Research Article

Spatiotemporal Distribution of Air Pollution Characteristics in Jiangsu Province, China

Rong Song, Liumei Yang, Mengyuan Liu, Can Li, and Yanrong Yang

Collaborative Innovation Center of Sustainable Forestry in Southern China of Jiangsu Province, College of Biology and Environment, Nanjing Forestry University, Nanjing 210037, China

Correspondence should be addressed to Yanrong Yang; yangyanrong@njfu.edu.cn

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Following the deepening of climate change and the increasing industrialization in recent years, the problem of air pollution in cities has become increasingly prominent. Based on the data of air pollutants and meteorological elements in Jiangsu Province, China (2013–2017), we analyze the spatiotemporal characteristics of air pollution. The results show that the air-quality index (AQI) in Jiangsu Province decreased from 2013 to 2017 and the highest AQI is in winter and the lowest in the summer, while its values in coastal cities of Jiangsu are less than those of inland cities. For the temporal distribution of primary pollutants, PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, and CO present the same trend under seasonal and monthly time scales, i.e., winter is higher and summer is lower; however, the other secondary pollutant, O$_3$, presents opposite characteristics under the same time scale: it has higher concentration levels in summer and lower in winter. For the spatial distribution, PM$_{2.5}$ and PM$_{10}$ are in good concord: the higher values are found in the west of Jiangsu Province and lower in the east. For the spatial distribution of NO$_2$, this presents higher concentrations in south and lower concentrations in north according to the position of Yangzi River, while the distribution of O$_3$ concentration is opposite to that of NO$_2$. The meteorological elements selected are related to air pollution, the AQI is significantly negatively correlated with monthly temperature (including average, minimum, and maximum temperatures), monthly average water vapor pressure, monthly precipitation, and monthly sunshine duration; the correlation coefficients are $-0.852$, $-0.846$, $-0.850$, $-0.797$, $-0.727$, and $-0.599$, respectively. As far as the relationships between air pollutants are concerned, there is a significant positive correlation between AQI, PM$_{2.5}$, PM$_{10}$, SO$_2$, and NO$_2$, while O$_3$ is remarkably negatively correlated with other pollutants and AQI. The most prominent correlations are distinguished into two groups: one is AQI, PM$_{2.5}$, and PM$_{10}$, with correlation coefficients of 0.876 and 0.966, and the other is SO$_2$, NO$_2$, with correlation coefficient of about 0.9.

1. Introduction

With the rapid social and economic development of China, the urbanization process has accelerated and energy consumption has been increasing continuously. Consequently, the threat of urban air pollution to the physical and mental health of city inhabitants has become increasingly prominent [1–3], drawing considerable attention to the issue. Research on the spatial and temporal characteristics of urban air pollution can help understand air pollution status in cities as a whole, control the source areas of urban air pollution, and provide a scientific reference for developing practical air-pollution control policies. Therefore, such research has a far-reaching significance for the sustainable development of cities.

China is the disaster area of air pollution in the world [4, 5]. The “Environmental Performance Index: 2016 Report” released by Yale University shows that the air quality in China is the second-lowest in the world, even behind India, only slightly better than Bangladesh [6]. Chinese population-weighted mean PM$_{2.5}$ (particulate matter with an aerodynamic equivalent diameter $\leq 2.5\mu m$) concentration is the highest value of the world’s 10 most populous countries and increased significantly between 1990 and 2010 [7].
Therefore, Chinese air pollution problem attracts more and more attention from the government and researchers. In recent years, many researchers have carried out relevant studies on the spatiotemporal distribution of AQI (air-quality index) characteristics in China and have obtained some consistent results in terms of temporal characteristics. For example, Jiang and Bai [8], Yue and Wang [9], and Xia et al. [10] noted that the AQI shows a temporal distribution of being high in winter and low in summer. However, due to differences in topographic features, landforms, and human activities, the AQI has strong regional characteristics. Litao et al. [11] analyzed the temporal and spatial distribution characteristics of air pollution in China and found that air pollution is generally more severe in the north than the south of the country. Zhang et al. [12] analyzed the temporal and spatial distribution of the AQI in Beijing from January to February 2013 and found that it gradually decreased from southeast to northwest. Liu et al. [13], moreover, analyzed the characteristics of air-quality changes in Jiangsu during the 2016 Spring Festival and found that the AQI in the northern part of Jiangsu was higher than that in the southern part, indicating that the spatial distribution in both areas is not consistent. In addition to being affected by local air-pollutant emissions, air quality is also affected by local meteorological parameters. When the pollution source is relatively stable, the meteorological conditions play a leading role in air quality [14]. In the Huai’an area of Jiangsu Province [15], through an analysis of the relationship between air-pollution changes and meteorological conditions, one study found that the AQI was negatively correlated with wind speed, precipitation, temperature, and relative humidity. In Chuzhou [16], the AQI showed a significant negative correlation with average temperature, average wind speed, and daily precipitation and a significant positive correlation with average air pressure and daily temperature range. In a study of the Tianjin area [17], the correlation between meteorological factors and air quality during the hot season was analyzed, and it was found that the influence of the surface wind field on air quality exhibited a dual effect. These studies all indicated that the meteorological conditions have a close correlation with atmospheric pollution and play important role in the spread of urban air pollution.

Jiangsu Province is an economically developed Province in eastern China comprising a concentrated area of metropolises and large rural areas [18]. This leads to the release of air pollutants from point-and-line sources (e.g., urban constructions, transportation, and industrial production), as well as area sources (e.g., straw burning in agricultural production); these factors are complex and diverse. The terrain of Jiangsu Province is flat, situated in the climate transition zone between the northern and southern parts of China. It is a buffer zone between the Beijing–Tianjin–Hebei region and the Yangtze River Delta, two areas with severe air pollution. The changes in the prevailing wind direction (monsoon) and rain belt caused by the summer-fall and winter-spring transition seasons complicate the spatial and temporal changes in air pollution over Jiangsu [19]. Based on the AQI of Jiangsu Province from 2013 to 2017, primary air pollutants, and meteorological data for that period, this study aims at analyzing changes in the AQI of this province and conducting correlation analyses in combination with conventional meteorological parameters. The findings of this study can, therefore, provide a scientific basis for making rational decisions in the planning of urban industrial layouts, improving environmental air quality, and actively responding to ambient air pollution.

2. Data and Methods

Jiangsu is located in eastern China (116°18′–121°57′E and 30°45′–35°20′N) and includes 13 prefecture-level cities (Suzhou, Wuxi, Changzhou, Zhenjiang, Nanjing, Nantong, Yangzhou, Taizhou, Huai’an, Yancheng, Suqian, Xuzhou, and Lianyungang), with an area of 107,200 km². In 2015, the resident population was 79.763 million, and the gross domestic product (GDP) per capita was 12,805 dollars, ranking it first among all provinces. Southern Jiangsu is an economically developed area while northern Jiangsu is relatively retarded. The terrain of the province is flat, and the plains area accounts for more than 70% of the total area. The cultivated area per capita is less than 600 m²; Jiangsu is an important grain-producing area in China. The transitional characteristics of climate and vegetation are obvious; the southern part is dominated by a subtropical humid monsoon climate while the northern part is dominated by a temperate humid monsoon climate. The southern vegetation is dominated by evergreen broad-leaf forest, while the northern vegetation is dominated by deciduous broad-leaf forest. The prevailing wind direction in winter is northwest, while in summer southeast [20]. The annual average temperature is 13–16°C, and the annual rainfall is about 1,200 mm.

In March 2012, the Chinese Ministry of Environmental Protection (MEP) released the official revisions of the ambient AQI, which were calculated based on six pollutants, including SO₂, NO₂, PM₂.⁵, PM₁₀, CO, and O₃ (8 h peak) [12]. The AQI is proposed to evaluate the pollution level of the air and adverse effects on human body after a long-term exposure in the polluted air. The classification of the AQI is as follows: when the AQI lies between 0 and 50, the air-quality level is level 1, it implies that the air quality is favorable and the air environment is hardly polluted; when the AQI lies between 51 and 100, the air-quality level is level 2, it implies that the air quality is acceptable and it may generate a weak influence on susceptible populations; when the AQI lies between 101 and 150, the air-quality level is level 3, it implies that the air environment is mildly polluted and it may cause adverse effects on healthy populations. Therefore, we used the AQI data to evaluate the air quality in Jiangsu Province.

Daily AQI data were collected for 71 air-quality monitoring stations in Jiangsu Province from January 2013 to August 2018, along with corresponding meteorological parameters (from January 2013 to December 2017) such as temperature, wind speed, water vapor pressure, and sunshine duration, from the National Urban Air-Quality Real-Time Publishing Platform of the China National Environmental Monitoring Center. Figure 1 shows the distribution of the stations and is represented by the symbol “o.” For convenience, the names of cities which represent central, northern,
and southern Jiangsu are expressed in letters (Table 1). Their geographical distributions are shown in blue solid dots and blue letters, as also shown in Figure 1. The area surrounding each air-quality monitoring station is flat and open with no obvious local air-pollutant emission sources nearby.

Daily data of atmospheric pollutants (PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, CO, and O$_3$) in the major cities of Jiangsu Province from September 2017 to August 2018 were also downloaded from http://www.tianqihoubao.com/. AQI, meteorological elements, and primary pollutants were analyzed using the plotting software GrADS 19 (grid analysis and display system) and the statistical software SPSS 22.0 (statistical product and service solutions).

Because of the time differences of the establishment of air pollution monitoring stations, in this paper, the analysis of annual AQI and the research of the relationship between AQI and meteorological elements are from January 2013 to December 2017; the time range of the primary pollutant research is from September 2017 to August 2018.

3. Results and Analysis

3.1. Temporal Variation Characteristics of AQI

3.1.1. Annual Change. Figure 2 shows the average annual change in AQI in Jiangsu Province from 2013 to 2017. It can be seen that there is a decreasing annual trend. The average annual AQI is 93.88, belonging to grade II (good). The largest value (106.8) was reached in 2013, when the air quality was grade III (mild pollution). The average annual AQI values of 2014, 2015, and 2016 are 98.8, 93.9, and 87.9, respectively; air quality did not, therefore, exceed grade II and belonged to grade II (good). The lowest annual value (82.1) was found in 2017, which was 23.1%, 16.9%, 12.6%, and 6.6% lower than the AQIs in 2013, 2014, 2015, and 2016, respectively.

3.1.2. Seasonal Changes. The AQI of Jiangsu Province shows an apparent seasonal variation in Figure 3. The average values were in the order of winter (113.3) > spring (93.6) > fall (81.8) > summer (81.1). The air quality in winter and summer was grade III (mild pollution) and grade II (good), respectively; the value for winter was 1.4 times that of summer. This is because in winter, the lower temperature means more atmospheric consolidation and stable weather, resulting in that the air pollutants are not easy to spread, and may be the straw burning in Jiangsu province in winter produces a large number of particulate matter [21]. While the strong convection and precipitation in summer will be conducive to the diffusion and settlement of pollutants.
3.1.3. Monthly Change. Figure 4 shows the average monthly change in AQI in Jiangsu Province from 2013 to 2017. The figure shows that the average monthly AQI was relatively high in January, February, and December and relatively low in July, August, and September, which is consistent with Figure 3. The average monthly values were in the order of January (125.7) > December (124.6) > February (101.7) > November (99.1) > March (95.8) > May (94.4) > June (92.3) > April (90.8) > October (77.4) > July (75.9) > August (75) > September (74.8). The maximum AQI appeared in January, reaching 125.7, belonging to grade III (mild pollution); the lowest appeared in September, reaching 74.8, belonging to grade II (good).

3.2. Spatial Distribution of AQI. Figure 5 shows the spatial distribution of average AQI for the period 2013–2017. As seen in the figure, the AQI shows significant east-west differences, while the north-south difference is not so large. The situation of Jiangsu coastal cities is generally better than that of inland cities. With the cities of Suqian (M) and Zhenjiang (K) as the dividing line, the average value of the east is 90.7, with an air quality of grade II (good), while the average value of the west is 101, with an air quality of grade III (mild pollution). The AQI for Yancheng (R), Lianyungang (G), and Nantong (U) shows low values of 84.3, 87.4, and 87.9, respectively. The area with the maximum value (103.3) is located in Xuzhou (C). The air quality in eastern Jiangsu is good, mainly due to long-term dilution via sea breeze [22]. Because of the impact of the monsoon climate, the southeast wind prevails in summer, which promotes an increase in the transport of the air pollutants O₃, SO₂, and NO₂ from southern Jiangsu to northern China. The northwest wind prevails in winter. Northern Jiangsu is close to the heavily polluted areas in northern China and is easily affected by polluted air from that region.

Figure 6 shows the seasonal distribution of AQI in Jiangsu from 2013 to 2017. In terms of seasons, the spatial distribution of AQI varies from one season to the other. In summer (Figure 6(b)) and fall (Figure 6(c)), the level of air pollution gradually increases from northeast to southwest, that is, from Yancheng (R) and Lianyungang (G) in the northeastern part of Jiangsu Province to Nanjing (A), Changzhou (D), and other places. In winter (Figure 6(d)), there is a central high value (124.2) in Huai’an (H). In addition, there are differences between east and west, with Lianyungang (G), Yangzhou (S), and Zhenjiang (K) as a

<table>
<thead>
<tr>
<th>Letters</th>
<th>Representative stations</th>
<th>Longitude (degree)</th>
<th>Latitude (degree)</th>
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<tbody>
<tr>
<td>C</td>
<td>Xuzhou</td>
<td>117.20</td>
<td>34.26</td>
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<tr>
<td>H</td>
<td>Huai’an</td>
<td>119.15</td>
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<td>G</td>
<td>Lianyungang</td>
<td>119.16</td>
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<td>R</td>
<td>Yancheng</td>
<td>120.13</td>
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<td>M</td>
<td>Suqian</td>
<td>118.30</td>
<td>33.96</td>
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<td>U</td>
<td>Nantong</td>
<td>120.86</td>
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<td>S</td>
<td>Yangzhou</td>
<td>119.42</td>
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<td>Taizhou</td>
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<td>A</td>
<td>Nanjing</td>
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<td>D</td>
<td>Changzhou</td>
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<td>B</td>
<td>Wuxi</td>
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The difference between east and west is about 15; the maximum AQI value (134.1) is found in Xuzhou (C), not Nanjing. In spring (Figure 6(a)), a pronounced east-west difference is also observed.

To further explore the spatial distribution characteristics of air pollution, Figure 7 shows the distribution of AQI differences between winter and summer. It can be seen that areas with large differences in the AQI values appear in Huai’an (H) and Xuzhou (C), with values of 44.2 and 49.2, respectively. Low-value areas are located in Nantong (U), Yangzhou (S), and Nanjing (A), with values of 19.6, 22.5, and 26.2, respectively. The areas north of the Yangtze River generally exhibit higher values than the areas south of it, suggesting that the effect of winter on northern Jiangsu is more serious than that on southern Jiangsu. Jiangsu is an important monsoon region in China. The northwest wind prevails in winter; the northern part of Jiangsu is close to the inland region and is easily affected by polluted air from northern China [23].

3.3. Relationship between AQI and Meteorological Conditions

3.3.1. Correlation Analysis between Seasonal AQI Values and Meteorological Factors. Based on meteorological data for Jiangsu Province from 2013 to 2017, the correlation coefficients between Jiangsu’s AQIs in different seasons and meteorological factors were analyzed (Table 2). The selected meteorological parameters include sunshine duration, average water vapor pressure, precipitation, average temperature, average minimum temperature, average maximum temperature, average wind speed, and maximum wind speed. All these meteorological elements affect the AQI’s value and distribution more or less [4, 10, 12, 14–17, 23–26]. It can be seen in Table 2 that the correlation between AQI and the meteorological factors in Jiangsu varies among the seasons; that is, the effect of the meteorological factors in different seasons on air-quality changes are different.

The spring AQI is positively correlated with all of the meteorological factors, but not significantly. As for the summer AQI, it is mostly negatively correlated with all meteorological factors except precipitation and average wind speed, the largest correlation is with average water vapor pressure (correlation coefficient: -0.712), and the two correlation coefficients of average and maximum wind speed show opposite signs, yet the both values are small, which may be attributed to the effects of different wind directions on air quality [27]. The fall AQI shows negative correlation with all the meteorological factors, among which sunshine hours and average water vapor pressure are the two largest ones, and the correlation coefficients are -0.780 and -0.759 respectively. In winter, the correlation

![Figure 5: Spatial distribution of the annual average value of the AQI in Jiangsu Province in the period 2013–2017.](image-url)
between AQI and various meteorological parameters is not significant.

3.3.2. Correlation between Monthly AQI Values and Meteorological Factors. To further determine the effect of meteorological factors on changes in air pollution, the correlation characteristics of monthly AQI and meteorological elements were analyzed. Table 3 shows the analysis results.

As for the monthly time scale, mean monthly AQI and all the mean monthly temperature factors (average temperature, average minimum temperature, and average maximum temperature) show a significant negative correlation, all the absolute values of correlation coefficient are larger than 0.8, suggesting that rising temperatures are good for improving air quality. That means the higher the temperature, the stronger convective, resulting in stratification instability and easy diffusion of pollutants. Meanwhile, a
lower temperature is more unfavorable for the diffusion and dilution of pollutants; then the concentration of pollutants may increase [28]. This also can be found in Figures 3 and 4, the higher the temperature in summer, the lower the AQI in summer, but in winter, it is the other way around.

As for monthly average water vapor pressure and monthly precipitation, it also shows negative correlation with monthly average AQI (the absolute values of correlation coefficient are larger than 0.7), indicating that the amount of water in the atmosphere, such as water vapor
pressure and precipitation, also plays an important role in improving air quality. In particular, they can effectively reduce the concentration of inhalable PMs [29].

From Table 3, it indicates that the monthly mean AQI is not significantly correlated with wind speed, which may be related to different effect of the different wind directions on air quality [27].

4. Status of Primary Air Pollutants in Jiangsu Province

4.1. Temporal Variation Characteristics. Figure 8 shows that the seasonal variations in the PM$_{2.5}$ and PM$_{10}$ concentrations are basically similar, and the characteristics of the seasonal variations are as follows: values are high in winter and low in summer; the concentration values in spring and fall are between those in winter and summer, consistent with the research findings for Chongqing, Hangzhou, and Shenzhen [26, 30, 31]. The mass concentration of PM$_{10}$ in inhalable PM is greater than that of PM$_{2.5}$, with average values of 83.6 $\mu$g/m$^3$ and 48.9 $\mu$g/m$^3$, respectively. On the monthly scale (Figure 9), the mass concentration of PM$_{2.5}$ and PM$_{10}$ shows a significant U-type shape, high at both ends and low in the middle, and the level of fine particles reach a maximum value of 86.3 $\mu$g/m$^3$ in January and a minimum value of 23.4 $\mu$g/m$^3$ in July. The level of inhalable PM reaches a maximum value of 128 $\mu$g/m$^3$ in December and a minimum value of 48.6 $\mu$g/m$^3$ in August.

Figure 8 shows the seasonal variation in the SO$_2$ concentration. The concentrations are in the descending order of winter (16.7 $\mu$g/m$^3$) > fall (14.5 $\mu$g/m$^3$) > spring (13.6 $\mu$g/m$^3$) > summer (10.9 $\mu$g/m$^3$). In summer, due to high temperatures and strong oxidation, SO$_2$ is easily converted into sulfate, and the cleaning effect of precipitation reduces SO$_2$ concentration [24].

The seasonal variation in the CO concentration (Figure 8) shows that concentration is highest in winter and lowest in summer. In summer, due to high temperatures and strong solar radiation, the conversion efficiency of CO in photochemical reactions is higher than that in other seasons, and its concentration is reduced because of the conversion [24]. High CO concentration values are mainly found in November, December, January, and February (Figure 9); changes during the other months are relatively flat.

NO$_X$ in Jiangsu Province is mainly derived from combustion and motor vehicle exhaust [32]. NO$_2$ is an important component of NO$_X$. The seasonal variation in NO$_2$ concentration shows high values in winter and low values in summer (Figure 8). Zhang [33] suggested that if the highest concentration of NO$_2$ occurs in winter, anthropogenic emission is dominant; if the highest concentration of NO$_2$ occurs in summer, natural-source emission is dominant. Thus, NO$_2$ pollution in Jiangsu Province is dominated by anthropogenic emissions.

It is noteworthy that O$_3$ concentration exhibits changes opposite to other primary pollutants, showing a high value in summer and a low value in winter (Figure 8). This is mainly due to the strong solar radiation in summer, which accelerates photochemical reactions converting NO$_2$ to O$_3$; here, the O$_3$ concentration increases, and the NO$_2$ concentration decreases. This is consistent with the results of previous studies of Hangzhou and Chongqing [26, 30]. The O$_3$ concentration in fall is lower than in spring (Figure 8), mainly because there is heavy rainfall in Jiangsu during this season, and increase in relative humidity inhibits the photolysis rate [24]. On the monthly scale (Figure 9), the O$_3$ concentration shows a significant inverted U-type shape, low in the middle and high at both ends. The high O$_3$ concentration value is found mainly in June (103.2 $\mu$g/m$^3$), and the low value in December (31.5 $\mu$g/m$^3$).

Pollutants with concentrations exceeding the National Secondary Air-Quality Standard are excess pollutants, that is, pollutants with an air-quality index of greater than 100 [34]. Table 4 shows the statistical data for the seasonal average daily concentration of each pollutant. The seasonal average values of PM$_{10}$ are in the order of winter (112.4 $\mu$g/m$^3$) > spring (93.7 $\mu$g/m$^3$) > fall (76.1 $\mu$g/m$^3$) > summer (53.2 $\mu$g/m$^3$) and did not exceed the National Secondary Standard. It can be seen in Table 3 that the seasonal average values of PM$_{2.5}$ are in
the order of winter (75.9 \mu g/m^3) > spring (49.6 \mu g/m^3) > fall (43.0 \mu g/m^3) > summer (27.0 \mu g/m^3); the daily average value in winter exceeded the National Secondary Standard. The concentration ratio of fine PM_{2.5} to inhalable PM_{10} (PM_{2.5}/PM_{10}) can reflect the content of inhalable particles in the total PM mass. The PM_{2.5}/PM_{10} values during the four seasons in Jiangsu are in the order of winter (0.68) > fall (0.57) > spring (0.53) > summer (0.52). The average annual value is 0.58, which is lower than the average annual value of 0.85 in Chengdu [25] and higher than the average of 0.52 in Beijing [35]. Fine PM_{2.5} is dominant in the atmospheric inhalable PM in Jiangsu Province during the whole year; the PM_{2.5} content is higher in winter. Except for O_3, the remaining pollutants show characteristics similar to those of PM_{10} and PM_{2.5}, with highest content in winter (Table 4).

The seasonal average daily O_3 content is in the order of summer (82.6 \mu g/m^3) > spring (73.9 \mu g/m^3) > fall (55.5 \mu g/m^3) > winter (40.7 \mu g/m^3). Following the current National Environmental Protection Standards, the O_3 pollution situation is described based on an 8-h moving average value. The seasonal averages for the daily 8-h maximum O_3 values are in the order of summer (142.8 \mu g/m^3) > spring (125.8 \mu g/m^3) > fall (98.2 \mu g/m^3) > winter (65.5 \mu g/m^3), which did not exceed the National Secondary Standard.

4.2. Correlations between Primary Pollutants. Table 5 shows the results of correlation of daily AQI and average daily concentration of primary pollutants in Jiangsu Province from September 2017 to August 2018. The table shows that AQI, PM_{2.5}, PM_{10}, SO_2, and NO_2 exhibit significant positive correlations in pairs. Among them, the optimal correlation is observed among AQI, PM_{2.5}, and PM_{10} with correlation coefficients of 0.876–0.966. The results show that PM_{2.5} and PM_{10} had the greatest contribution to AQI; SO_2 exhibits optimal correlation with NO_2 (correlation coefficient: 0.940). Meanwhile, O_3 has a significant negative correlation with other pollutants.

Studies have found correlations between air pollutants generated from similar causes. If pollutants exhibit good correlations, then they have similar sources, the change patterns in air pollution are similar, and they possibly follow the same migration and transformation patterns [36]. For example, PM_{2.5}, PM_{10}, SO_2, and NO_2 showed significant correlations in pairs, indicating that the pollution sources affecting mass concentrations of PM_{2.5}, PM_{10}, SO_2, and NO_2 have strong correlations. Vehicles are the main source for the release of PM_{2.5}, SO_2, and NO_2. In addition, the contribution of road dust to PM_{10} generated by motor vehicles cannot be ignored. Further, industrial pollution from fossil-fuel combustion is an important source of mass concentrations of PM_{2.5}, PM_{10}, and SO_2. Moreover, NO_2 and SO_2 are positively correlated with PM_{2.5} and PM_{10}, respectively. This is because NO_2 and SO_2 undergo a gas phase, or multiple reaction oxidation, to form acidic aerosol, which then reacts with ammonia in the atmosphere to form ammonium sulfate and ammonium nitrate aerosol particles. These are converted into sulfate and nitrate particles, which are important components of PM_{2.5} and PM_{10} [37, 38].

4.3. Spatial Distribution of Primary Pollutants. The spatial distributions of different primary air pollutants in Jiangsu Province from 2017 to 2018 are different to some extent (Figure 10). Figure 10 shows that the spatial distribution of PM_{2.5} is similar to that of PM_{10}, showing pronounced east-west differences. With Lianyungang (G), Yangzhou (S), and Zhenjiang (K) as a dividing line, PM_{2.5} and PM_{10} are generally high in the west and low in the east. The PM_{2.5} values are in the order of west (56 \mu g/m^3) > east (43.1 \mu g/m^3), and the PM_{10} values are in the order of west (90.4 \mu g/m^3) > east (72.6 \mu g/m^3); the differences between east and west are about 15 \mu g/m^3. Areas of low PM_{2.5} and PM_{10} concentrations are mainly distributed in Lianyungang (G), Yancheng (R), and Nantong (U), while Xuzhou (C) shows peak PM_{2.5} and PM_{10} values (70 \mu g/m^3 and 113 \mu g/m^3, respectively). This is because the
Figure 10: Continued.
Xuzhou area has a special geographical location, is very vulnerable to dust or polluted air from northern China, and is an important base for coal production in the Province. Therefore, the effect of PM_{2.5} and PM_{10} on the environmental air quality of this area is relatively more pronounced.

The spatial distribution of NO_{2} shows apparent south-north differences. The NO_{2} concentrations are in the order of southern Jiangsu (44.6 μg/m^3) > central Jiangsu (35.3 μg/m^3) > northern Jiangsu (31.3 μg/m^3). The high-value areas are located in Changzhou (D) and Suzhou (E), with values of 49.6 μg/m^3 and 46.6 μg/m^3, respectively, while the low-concentration areas are mainly distributed in Yancheng (R) and Lianyungang (G), with values of 23.8 μg/m^3 and 29 μg/m^3, respectively, which are significantly lower than those of the areas along the Yangtze River. This reflects the fact that the NO_{2} pollutant, which is closely related to human activities, is mainly concentrated in the high-density industrial enterprises and the high traffic volume of southern Jiangsu.

However, the spatial characteristics of O_{3} concentration are opposite to those of NO_{2}, showing a trend of being high in the north and low in the south, in the order of northern Jiangsu (70.9 μg/m^3) > central Jiangsu (67.5 μg/m^3) > southern Jiangsu (60 μg/m^3). The high-concentration areas are located in Yancheng (R) and Suqian (M), with values of 74 μg/m^3 and 71.6 μg/m^3, respectively, while the low-concentration areas are mainly distributed in Changzhou (D), with a value of 47.5 μg/m^3.

SO_{2} and CO contents are relatively uniform. Two centers with high SO_{2} content are located in Xuzhou (C) and Nantong (U), with values of 17.6 μg/m^3 and 17.1 μg/m^3, respectively. CO exhibits a high-value center in Changzhou (D), with 1.04 mg/m^3. In general, the maximum-minimum difference of SO_{2} content in Jiangsu is about 7 μg/m^3, and that of CO about 0.3 mg/m^3.

5. Conclusions and Discussion

This study investigated the temporal and spatial distribution characteristics of AQI and various primary pollutants in Jiangsu Province in recent years and their correlations with meteorological parameters. The following conclusions were drawn:

(1) Regarding the temporal distribution, the average annual AQI value in Jiangsu Province has gradually declined in recent years. Its lowest value (82.1) was observed in 2017; this was 23.1%, 16.9%, 12.6%, and 6.6% lower than in 2013, 2014, 2015, and 2016, respectively. The AQI values showed significant differences between the four seasons. The highest and lowest values occurred in winter and summer, respectively. The highest average AQI value was found in January (125.7), belonging to grade III (mild pollution), and the lowest value in September (74.8), belonging to grade II (good). The variation trends in PM_{2.5}, PM_{10}, SO_{2}, NO_{2}, and CO were basically the same, all showing a U-type shape, characterized by being low in winter and high in summer. However, the O_{3} mass concentration showed an apparent inverted U-type shape, high in the middle and low at both ends, characterized by being low in summer and high in winter.
(2) Regarding the spatial distribution, Jiangsu's AQI generally showed higher values in inland cities than in coastal ones. PM$_{2.5}$ and PM$_{10}$ were generally characterized by being high in the west and low in the east. The NO$_2$ concentration was characterized by being high in the south and low in the north, while the distribution of the O$_3$ concentration was the opposite.

(3) Regarding the influence of meteorological parameters at seasonal scales on AQI, the effects of the different seasons on AQI were different. In spring, the AQI is positively correlated with all of the meteorological factors, but not significantly. In summer, the AQI is mostly negatively correlated with all meteorological factors except precipitation and average wind speed, the largest correlation is with average water vapor pressure (correlation coefficient: −0.712). In fall, the AQI shows negative correlation with all the meteorological factors, among which sunshine hours and average water vapor pressure are the two largest ones, and the absolute value of correlation coefficients are larger than 0.750. In winter, the correlation between AQI and various meteorological parameters is not significant.

(4) Regarding the correlations among various pollutants, AQI, PM$_{2.5}$, PM$_{10}$, SO$_2$, and NO$_2$ showed significant positive correlations in pairs, while the O$_3$ concentration was significantly negatively correlated with other pollutants. The most pronounced correlations were found in two groups: the groups of AQI, PM$_{2.5}$, and PM$_{10}$ and the group of SO$_2$ and NO$_2$. This has a value for an analysis of pollution sources.

Air pollution is an important environmental problem that endangers urban development. According to the limited data analysis in this paper, with the gradual emphasis on environmental governance in China and the promulgation and implementation of a series of policies and regulations, the air-quality problem in Jiangsu province is gradually improving, which is a very good development direction. The study found that the primary pollutants with the highest contribution to AQI in Jiangsu province are PM$_{2.5}$, PM$_{10}$, and NO$_2$, among which PM$_{2.5}$ and PM$_{10}$ are mainly distributed in northern Jiangsu, which is also the reason why the high value of AQI is distributed in northern Jiangsu. The NO$_2$ is mainly located in southern Jiangsu. The reason for this phenomenon may be due to the influence of monsoon climate and the development of local heavy industry, the particulate matter concentration in the inland area of northern Jiangsu is relatively high, while the NO$_2$ content is significant due to the population and car ownership in southern Jiangsu [39]. O$_3$ is higher in spring and summer, and the other five main pollutants are the highest in winter. Therefore, winter should be the most important season for air pollution control in Jiangsu Province. In addition, the burning of straw in northern Jiangsu should also be banned [40]. From the point of view of this study, temperature growth may reduce the AQI, but this is another global environmental problem, and many factors are involved.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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