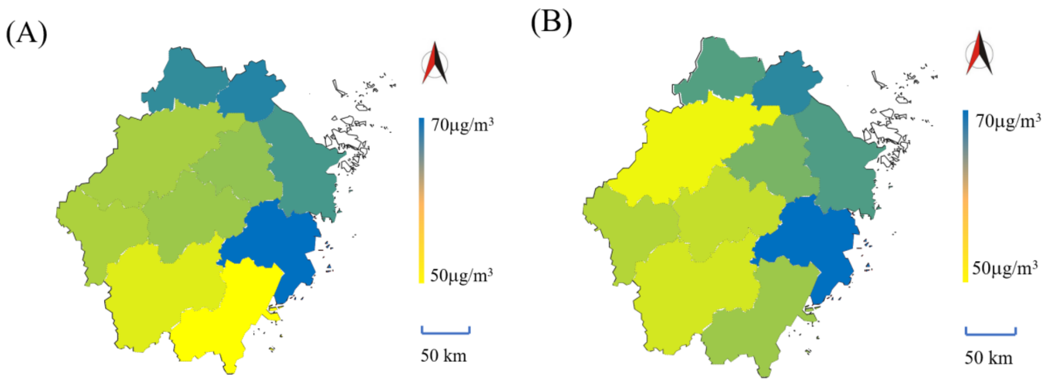

Figure 2 Spatial distribution of ozone concentration at each representative location in Zhejiang Province in 2019 (A) and 2020 (B)

Based on the spatial distribution characteristics of ozone concentration, we further explored the annual changes in ozone concentration in each representative site in Zhejiang Province in 2019 and 2020 (Fig. 3). The average annual change of ozone concentration in Zhejiang Province in 2019 and 2020 is between 50 and 80 µg/m3. Among them, the average ozone concentration value in Shaoxing, Wenzhou, and Taizhou in 2020 is higher than in 2019. Overall, the annual mean value of ozone concentration before and after the outbreak is not significantly different.

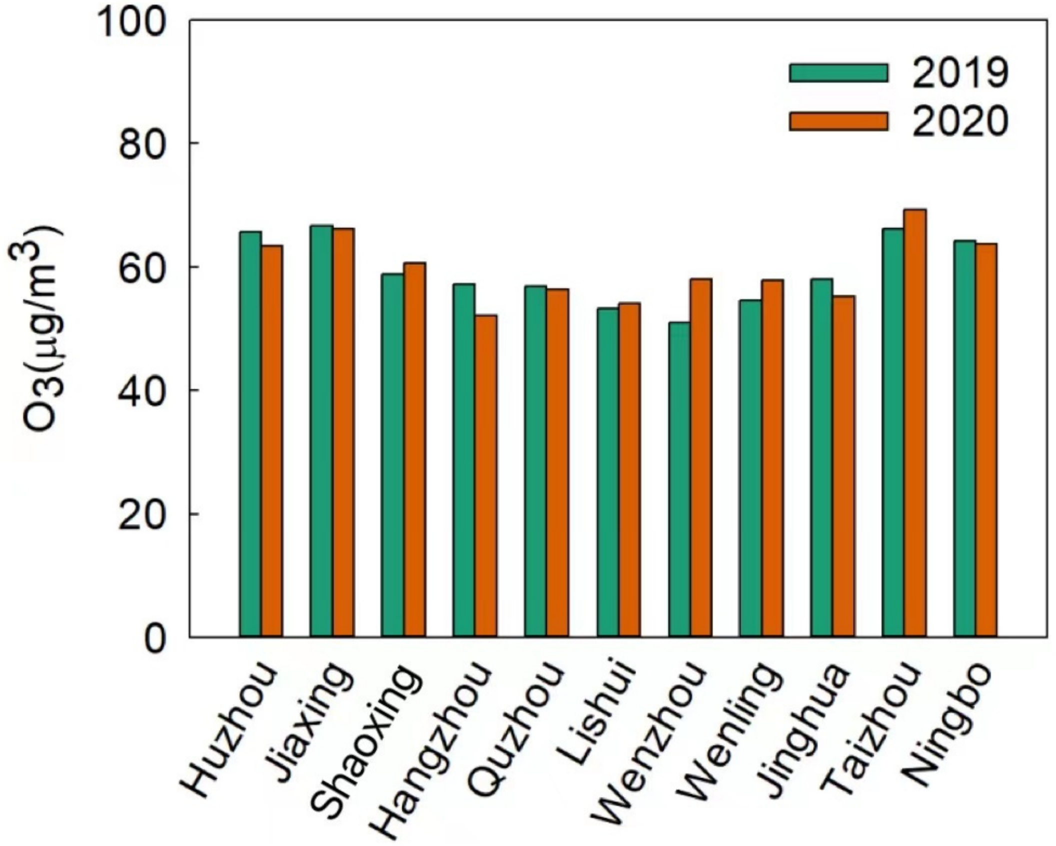

Figure 3 The annual change of ozone concentration at each representative site in Zhejiang Province

Based on the first-level ozone concentration limit (100 μg/m3) specified in the National Ambient Air Quality Standard (GB3095-2012), we calculated the ozone concentration exceeding the standard at each representative site (Fig. 4). Except for Wenling, the annual number of days with ozone exceeding the standard exceeded 150 days in all cities. Among them, the days exceeding the standard ozone concentration in Huzhou ranked first before and after the outbreak, while the rate of exceeding the standard ozone concentration in Wenling is the lowest. Among them, the number of days where the ozone concentration exceeded the standard in Wenzhou and Wenling after the outbreak is slightly higher than the days before the outbreak. Overall, the inter-annual ozone excess days in each city do not differ much before and after the outbreak, which is consistent with the annual change in ozone concentration.

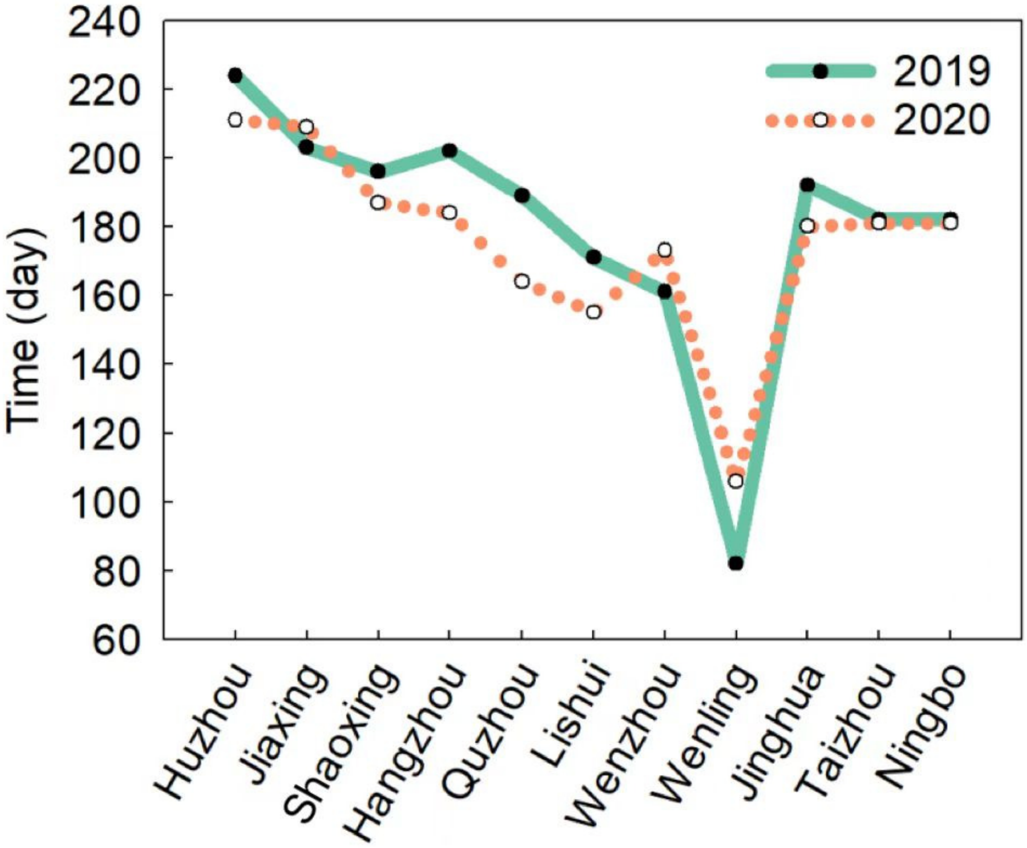

Figure 4 The number of days with excessive ozone concentration in Zhejiang Province in 2019 and 2020

3.1.2 Seasonal variation characteristics of ozone concentration

The climate of Zhejiang Province is a temperate continental climate characterized by a semi-humid and semi-arid climate, with hot summers and cold winters. According to the characteristics of meteorology, March-May is defined as spring, June-August is defined as summer, September-November is defined as autumn, and December-February is defined as winter.

Before the outbreak, each city's seasonal spatial distribution of near-ground ozone concentration is significantly different (Figure 5). All representative city sites showed the highest in spring and summer, the lowest in winter, and fall in between. In spring and summer, ozone concentrations in northern cities (Huzhou, Jiaxing, Shaoxing, and Hangzhou) are higher than in southern cities (Quzhou, Lishui, Wenzhou, and Wenling). The city with the highest ozone concentration in spring and summer is Jiaxing; the highest concentration in autumn is Quzhou; the highest concentration in winter is Wenling. Lishui has the same attention in spring and autumn, and the ozone concentration in Wenling is similar each season. Overall, the seasonal differences in ozone concentration in northern cities are more obvious than those in southern towns.

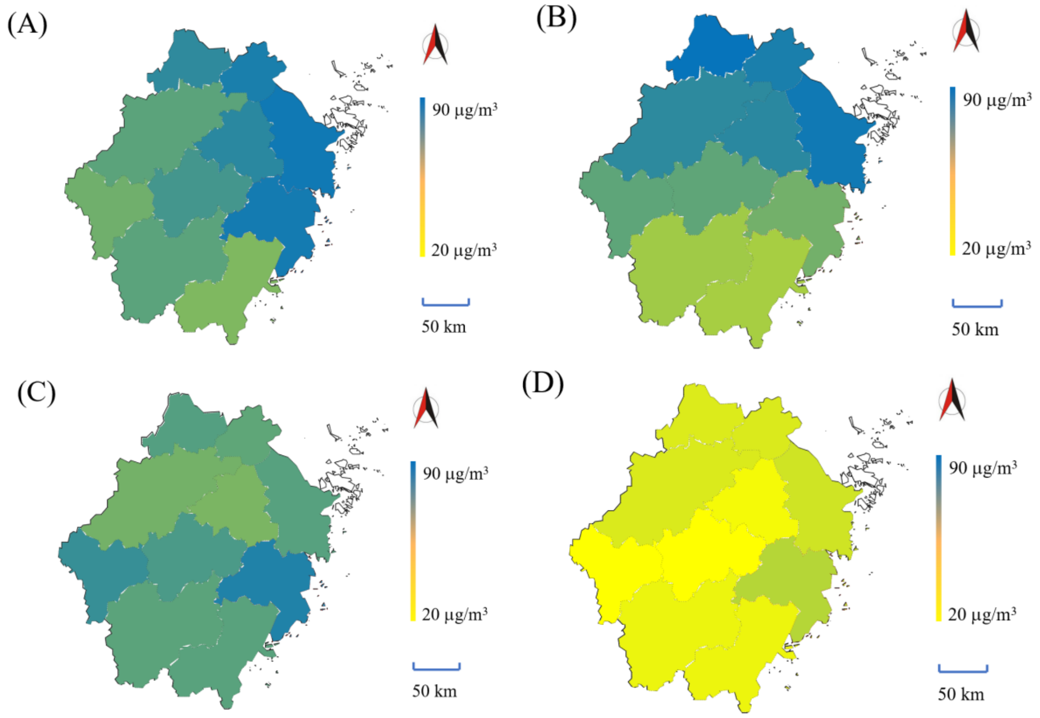

Figure 5 Spring (A), summer (B), autumn (C), and winter (D) of each representative location in Zhejiang Province in 2019

After the epidemic outbreak, the seasonal spatial distribution of near-ground ozone concentrations in various cities differed significantly. Each city's seasonal near-ground ozone concentration is the highest in spring, the lowest in winter, and between the two in spring and autumn. In spring and summer, the seasonal ozone concentration of northern cities is still higher than that of southern towns, and the seasonal ozone concentration of eastern cities is higher than that of western cities. For autumn and winter, Taizhou still maintains the highest seasonal ozone concentration, and the ozone concentration in the southwestern cities of Zhejiang Province is relatively high. In contrast, the seasonal ozone concentration in the northern cities decreases significantly (Figure 6).

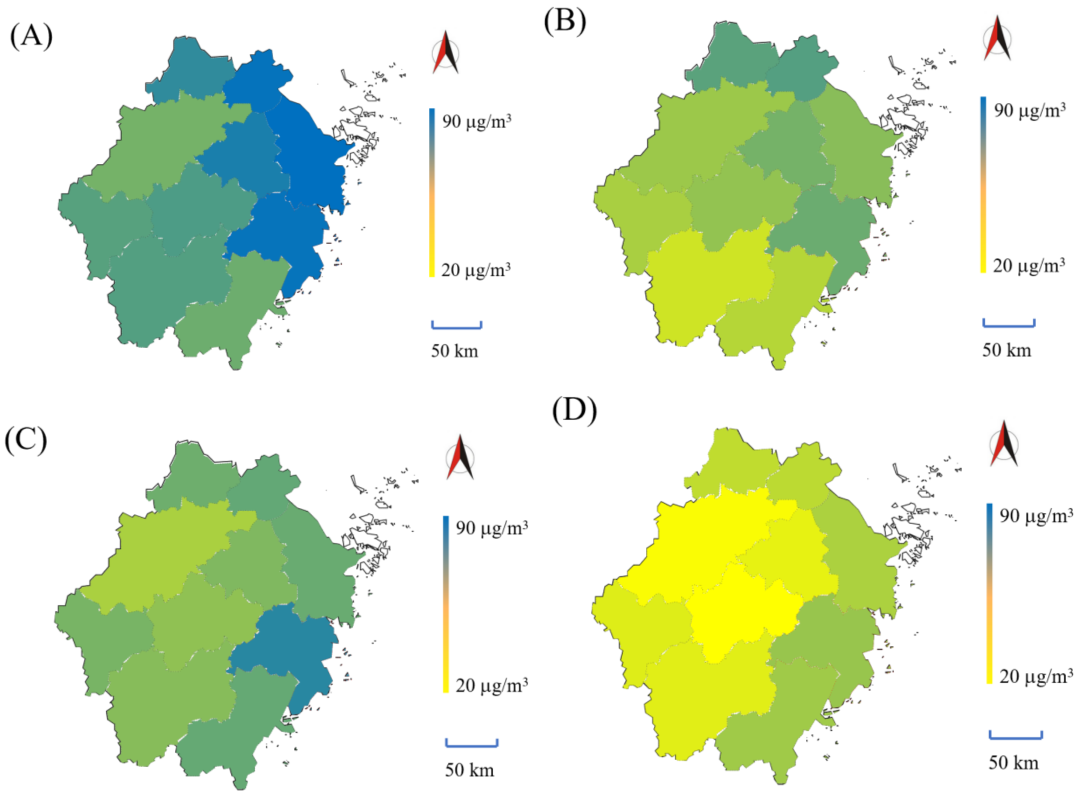

Figure 6 Spatial distribution of ozone concentration in spring (A), summer (B), autumn (C), and winter (D) at each representative location in Jiang Province in 2020

From the seasonal changes in ozone concentration at each representative site before and after the outbreak (Fig. 7), it can be seen that before the outbreak, the ozone concentration ranges in spring, summer, autumn, and winter are 57.16 μg/m3-82.26 μg/m3, 47.22 μg/m3-85.69 μg/m3, 58.10 μg/m3-78.64 μg/m3 and 28.30 μg/m3-50.68 μg/m3, with obvious "fault phenomenon," the largest difference in ozone concentration between seasons Over 50 μg/m3. After the outbreak, the ozone concentration ranges in spring, summer, autumn and winter are 62.06 μg/m3-82.67 μg/m3, 46.17 μg/m3-67.94 μg/m3, 52.78 μg/m3-75.62 μg, respectively /m3, 37.68 μg/m3-55.95 μg/m3. After the outbreak, the seasonal differences narrowed, and the maximum difference in ozone concentration between seasons is less than 40 μg/m3. The four-season differences in ozone concentration in northern cities are also more significant than those in southern cities. Still, the differences in ozone concentrations in four seasons in each city are significantly reduced. Meanwhile, the ozone concentration of each city in spring is higher than in summer, autumn and winter. Moreover, in the spring of 2020, Jiaxing and Hangzhou are the two cities with the highest and lowest ozone concentrations in the four seasons, respectively. In addition, we found that the ozone concentrations in the selected seven cities are all less than 100 µg/m3, which met the required concentration limit.

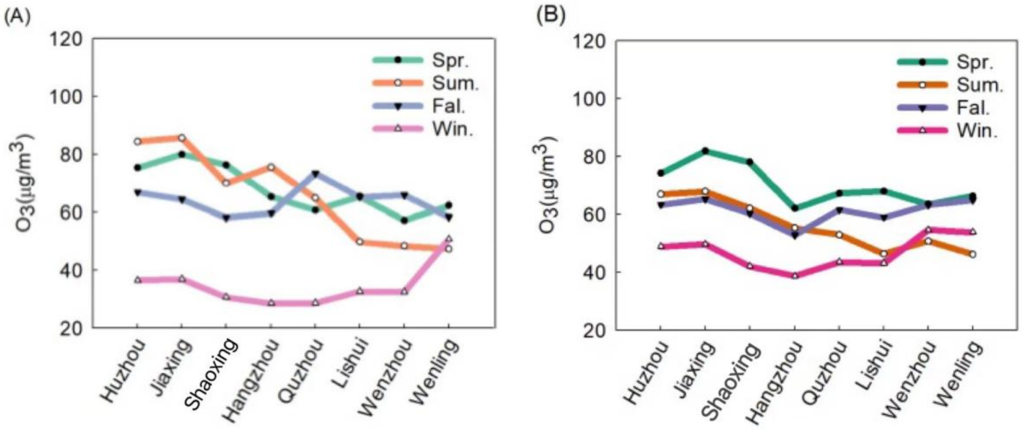

Figure 7 Changes in the mean ozone concentration in each season at each representative site in Zhejiang in 2019 (A) and 2020 (B)

We further calculated the number of days that the seasonal ozone concentration exceeded the standard at each representative site before and after the outbreak. From the stacked column charts of the number of days with ozone concentration exceeding the standard in spring (A), summer (B), autumn (C), and winter (D) before the outbreak, it can be seen that in spring, except for Wenling, the monthly ozone days exceeding the standard in ten cities Both are between 50-70 days, accounting for about 2/3 of the spring days. In summer, the five towns of Huzhou, Jiaxing, Shaoxing, Hangzhou, and Quzhou, continued to increase the number of days with excess ozone. In contrast, the number of days with excess ozone in Wenling remained at 18 days, and the number of days with excess ozone in other cities decreased. In autumn, the number of days with excess ozone in eleven cities increase, with Wenling reaching 39 days and the remaining ten cities with 55-75 days. In winter, the days with ozone exceeding the standard dropped rapidly in 11 cities, reaching the lowest values in the four seasons. The number of days exceeding the standard ozone did not exceed ten days.

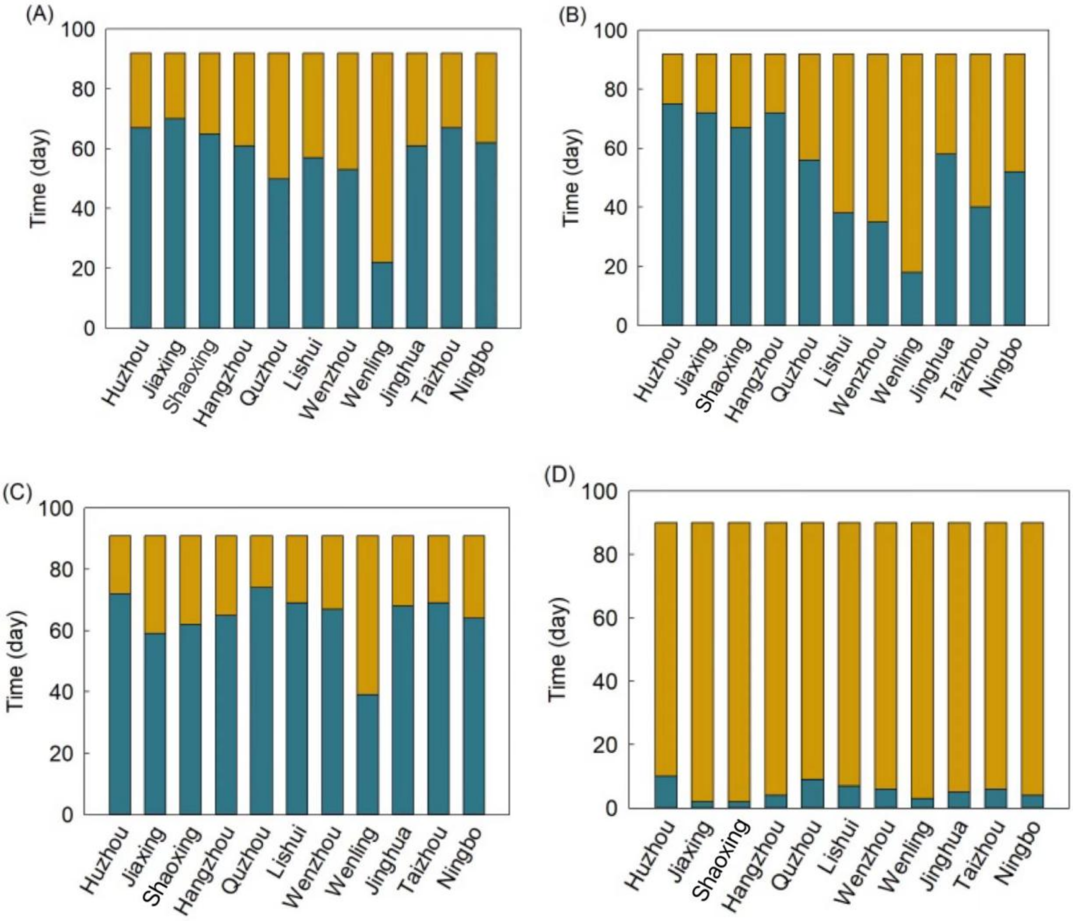

Figure 8 Stacked column chart of the number of days with ozone concentration exceeding the standard in spring (A), summer (B), autumn (C), and winter (D) at each representative site in Zhejiang in 2019 (Note: blue represents the number of days exceeding the standard, and yellow represents the number of days not exceeding the standard)

After the outbreak, the number of days when the ozone concentration exceeded the standard in spring (A), summer (B), autumn (C), and winter (D) at each representative station (Fig. 9) is as follows: In spring, except for Wenling, the ozone concentration in the other ten cities The monthly excess days are between 45-60 days. In summer, the number of days with excessive ozone in three cities, Huzhou, Jiaxing, and Wenling, continued to rise. In contrast, the days with excessive ozone in other cities decreased. Lishui has the least ozone days, exceeding the standard among the eleven cities. In autumn, the number of days with excess ozone in eleven cities increase, with 32 days in Wenling and more than 60 days in the remaining ten cities. In winter, the number of days with ozone exceeding the standard dropped rapidly in eleven cities, reaching the lowest values in the four seasons. The number of days exceeding the standard ozone did not exceed 20 days. Among them, Wenling has the least number of ozone exceeding days in winter, only two days.

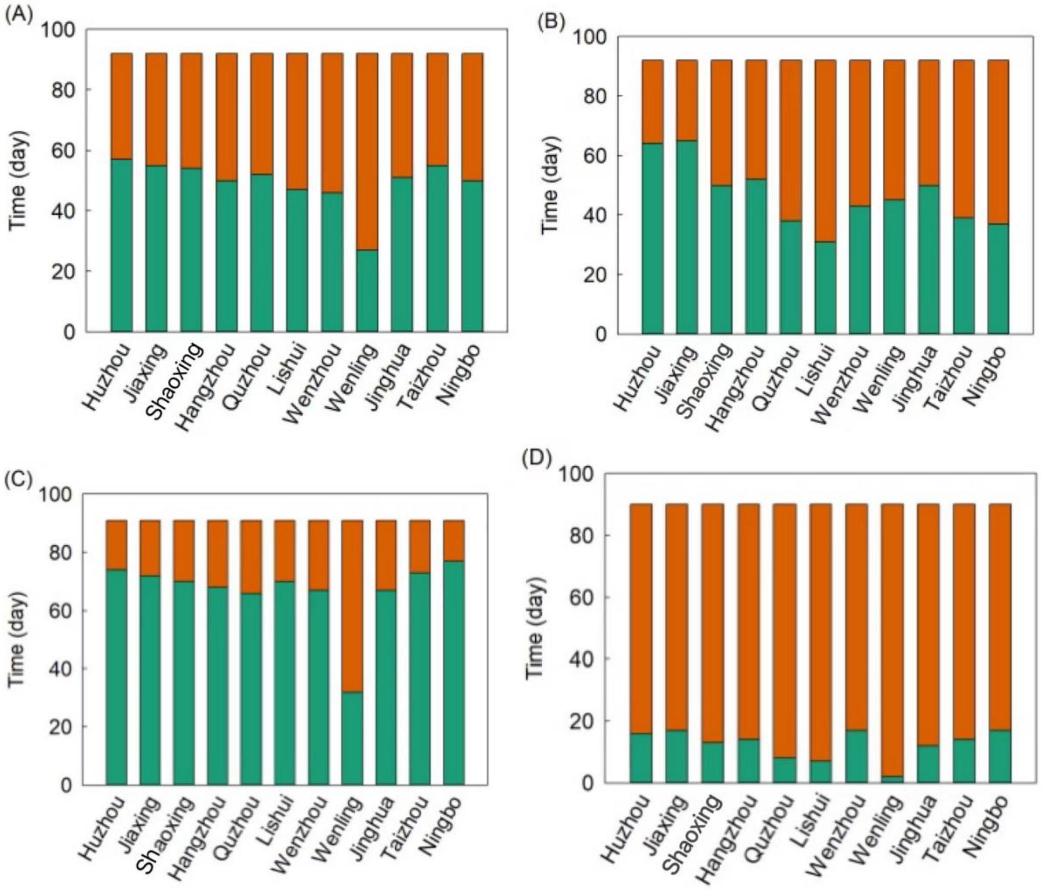

Figure 9 Stacked column chart of the number of days with ozone concentration exceeding the standard in spring (A), summer (B), autumn (C), and winter (D) at each representative site in Zhejiang in 2020 (Note: green represents the number of days exceeding the standard, and orange represents the number of days not exceeding the standard)

3.1.3 Monthly variation characteristics of ozone concentration

Figure 10 shows the monthly changes in ozone concentration values in 4 cities in the northern part of Zhejiang Province before and after the epidemic outbreak. Before the outbreak, the monthly variation characteristics of ozone concentration did not differ much among the four northern cities. The monthly variation trend of the overall ozone concentration shows a less obvious "M"-shaped curve, that is, a bimodal characteristic of first increase and then decrease. The ozone concentration in the two cities of Huzhou and Jiaxing gradually increase from January to June 2019, reached the highest value in June, then dropped from June to August, rose again from August to September, and then increase from September to December. Month and then gradually decrease. The ozone concentration in Shaoxing and Hangzhou began to increase significantly from January to May 2019, gradually decreased from May to July, reached the minimum value in July, rose again from July to September, and then increase again in December 2019. month to the lowest value. Overall, the ozone concentrations in Huzhou and Jiaxing are higher than those in Shaoxing and Hangzhou. At the same time, the monthly ozone concentrations in Huzhou, Jiaxing, Shaoxing, and Hangzhou did not exceed the first-level concentration limit (100 µg/m3) specified in the ambient air quality standard (GB3095-2012). After the outbreak, the changing trend of ozone concentration in the four northern cities roughly showed an "M"-shaped curve. The four cities had high ozone concentration levels in April and September 2020. They dropped significantly in July of the same year, reaching the lowest ozone concentration levels for the year. At the same time, Hangzhou is the city with the lowest ozone content among the four cities, and it is also the city with the fastest drop in ozone from April 2020 to June 2020. Compared with 2019, we found that the ozone concentration in January and February 2020 in the four cities increase faster than in the same period in 2019.

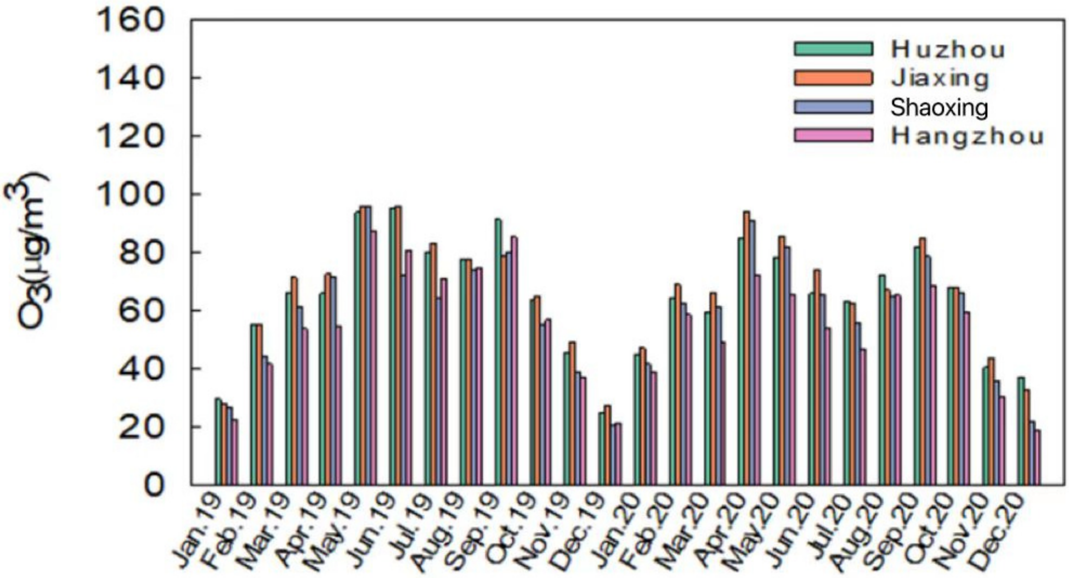

Figure 10 Monthly variation of ozone mass concentration at representative sites in the northern part of Zhejiang

The monthly exceeding days of ozone concentration at representative sites in the northern part of Zhejiang before and after the outbreak showed that the ozone concentration in four cities had fewer exceeding days in January, February, and December 2019. The ozone concentration in Jiaxing and Shaoxing is even higher than 2. The monthly average is less than 100 µg/m3. Hangzhou did not show the ozone concentration exceeding the standard in December 2019. The concentrations in the four cities are the lowest in January 2020, then rose in April, reaching the maximum number of days with excess ozone (Figure 11(B)). Compared with the number of days with ozone exceeding the standard before the outbreak, the ozone exceeding the standard in February 2020 is the most abnormal. The number of days in which the ozone exceeding the standard is exceeded in the four cities is 1.17, 1.24, 1.41, and 1.40 times that of February 2019, respectively.

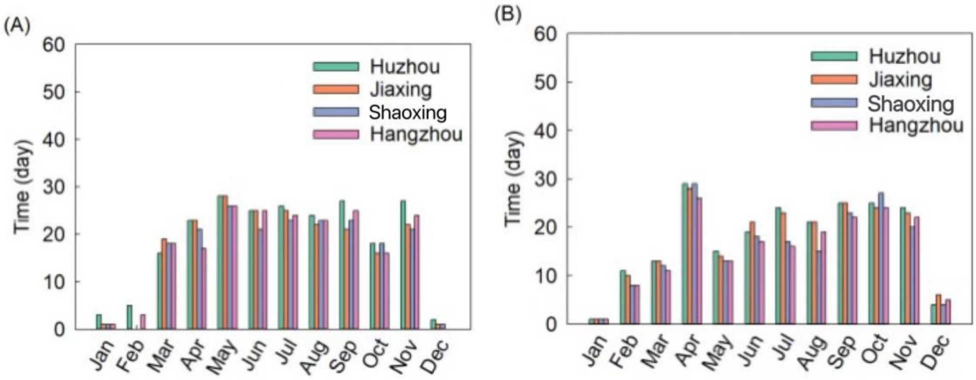

Figure 11 Monthly exceeding days of ozone concentration in 2019 (A) and 2020 (B) at representative sites in the northern part of Zhejiang

Figure 12 shows the monthly changes in ozone concentration values in four cities in southern Zhejiang Province (Quzhou, Lishui, Wenzhou, and Wenling) before and after the outbreak. For the four southern cities, Quzhou, Lishui, and Wenzhou all showed an "M"-shaped curve for the monthly changes in ozone concentration before the outbreak; that is, it gradually increase from January to May, and from May to It gradually decreased in July, reached a minimum value in July, then rose, and finally steadily reduced to a minimum value from September to December. Among them, the change in ozone concentration in Quzhou is the most obvious among the four southern cities, reaching peaks in May and September, respectively. However, the ozone concentration in Wenling did not change significantly from January to May, and then an inverted "V" curve appeared. For the ozone concentrations in the four southern cities, January and February 2020 also rose faster than the same period in 2019.

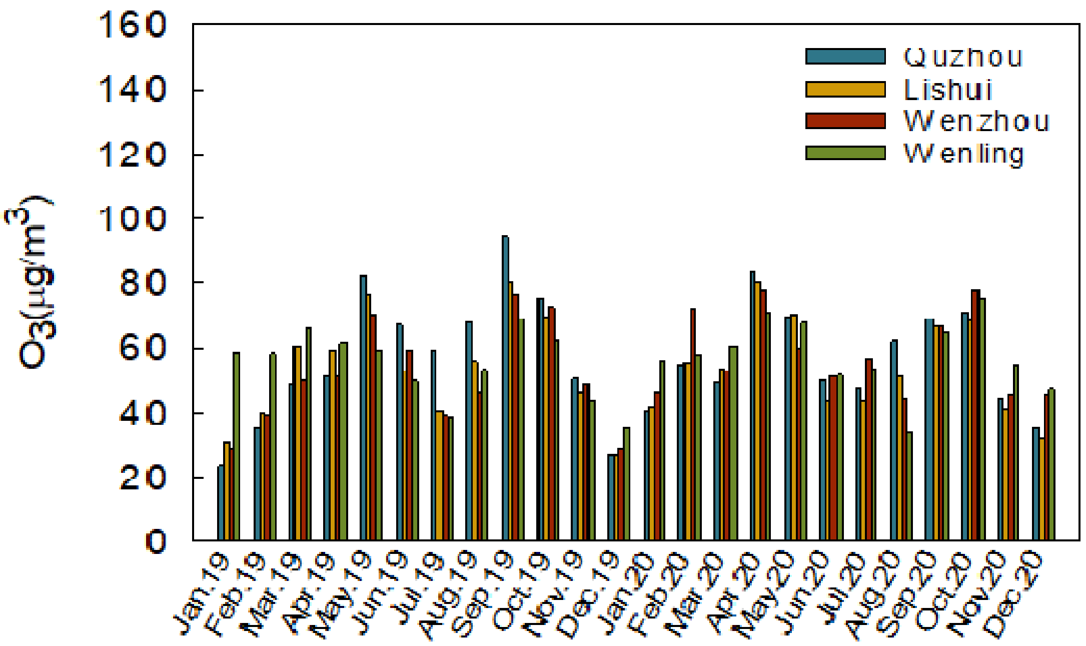

Figure 12 Monthly variation of ozone mass concentration at representative sites in the southern part of Zhejiang

Figure 13 shows the monthly number of days when the ozone concentration value exceeded the standard before and after the outbreak in the four cities in southern Zhejiang Province (Quzhou, Lishui, Wenzhou, and Wenling) before and after the outbreak. For the four southern cities, the trend of monthly ozone concentration exceeding days in the four cities in 2019 showed an "M" shape. In January 2019, ozone concentrations in the four cities did not exceed 100 µg/m3. The number of excess ozone days rose to a peak in May, followed by a decline in June, July, and August. The three cities of Quzhou, Lishui, and Wenzhou had more than 20 days of ozone exceeding the standard from October to December and then dropped significantly in December. However, the days when the ozone concentration in Wenling exceeded the standard dropped substantially in November, only one day.

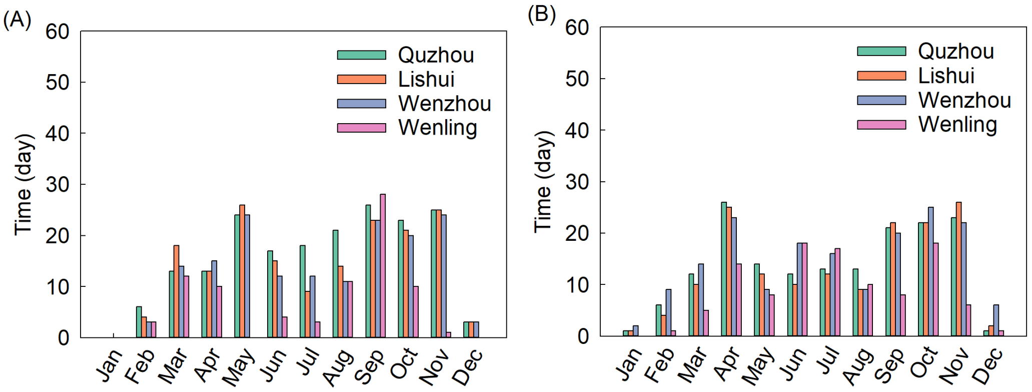

Figure 13 Monthly exceeding days of ozone concentration in 2019 (A) and 2020 (B) at representative sites in the southern part of Zhejiang

Figure 14 shows the monthly changes in ozone concentration values before and after the outbreak in the four cities in Zhejiang Province from west to east. The monthly variation characteristics of ozone concentration in 2019 did not differ much among the four cities. The monthly variation trend of the overall ozone concentration is an "M"-shaped curve, a bimodal characteristic of first increase and then decrease. The ozone concentration in the four cities gradually increase from January to May 2019, reached the highest value in May, then gradually decreased from May to July, rose again from July to September, reached a small peak, and then reached a small peak in September. From January to December, it gradually decreases again. At the same time, the monthly ozone concentrations of the four cities did not exceed the first-level concentration limit (100 μg/m3) specified in the ambient air quality standard (GB3095-2012). In 2020, the changing trend of ozone concentration in four cities from west to east also showed an "M"-shaped curve. The four cities had high ozone concentration levels in April and September 2020. They dropped significantly in July of the same year, reaching the lowest ozone concentration levels for the year.

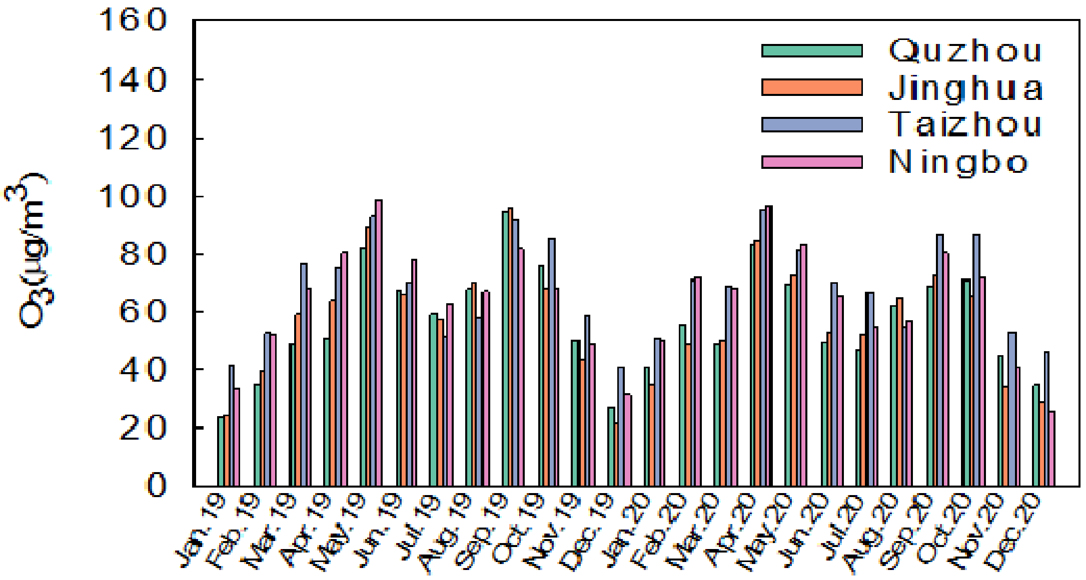

Figure 14 Monthly variation of ozone mass concentration at representative sites in Zhejiang from west to east

The monthly excess days of ozone concentration in 4 cities from west to east in Zhejiang Province (Quzhou, Jinhua, Taizhou, and Ningbo) before and after the outbreak of the epidemic show that the trend of the monthly excess days of ozone concentration in 4 cities in 2019 is "M"-shaped. In January 2019, the number of days with no extra ozone concentration in the four cities. The four cities reached their peaks in May and September, respectively, followed by the minimum number of excess days in the four cities in December. From January to August 2020, the number of days with excessive ozone concentration showed an inverted "V" shape. The four cities reached their respective maximums in April, exceeding 25 days. The monthly ozone concentration in the four cities exceeded 20 days from September to November and decreased significantly in December (Figure 15).

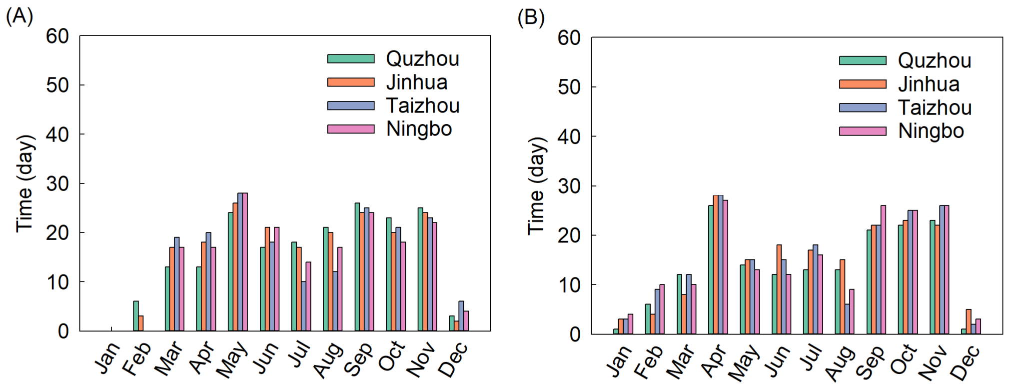

Figure 15 The number of days with monthly ozone concentration exceeding the standard in 2019 (A) and 2020 (B) at representative sites in Zhejiang from west to east

3.1.4 Weekly variation characteristics of ozone concentration

Ozone concentration data before and after the epidemic outbreak are analyzed in this paper to determine the characteristics of weekly ozone changes in various regions of Zhejiang Province. The results are shown in Figures 16 and Figure 17. The weekly trend of ozone concentration varies in the different areas. Before the outbreak, the weekly ozone concentration in Huzhou, Jiaxing, and Wenling is always high. The rest of the cities showed other trends, with Quzhou showing a trough in ozone concentration on Tuesday and Shaoxing, Hangzhou, Lishui, Wenzhou, and Taizhou showing troughs on Wednesday. Quzhou, Lishui, and Jinhua experienced troughs in ozone concentration on Saturday. Overall, eleven cities saw their peak ozone concentrations on Sunday. After the outbreak, Taizhou and Ningbo always maintained high ozone concentrations. At the same time, Huzhou, Jiaxing, Shaoxing, Hangzhou, Quzhou, Lishui, Wenzhou, and Jiaxing showed a unimodal trend but dropped to a low value on Sunday.

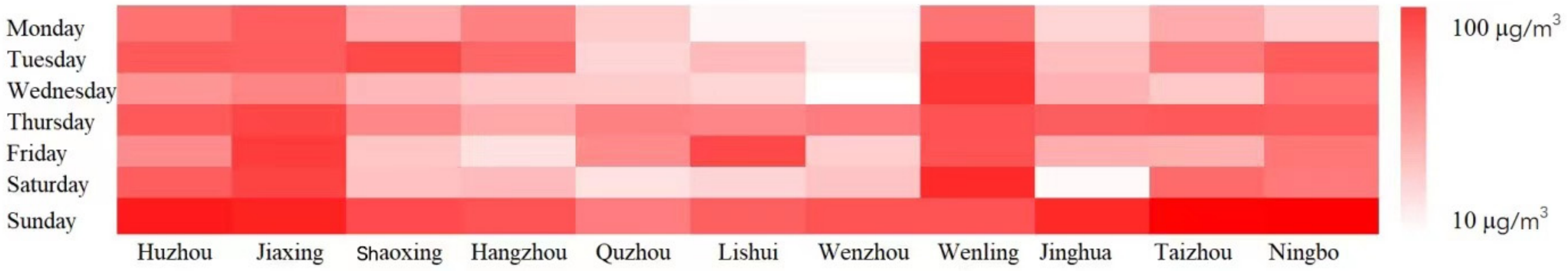

Figure 16 Thermal map of the weekly variation of ozone concentration at each representative site in Zhejiang Province in 2019

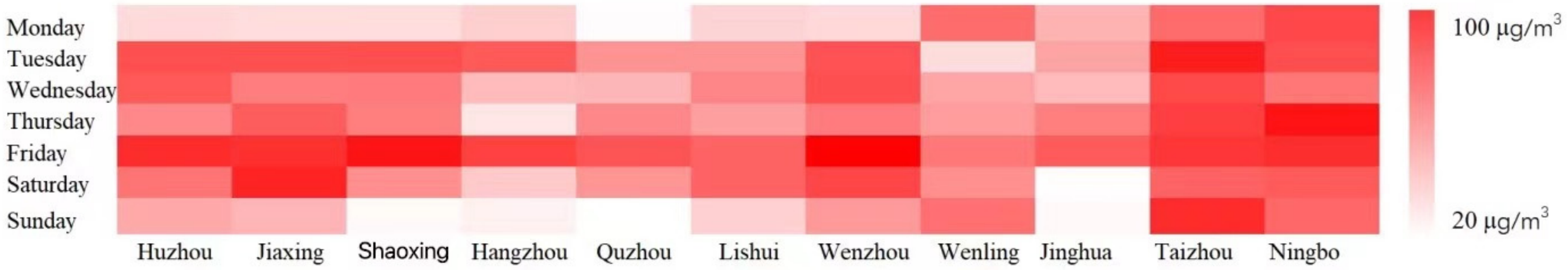

Figure 17 The heat map of the weekly variation of ozone concentration at each representative site in Zhejiang Province in 2020

3.1.4 Characteristics of intraday variation of ozone concentration

The intraday change (24-hour) heat map of ozone concentration at each representative site is analyzed before and after the outbreak. We found that before the outbreak, the hourly variation of ozone concentration in Wenling is between 45-76 g/m3. Except for Wenling, the other cities showed higher ozone concentration from 10:00 am to 6:00 pm (Figure 18). After the outbreak, the ozone concentration in Wenling decreased with time, and the remaining cities maintained a high ozone concentration from 10:00 am to 11:00 pm. In addition, the ozone concentration in each city between 0:00 and 9:00 increase compared with the same period before the outbreak (Figure 19).

Subsequently, we further described the distribution of maximum ozone concentrations in 8 cities in Zhejiang Province before and after the outbreak in the form of boxplots (Figure 20). Before the outbreak, the daily maximum ozone concentration in Zhejiang Province gradually increase from north to south. Lishui and Wenzhou had the largest changes in the daily maximum ozone concentration before the outbreak, and Lishui had higher values than other cities. The maximum ozone concentration range in Huzhou and Jiaxing is less than 100 g/L, which does not exceed the first-level concentration limit specified in the ambient air quality standard (GB3095-2012). After the outbreak, the daily maximum ozone concentration range in Huzhou and Jiaxing in Zhejiang Province is still the first-level concentration. And the daily ozone concentration in southern cities is significantly higher than that in northern cities, which is consistent with the seasonal ozone variation.

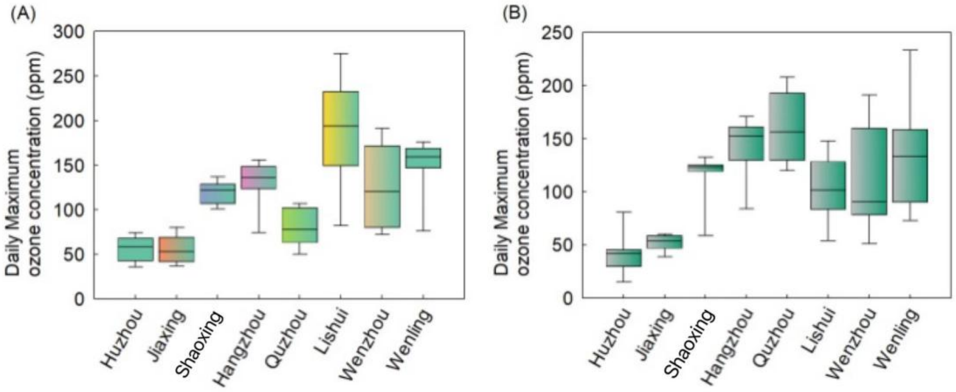

Fig. 20. The daily maximum ozone concentration trend is the boxplot for 2019 (A) and 2020 (B).

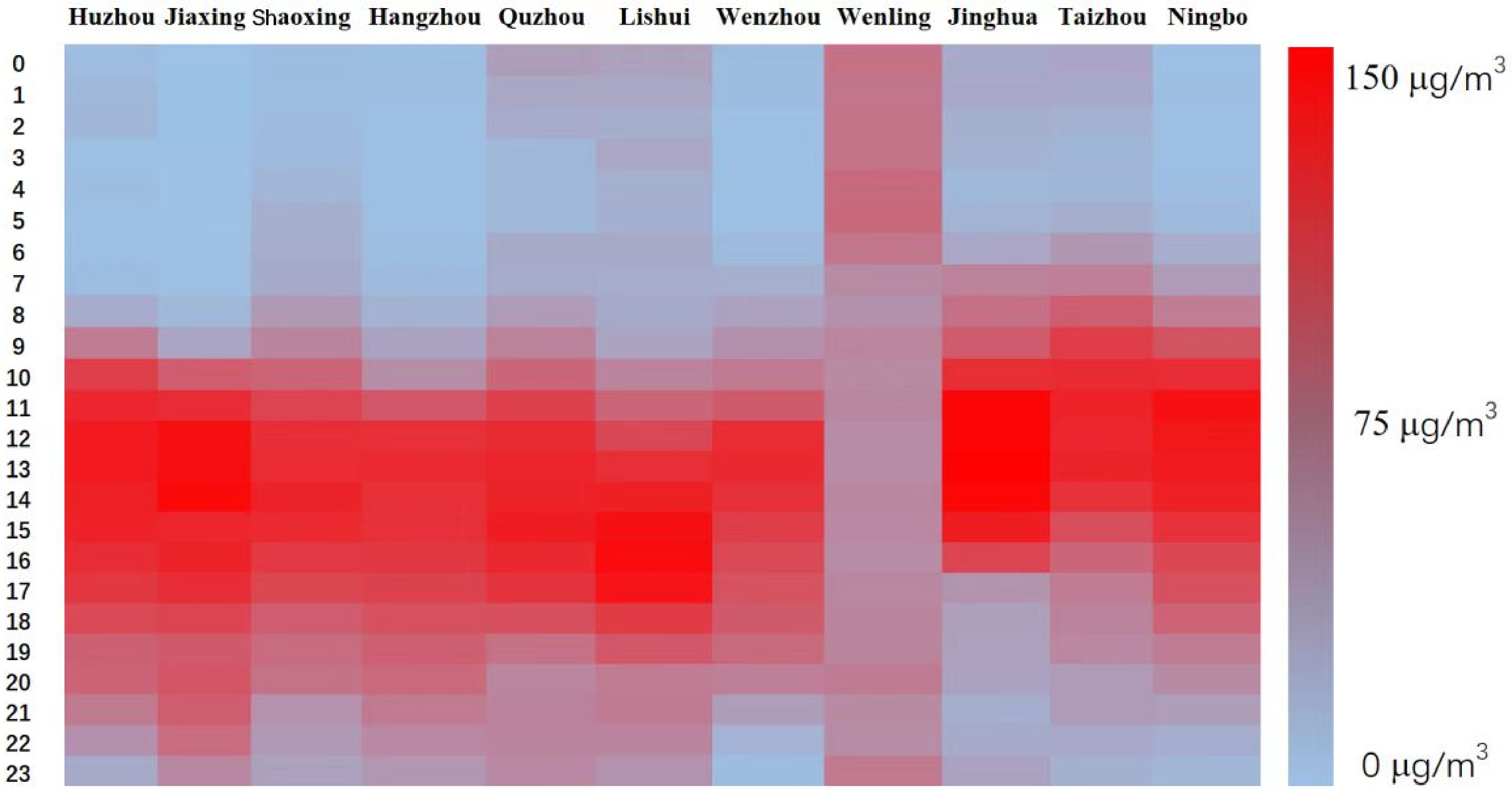

Figure 18 Hourly changes of ozone concentration at each representative site in Zhejiang Province in 2019

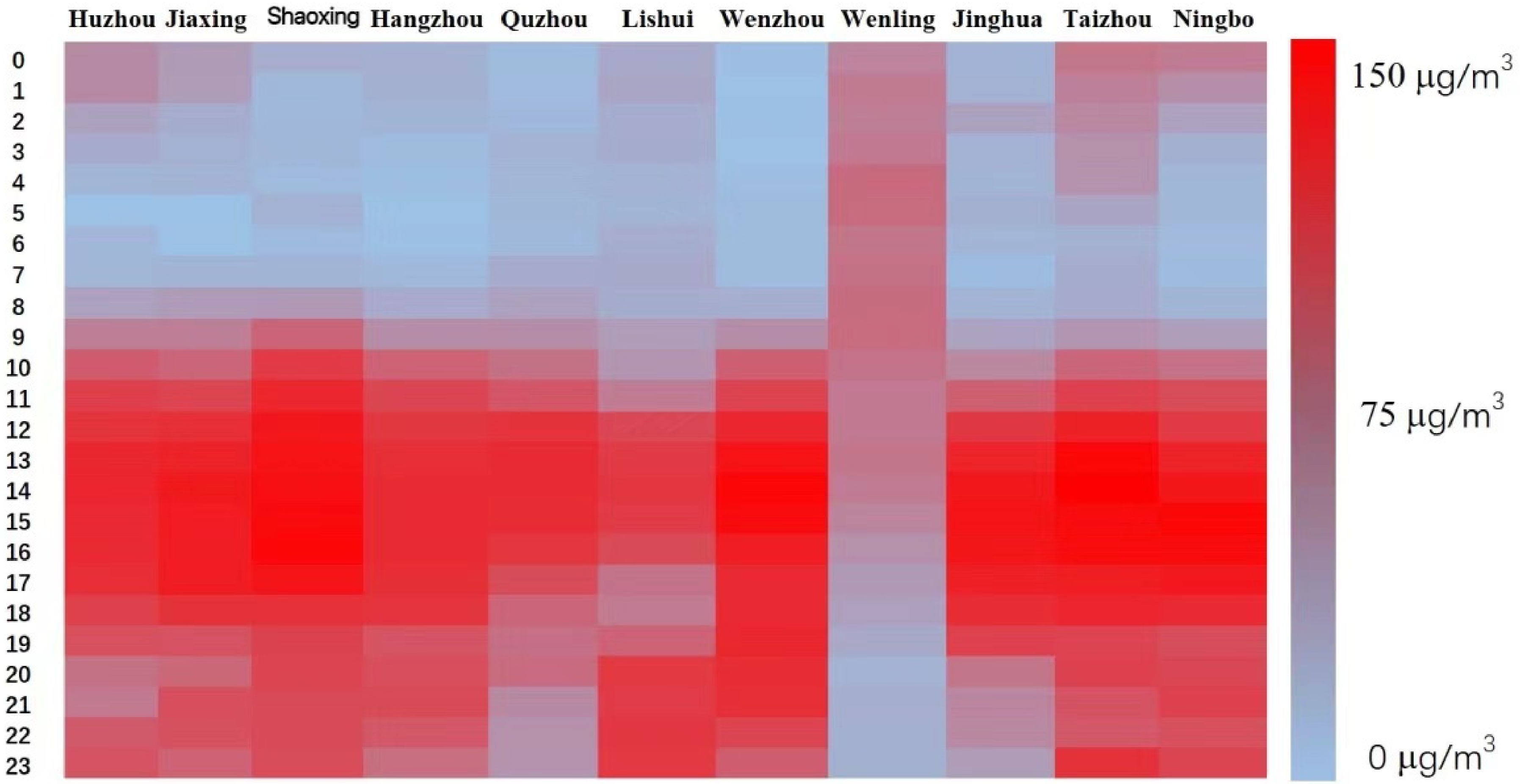

Figure 19 Hourly changes of ozone concentration at each representative site in Zhejiang Province in 2020

3.2 Analysis of factors affecting ozone concentration

From the perspective of meteorological conditions, ozone precursors NO_2, SO_2, $PM_{2.5}$, and PM_{10} particulate pollutants, the influencing factors of near-ground ozone are analyzed. Considering the amount of data and the influence of excluded geographical space on ozone concentration, we choose Zhejiang Province. The central city of Jinhua is used as a distinct research area to analyze the influencing factors of ozone concentration, and the period is from January 2019 to December 2020.

3.2.1 Analysis of the impact of meteorological elements on near-surface ozone

Zhejiang Province will implement a fully closed management from January 27, 2020, and cities will gradually lift the closure control from April. To better explore the influence of meteorological elements on ozone concentration before and after the epidemic containment period, we chose Jinhua City, Zhejiang Province, during the epidemic containment period in March 2020 and the period when the epidemic did not occur in March 2019 for comparative analysis.

Figure 21 shows the distribution of the daily maximum ozone concentration in Jinhua City before and after the outbreak and its scatter plot with the daily maximum dry bulb temperature change. Before the outbreak, the maximum ozone concentration in Jinhua City is proportional to the maximum dry bulb temperature, and the correlation is high; the daily ozone concentration increase with the increase of dry-bulb temperature. In March 2019, the maximum ozone concentration in Jinhua exceeded the first-class standard (100 (g/m3) is 18 days, and the number of days when the maximum temperature exceeded 15°C is 19 days. For the monthly mean value of ozone, the mean value of ozone in March 2019 is 60.17 μg/m3, and the mean value of temperature is 13.5℃. After the outbreak, the daily maximum ozone concentration in Jinhua is still proportional to the daily maximum temperature, and the temperature has a greater impact on the ozone concentration. In Jinhua City, the daily maximum ozone concentration exceeds the first-class standard (100 μg/L) for 12 days, and the daily maximum temperature exceeds 15 ℃ for 21 days. For the monthly average ozone value, the average ozone value in March 2020 is 74.88 μg/m3, and the average temperature value is 13.9℃.

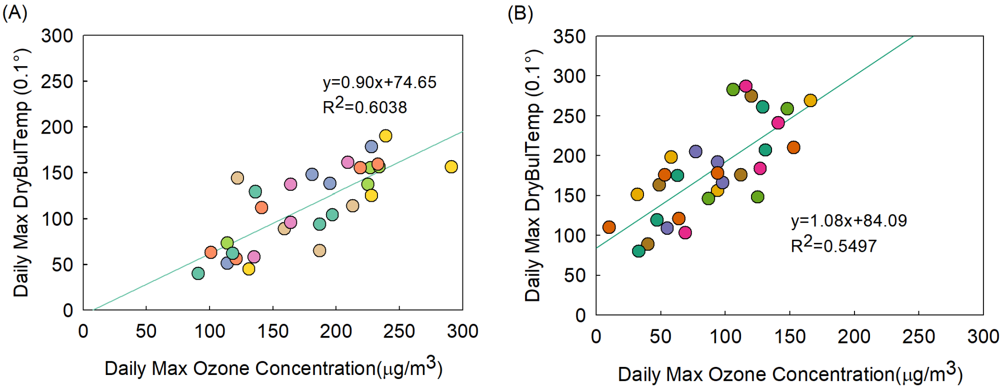

Fig. 21. Scatter plots of daily maximum ozone concentration and DryBulTemp for March 2019 (A) and March 2020 (B)

Figure 22 shows the daily maximum concentration distribution of ozone concentration and the daily maximum relative humidity before and after the outbreak in Jinhua City, Zhejiang Province. Before the outbreak, the maximum ozone concentration in Jinhua City is inversely proportional to the maximum relative humidity; the daily ozone concentration decreased with the increase in relative humidity. In March 2019, Jinhua's daily maximum ozone concentration exceeded the first-class standard (100 μg/m3) for 18 days, and the daily maximum relative humidity exceeded 90% for 21 days. For the monthly average ozone value, the average value of ozone in March 2019 is 60.17 μg/m3, and the average value of relative humidity is 62.79%. After the outbreak, the daily maximum ozone concentration in Jinhua City in March 2020 is still inversely proportional to the daily maximum relative humidity, and the impact of relative humidity on ozone concentration became greater. In Jinhua City, the daily maximum ozone concentration exceeded the first-class standard (100 μg/L) for 12 days, and the daily maximum relative humidity exceeded 80% for 19 days.

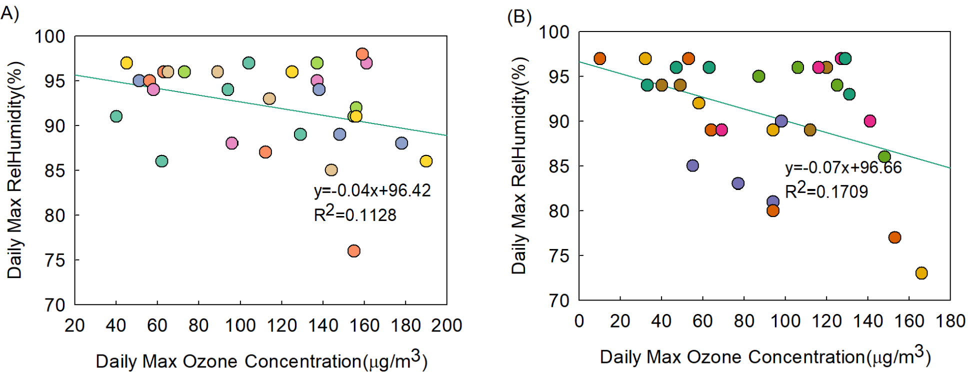

Fig. 22. Scatter plots of daily maximum ozone concentration and relative humidity for March 2019 (A) and March 2020 (B)

3.2.1 Analysis of the impact of polluting gases on near-surface ozone

Ozone is mainly produced by reacting precursors such as NOx, CO, and VOCs under suitable meteorological conditions. Due to the lack of observational data on VOCs, only the relationship between particulate matter and precursors such as NO_2, SO_2, and ozone concentration is analyzed. The monthly relationship between $PM_{2.5}$, PM_{10}, NO_2, SO_2, and ozone concentration in Jinhua City before and after the outbreak.

Before the outbreak, the monthly trends of $PM_{2.5}$ and PM_{10} in Jinhua are consistent, and the concentration of $PM_{2.5}$ is always lower than that of PM_{10}. The volatility of the two in 2019 peaked in March and October, respectively. A trough appeared in February 2019. The specific performance is as follows: $PM_{2.5}$ and PM_{10} showed a downward trend in January-February 2019, rose sharply in February-March, and then increase significantly in September-October, reaching the maximum value of the year in October. $PM_{2.5}$ and PM_{10} ushered in the trough again in January 2020 and reached the minimum value in 2020. The two showed a "V"-shaped trend after a small rebound in March, and then fell again in June 2020, and then gradually increase (Figure 23 (A)). NO_2 and SO_2 remained consistent before and after the outbreak, and the SO_2 concentration is lower than the NO_2 concentration.

The two peaked in March, August, and October 2019, respectively, and there are obvious troughs in February 2019 and February 2020. The fluctuations in 2019 peaked in March and October, respectively. A trough appeared in February 2019 (Fig. 23(B)). The ozone concentration showed a "wave"-like change before the outbreak.

The ozone concentration showed an upward trend from January to March 2019. After a slight decline in April, it rose until June and again ushered in a small wave trough in July and September. After a slight increase in the ozone concentration in October 2019, the value plummeted in January 2020; the ozone concentration continued to rise until April 2020 before ushering in a three-month decline again. After peaking in August 2020, ozone concentrations reached a trough in September, but their concentrations are still slightly higher than in January. Ozone concentrations rose significantly in September 2020, with a peak. Overall, the ozone trend in 2020 is “M” (Figure 23).

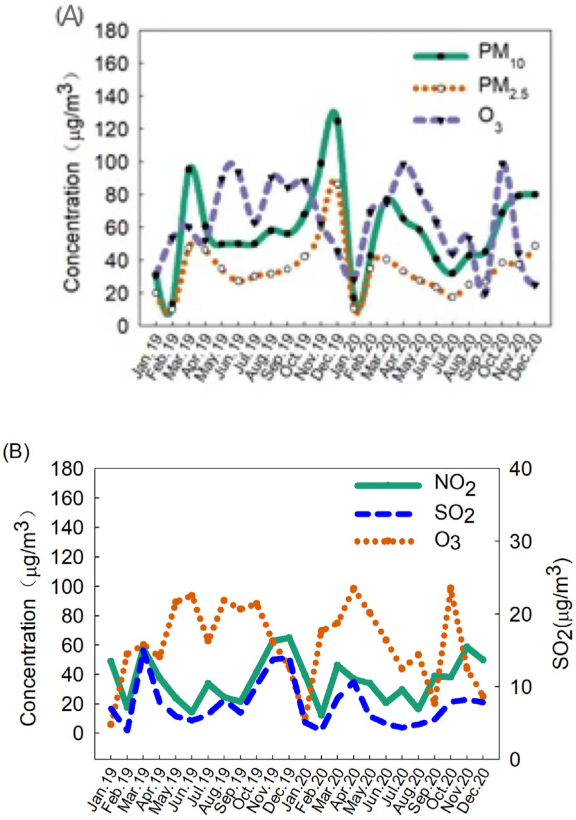

Figure 23 Monthly changes of ozone and PM_{10}, $PM_{2.5}$, SO_2 and NO_2 concentrations in Jinhua City（A and B）

Chapter 4 Discussion

4.1 Analysis of temporal and spatial variation characteristics of ozone pollution

4.1.1 Analysis of the interannual variation characteristics of ozone pollution

Before the outbreak, the inter-annual spatial variation of urban ozone concentration in Zhejiang Province showed a decrease from north to south and an increase from west to east. After the outbreak, cities at the same latitude still showed that the inter-annual ozone concentration gradually increase from west to east. Still, the inter-annual ozone concentration before and after the outbreak is not much different, indicating that the epidemic containment did not significantly affect the inter-annual change in ozone concentration. Influences. Taizhou, Wenzhou, and Ningbo are close to the East China Sea, and the ozone level is at a high level throughout the year, probably because the local temperature difference is small throughout the year, and the annual average temperature in the region is around 20 ° C. Many previous studies have shown that the distribution of pollutants is related to areas (Li Polan et al., 2018; Yu Yijun et al., 2020; Yue Yanyu et al., 2021). The interannual ozone concentration in northern cities is significantly higher than that in southern cities, mainly because the climates of the north and south of my country are quite different. The dry air in the north is more conducive to ozone production, while the relatively humid air in the south is conducive to deposing ozone precursors. Stratospheric ozone transport to the troposphere is another important reason for supporting high ozone concentrations in the northern regions. Tobias et al. (2020a) combined satellite and ground observations. They found that NO_2 in East Asia, Europe, and North America decreased significantly after the controlled epidemic, while ozone is compared with the climate average in previous years. The signal is mainly rising in East Asia and Europe and declining in North America, reflecting regional differences in ozone response.

The year-to-year changes in the number of days with ozone pollution exceeding the standard also reflect regional differences in ozone. Huzhou has the highest number of days with ozone concentration exceeding the standard before and after the epidemic outbreak. Huzhou is the northernmost city in Zhejiang Province, and its relatively dry climate provides ozone production conditions. On the other hand, Wenling had the fewest ozone-exceeding days before and after the outbreak. Wenling is located in the southeast of Zhejiang Province, near the East China Sea, and the temperature is relatively stable throughout the year. Secondly, Wenling is a prefecture-level city in Taizhou City, and the anthropogenic sources of ozone pollution, such as nitrogen oxides and VOCs emitted by motor vehicle exhaust, industrial iste gas, etc., are less than in other cities.

4.1.2 Analysis of seasonal variation characteristics of ozone pollution

The ozone distribution in different seasons is not uniform, showing obvious time-varying characteristics. Before and after the outbreak, 11 cities in Zhejiang Province showed that the ozone concentration in spring and summer is higher than in autumn and winter. This phenomenon is not difficult to understand. The photochemical reaction process that leads to ozone formation is affected by meteorological conditions such as light and temperature. The climatic conditions of high temperature and high ultraviolet intensity in summer are more conducive to forming and accumulating ozone, resulting in higher ozone concentration in summer. At the same time, the height of the boundary layer in summer is high, the atmospheric turbulence is strong, and the vertical transport process of ozone is obvious, resulting in the peak ozone concentration. My country's winter temperature is generally low, so the ozone pollution in winter is relatively slight. Seasonal changes in ozone are also reflected in space. In spring and summer, ozone pollution is most severe in the northern regions (Huzhou, Jiaxing, Shaoxing, and Hangzhou). The ozone concentration in cities from north to south gradually decreased each season. The possible reason is that the cities in the south are in the rainy season in June and July. The frequent precipitation will affect the sunshine and temperature, leading to a slightly lower ozone concentration in June and July. The decrease in ozone concentration in southern cities may also be caused by the climatic characteristics of the prevailing southwest monsoon in summer. The low value of ozone concentration in winter is related to intense radiation and temperature. In autumn, the center of gravity of ozone pollution gradually shifts to the south. In winter, the ozone pollution in Zhejiang Province is more than that of northern cities. In winter, the ozone pollution situation in the province is relatively moderate. Only a few towns have high ozone concentration levels, mainly in coastal areas with relatively warm winter climates.

In addition, the city's economic development and transportation level will also affect the seasonal variation of ozone concentration. When the city has the characteristics of low regional GDP and low road freight volume, the ozone pollution problem in summer and autumn is relatively moderate. However, some economically and industrially developed transportation hubs, such as Beijing, Shanghai, Shenyang, Zhengzhou, Chongqing, and other cities, often suffer from ozone pollution in summer. For example, in the summer of 2017, the daily maximum 8-hour average of ozone concentration in Shanghai once reached 285 μg/m3, which seriously exceeded the national secondary concentration limit. % or more, the second-level concentration limit exceeds the standard by nearly 50% (Yu Xinyang et al., 2022).

It is worth noting that before the outbreak, the maximum difference in ozone concentration between seasons could reach nearly 50 μg/m3. This phenomenon has an inseparable relationship with temperature. Low temperature has no obvious effect on ozone concentration. As the temperature increases, the ozone concentration shows an upward trend. After the temperature reaches 23 ° C, the ozone increase trend increases significantly. When the temperature reaches 35 ° C, the ozone concentration increases. It can be increase to about 200μg/m3. When the temperature reaches the highest value, the ozone concentration also reaches the extreme value. High temperature and high radiation intensity in summer accelerate photochemical reactions to generate ozone (Chen et al., 2020). Although coal consumption is large in winter, due to low temperature and weak solar radiation, the photochemical reaction that generates ozone is inhibited, and the ozone concentration is the lowest. After the outbreak, the largest difference in ozone concentration between seasons narrowed, mainly because the highest ozone concentration in the spring and the lowest in winter after the outbreak increase, respectively. When conducting the seasonal analysis of ozone concentration, we divided January, February, and December 2020 into the winter months after the outbreak. This result indicates that the seasonal ozone concentration in each city increase after the outbreak.

4.1.3 Analysis of monthly variation characteristics of ozone pollution

According to the monthly changes of ozone concentration in eleven cities, the trend of monthly changes before and after the outbreak is "M"-shaped, reaching the maximum monthly changes in ozone concentration in June and September, respectively, and a trough in July. This trend is mainly because solar radiation is an important factor affecting ozone production. The solar radiation intensity varies significantly with the month (Pekey and Ozaslan, 2013). In summer, the sun shines directly on the Tropic of Cancer, which makes Zhejiang Province in the northern hemisphere face the strongest and longest ultraviolet radiation in a year. In addition, fewer clouds in the high sky, and the temperature near the ground rises, which is prone to photochemical pollution, resulting in 6 The ozone concentration is higher around the month. In winter, the temperature drops, the solar radiation is weak, and there is more static and stable weather, so the ozone concentration is low. During the high-temperature month of July, the decrease in ozone concentration may be related to the large rainfall in July in Zhejiang Province. In the case of precipitation weather, the sky is generally densely covered with dark clouds, and the thick cloud layer has a strong absorption effect on the short-wave radiation of solar ultraviolet light from the upper boundary of the atmosphere, which will reduce the rate of photochemical reactions that form ozone, thereby causing near-ground Ozone production is limited. The study of Wang Mei et al. (2019) showed that the effect of rainfall on ozone is related to the magnitude of rainfall; moderate rain and heavy rain have a scavenging effect on ozone concentration, among which moderate rain has the best scavenging effect, and trace drizzle and light rain have a significant impact on ozone concentration. Enhancement effect; the first and second days of continuous precipitation had a scavenging impact on ozone concentration, and the third day's effect changed from scavenging to promoting. In addition, the individual weather with better sunlight in September (Duan Yuxiao et al., 2001) and the concentration changes of other pollutants may be the reasons for the small peak of ozone concentration at this time (Wang Xijiao et al., 2015).

By comparing related cities in longitude and latitude, we found that the number of days in which the ozone concentration exceeded the standard in March 2020 is significantly higher than that in March 2019. Still, the cities in the southwest showed the number of days exceeding the standard monthly after the outbreak. Falling situation. After June, the decrease in ozone concentration in southern cities may be caused by the prevailing southwest monsoon in summer. At the same time, in the southwestern region of my country, the change of ozone concentration is greatly affected by ultraviolet radiation, and the transport of stratospheric ozone to the troposphere is another important reason supporting the decline of ozone concentration in this region. We're guessing this should be closely related to COVID-19; in December 2019, China experienced the coronavirus outbreak. The rapid increase in confirmed cases and 55 deaths have led the government to implement preventive measures. From January 23 to 29, 2020, China activated a level 1 public health emergency response and imposed strict travel restrictions, involving 1.358 billion people. As a result, traffic, construction, and light industrial activity have decreased significantly. For example, on January 30, 2020, total traffic in China dropped by 87.7% compared to the same period last year. The coronavirus outbreak has had a major impact on society and the economy. The study also found that particulate matter can increase the optical thickness of the aerosol, weaken solar radiation, and then affect ozone generation (Miranda et al. 2005).In the context of the 2020 coronavirus epidemic, March is in a period of epidemic-controlled lockdown, which has resulted in the shutdown of many factories. The emission of ozone-forming precursors has dropped significantly due to human factors.

After the outbreak caused ozone concentrations to drop after March, ozone concentrations returned to normal levels, thus the lowest emission levels in March. Emissions fell slightly in August, which may also be the result of a rebound in the outbreak in August, leading to renewed lockdowns in some areas and a corresponding reduction in ozone concentrations due to human factors. However, lockdowns are only regional, so the drop in August is not as dramatic as in March. The monthly high ozone concentration at each site is concentrated in May and September, and the air pressure in summer is generally low. In the context of the 2020 coronavirus epidemic, March is in a period of epidemic-controlled lockdown, which has resulted in the shutdown of many factories. The emission of ozone-forming precursors has dropped significantly due to human factors. After the outbreak caused ozone concentrations to drop after March, ozone concentrations returned to normal levels, thus the lowest emission levels in March. Emissions fell slightly in August, which may also be the result of a rebound in the outbreak in August, leading to renewed lockdowns in some areas and a corresponding reduction in ozone concentrations due to human factors. However, lockdowns are only regional, so the drop in August is not as dramatic as in March. The monthly high ozone concentration at each site is concentrated in May and September, and the air pressure in summer is generally low. The monthly ozone variation is consistent with the seasonal variation, and both showed that the ozone concentration increase during the prevention and control stage. Studies have shown that ozone concentration and air pressure are negatively correlated. Relatively low air pressure usually occurs in summer, a period of high ozone concentration. Liu Jiaojiao et al. (Liu Jiaojiao et al., 2014) pointed out that the increase in ozone concentration is closely related to the decrease in atmospheric pressure. When the atmospheric pressure drops more than 0.4 kPa, the ozone mass concentration is higher; Under the increase control, the air pressure is high, and there is more sunny, hot, and high-temperature weather, which is conducive to the generation of ozone, so the air pressure on the over-standard day is high.

4.1.4 Analysis of weekly variation characteristics of ozone pollution

Before the outbreak, cities had their peak ozone concentrations on Sundays. Stephens et al. (2008) pointed out that ozone pollution has a "weekend effect"; ozone concentration on rest days is higher than on working days. Our results show that ozone concentrations in cities in Zhejiang Province showed a clear "weekend effect" before the outbreak, and the ozone concentrations are lower during workdays. After the outbreak, the peak of ozone concentration appeared on Tuesday or Friday, and the "weekend effect" is not very obvious. However, Das et al. (2021) compared the main air pollutants during the epidemic closure period with the atmospheric pollutants on weekdays and weekends in the same period of history. They found that the weekend effect of ozone during the period of closure is more obvious than that in the same period in history, which is consistent with ours. The results are inconsistent. We speculate that the possible reason is related to the high frequency of human productive activities during the working day. The epidemic has limited people's travel for work, resulting in people choosing off-peak travel for safety reasons and the large discharge of industrial pollutants, so the ozone concentration is higher than that on rest days. In addition, our study found that the spatial characteristics of the weekly ozone changes at each representative site before the outbreak showed that the ozone concentration in each city decreased sequentially from north to south and increase sequentially from west to east. The spatial characteristics are consistent. After the outbreak, the weekly ozone concentration in various urban sites at the same latitude still showed a gradual increase from west to east; however, in terms of longitude, Wenzhou, a southern city, performed abnormally, and the weekly change in ozone concentration increase instead.

4.1.5 Analysis of intraday variation characteristics of ozone pollution

The photochemical reaction process mainly controls ozone formation, and changes in photochemical reaction conditions will inevitably affect the appearance of ozone. In a day, as the sun rises in the east and sets in the west, meteorological conditions such as sunshine duration and temperature will change during the day, and the concentrations of ozone precursors such as NOx and VOCs also vary with people's daily activities. Fluctuations occur, and these changes undoubtedly lead to changes in ozone concentrations at different times of the day. The daily variation of ozone generally presents a "single peak" trend, and the daily variation of ozone concentration depends on atmospheric diffusion conditions and the intensity of photochemical reactions. Generally, the ozone concentration is the lowest between 8 and 9 o'clock, starting at 9 o'clock; with the gradual increase of the sun's altitude angle, the intensity of solar radiation from the upper atmosphere increases, and the photochemical reaction becomes more intense. The ozone concentration increases at 18-20 times to the highest value. From 8 to 9 o'clock the next day, the photochemical reaction weakened at night, which reduced the amount of ozone generated. The impact of ground deposition on ozone and the emission of human activities in the evening peak (especially the emission of traffic) led to an increase in nitric oxide and ozone. It is consumed by the continuous reaction of nitric oxide (Wang Xuesong et al., 2009), so the ozone concentration at this time continues to decrease until it reaches the lowest level in the early morning. Solar radiation can promote photochemical reactions, and photochemical reactions can accelerate the production of ozone.

Therefore, the ozone concentration in a day generally shows the characteristics of high during the day and low at night. At night, because the sunshine hours are 0, the photochemical reaction of ozone is very weak, and the concentration is at a low value; after sunrise, with the strengthening of solar radiation, the decomposition of oxygen molecules in the atmosphere is enhanced, and at the same time, the temperature rises, and the secondary photochemical reaction of ozone The rate increases, the concentration begins to rise. The maximum concentration is reached at 15:00-16:00, which lags behind the strongest period of solar radiation, which is mainly related to the reaction time of photochemical reaction to generate secondary pollutant ozone (An Junlin et al., 2009; Wang Hong et al., 2011; Wang Lei et al., 2018), the period of strongest radiation is also the period of rapid accumulation of ozone concentration. Then, as the solar radiation weakened, the ozone concentration began to decrease again. Its diurnal variation characteristics are consistent with those in Chengdu and other regions (Wu Kai et al., 2017). Before and after the outbreak, except for Wenling, each representative city station's daily high ozone concentration showed a decreasing order from north to south, consistent with the seasonal, monthly, and weekly ozone concentration changes before the outbreak. At the same time, after the outbreak, the ozone concentration in each city between 0:00 and 9:00 increase compared with the same period before the outbreak. This result also shows that the epidemic containment will lead to an increase in ozone concentration.

4.2 Analysis of factors affecting ozone concentration

4.2.1 Influence of meteorological elements on ozone concentration

To explore the correlation of meteorological elements to ozone pollution, we choose two commonly used meteorological indicators, temperature, and relative humidity. There is a good correlation between temperature and ozone concentration. It is similar to the research results in the literature (Cheng Nianliang et al., 2016; Jiang Lulu et al., 2016; Wu Kai et al., 2017), the higher the temperature and the stronger the sunshine, the more conducive to the generation of ozone. Due to the photochemical reaction of ozone precursors under the action of solar radiation, ozone is generated. The stronger the solar radiation, the radiation effect of surface warming, the higher the atmospheric temperature, and the faster the photochemical reaction of ozone precursors promotes ozone generation and the near ground. The increase in ozone concentration and the greenhouse effect of atmospheric ozone accumulation make its pollution more serious, and the surface temperature rises higher, resulting in the climate warming and self-feedback warming effect of ozone (Mao Bing et al., 2016). In addition, some studies have shown that evaporation has a close positive correlation with the near-surface atmospheric temperature, so the change of evaporation can reflect the evolution of near-surface air temperature in the region to a certain extent, so the effect of evaporation on ozone also reflects the impact of temperature on its In addition, with the increase of temperature, along with the enhancement of surface evaporation and vegetation transpiration, the volatilization of volatile substances (including VOCs) on the surface and vegetation is enhanced, which promotes the formation of ozone. Generated (Yijun Yu et al., 2020). Compared with before the outbreak, the ozone concentration increase significantly after the outbreak. Still, the concentrations of precursors such as NO_2 and SO_2 are lower than in the same period in previous years. Still, the ozone concentration did not decrease but increase, proving to a certain extent that the meteorological elements during the period significantly impacted ozone. Concentration increases contribute significantly.

The atmosphere's water vapor and ozone will react to generate free radicals such as OH and HO2. These free radicals can trigger photochemical reactions in the atmosphere and are an important "fuse" for photochemical reactions. Therefore, water vapor concentration (relative humidity) also affects photochemical reactions and atmospheric ozone concentration. Our research shows that the ozone concentration before and after the outbreak negatively correlates with relative humidity; high relative humidity is not conducive to ozone generation. Junlin et al. (2009) found a critical value of photochemical reaction intensity at about 60% relative humidity. When the relative humidity is greater than 60%, the ozone concentration decreases with the increase of relative humidity. The ozone generation results from the combined action of local photochemical pollution and regional transport (Cheng Nianliang et al., 2016). At the same time, studies have shown that the high humidity environment is conducive to the wet growth of particulate matter, the increase of $PM_{2.5}$ concentration, and the inhibition of ozone generation (Wang Hong et al., 2011). After the outbreak, the relative humidity of the air decreased, thereby increasing the ozone concentration. Humid air conditions not only make solar radiation attenuated by the extinction mechanism under the action of water vapor (Liu Jingmiao et al., 2003) but also facilitate the occurrence of dry ozone deposition. Regional short-term precipitation can remove some nitrogen oxides.

Meanwhile, on rainy days, the cloud layer is thicker, and the solar radiation is weak, which is not conducive to the volatilization of organic matter in the precursor, and also weakens the photochemical reaction (Liang Biling et al., 2017). In the case of high relative humidity, the free radicals -H and -OH contained in water vapor in the air quickly decompose ozone into oxygen molecules, reducing the ozone concentration (Cheng Nianliang et al., 2016); water vapor also affects the sun through extinction mechanism. The radiation causes the attenuation of ultraviolet radiation, reducing the ozone concentration (Wang Lei et al., 2018).

4.2.2 Analysis of the influence of polluting gases on ozone concentration

Before the outbreak, the monthly variation trend of ozone concentration is negatively correlated with the concentrations of NO_2, SO_2, $PM_{2.5}$, and PM_{10}. The ozone concentration first increase and then decreased, and the other four pollutants decreased first and then increase. The trend of SO_2 and NO_2 in the city is the same, and the trend of $PM_{2.5}$ and PM_{10} concentration is the same. According to relevant research, NO_2 and SO_2 are both precursors of ozone and reactants of $PM_{2.5}$ (Li Hong et al., 2019). $PM_{2.5}$ mainly comprises secondary components such as sulfates, nitrates, ammonium salts, and secondary organic aerosols, while PM_{10} also contains many crustal elements. May-September is the high incidence period of ozone pollution in Zhejiang Province. This period coincides with the high-temperature season in Zhejiang Province.

In addition, due to the instability of the atmosphere, the diffusion of pollutants is strong, the concentration of $PM_{2.5}$ is reduced, and the visibility of the atmosphere is enhanced. The amount of radiation increases accordingly, and ozone precursors, especially NO_2 and SO_2, are prone to photochemical reactions to generate ozone under these conditions. The concentrations of NO_2 and SO_2 decrease, and the amount of ozone increases. The ozone concentration is at the lowest in January, November, and December. Due to the low average temperature in winter in Zhejiang Province, and it is prone to the stable atmospheric formation, no wind or downwind, especially in the heating season, more pollutants are discharged. And it is not easy to diffuse; the pollution of $PM_{2.5}$ is strengthened, the radiation of sunlight is blocked, and pollutants such as NO_2 and SO_2 are easily converted into secondary particulate pollution. Under these conditions, ozone is not easily generated, so the concentration is relatively low. At the same time, Yu Yijun et al. (2020) found through research and analysis that the most important factor for the increase of ozone concentration in Beijing, Hengshui, and other regions is the decrease in $PM_{2.5}$ concentration, which also means that we must effectively offset the reduction in $PM_{2.5}$ concentration. The reverse effect, so that the ozone concentration also decreases, requires further reduction of the emission of precursor substances.

After the outbreak, the ozone concentration increase rapidly from January to May 2020, and compared with before the outbreak, the ozone concentration increase, but SO_2 and NO_2 showed a downward trend. This occurrence does not seem surprising. SO_2 mainly comes from fuel combustion and industrial production emissions, while NO_2 mainly comes from industry, coal-burning sources, and vehicle exhaust emissions. Zhejiang Province launched the first-level response to public health emergencies on January 23, 2020. Under strict prevention and control measures, the movement of people is restricted, and traffic emissions are reduced. At the same time, some studies have shown that the migration index of Zhejiang Province dropped significantly after the Spring Festival after the epidemic outbreak (FU et al., 2019). Zhejiang Province, as a province with a large inter-provincial floating population, the decline in the migration index after the holiday shows that the degree of resumption of work and production after the holiday has been affected. In addition, Tobias et al. (2020a) found a significant decrease in NO_2 and a significant increase of 33%-57% in the ozone-8 h sliding maximum through the observation data of the Barcelona area. Das t et al. (2021) used the WRFCHIMERE model to simulate the situation of epidemic containment and no epidemic containment in Western Europe during the same period. They found that containment measures would lead to a large reduction in primary NO_2 emissions, a small reduction in fine particulate matter, and a small decrease in ozone concentration. Most areas showed an increase, and the more densely populated areas, the greater the growth. After the closure of the city, the concentrations of SO_2 and NO_2 all declined, but the concentrations of $PM_{2.5}$, PM_{10}, and ozone are on the rise as time went on until March. So emissions are not the only factor determining pollution during the COVID-19 control period; there are other factors such as transmission, atmospheric chemistry, and deposition.

Chapter 5 Conclusions and Outlook

5.1 Research conclusions

This study takes eleven cities in Zhejiang Province as the research objects, selects the ozone concentration data in 2019 before the outbreak of the new crown epidemic and in 2020 after the outbreak, and used statistical methods to analyze the temporal and spatial distribution characteristics of ozone concentration in Zhejiang Province and the number of days when the ozone concentration exceeded the standard. Including interannual, seasonal, monthly, weekly, daily, and hourly changes and selecting Jinhua, the central city of Zhejiang Province, to further explore the relationship between ozone concentration and meteorological factors and other pollutants. The main conclusions are as follows:

(1) Before the outbreak of the new crown epidemic, the spatial changes of ozone concentration on different time scales in Zhejiang Province showed a decrease from north to south, and cities at the same latitude showed a gradual increase from west to east. After the outbreak of the new crown epidemic, different The spatial variation trend of urban ozone concentration is generally similar to that before the epidemic, but there are local anomalies in the changes in the same longitude. For example, Wenling, a seaside city, is greatly affected by temperature changes.

(2) The interannual variation of ozone concentration and the number of days with excess concentration are not significantly different before and after the outbreak of the new crown epidemic. The seasonal changes in ozone concentration and the number of days with extra concentration show that the ozone concentration in spring and summer is higher than in autumn and winter. Still, the ozone concentration between seasons after the outbreak occurs. The difference in concentration decreased; the weekly variation of ozone concentration showed an obvious "weekend effect" before the outbreak, but the peak of ozone concentration appeared on Tuesday or Friday after the outbreak; intraday changes in ozone concentration are all 18- The highest value of ozone concentration is reached between 20:00, but after the outbreak, the ozone concentration increase from 0:00 to 9:00 compared with the data before the outbreak.

(3) Before and after the outbreak of the new crown epidemic, ozone concentration and temperature changes showed a positive correlation, which increase with the rise of temperature but is negatively correlated with relative humidity. After the new crown epidemic outbreak, the correlation between ozone concentration and temperature decreased compared to before the outbreak. In contrast, the correlation between ozone concentration and relative humidity increase slightly. In addition, the monthly trend of ozone concentration is negatively correlated with NO_2, SO_2, $PM_{2.5}$, and PM_{10} concentrations before and after the outbreak of the new crown epidemic. After the outbreak, the concentrations of $PM_{2.5}$, PM_{10}, and ozone have been on an upward trend until March. Compared with the data before the outbreak, the ozone concentration has increase, but SO_2 and NO_2 have decreased significantly.

5.2 Deficiencies and Prospects

The shortcomings of this study and the areas that need to be improved are as follows:

(1) Research on regional scale issues: This study mainly focuses on comparing and analyzing urban ozone concentration in Zhejiang Province. According to relevant air pollution research, it is found that there is a regional transmission of air pollutants, so ozone pollution in Zhejiang Province is also related to surrounding areas. Study the region's scope and the ozone pollution problem between regions.

(2) Research time scale problem: This study only selects the air pollutants in the two years from 2019 to 2020, the temporal and spatial distribution of the concentration data can reflect a certain trend of change. However, since the station pollutant data before 2019 and after 2020 are not obtained, the explanatory power of the long-term change characteristics of ozone pollution in the study area is not strong. Multi-year data is added to analyze the change characteristics.

(3) Problems on selecting research indicators: VOCs are another important ozone precursors. Due to the lack of data acquisition channels, this paper fails to analyze the impact of VOCs and their interaction with other factors on ozone deeply. Therefore, data acquisition channels should be expanded to obtain more detailed multi-year data to ensure the scientificity and rigor of the research results.

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