Air Quality Index, Indicatory Air Pollutants and Impact of COVID-19 Event on the Air Quality near Central China

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ABSTRACT

Both the air quality index (AQI) and indicatory air pollutants of Anqing, Hefei, and Suzhou near central China from 2017 to 2019, and the impact of COVID-19 epidemic prevention and control actions on air quality were investigated. The combined data for the three cities from 2017 to 2019 indicated that the lowest AQI (averaged 78.1) occurred in the summer season, for which the AQI proportions for classes I, II, III, IV, V, and VI were 25.6%, 49.9%, 21.9%, 2.7%, 0%, and 0%, respectively. The highest (AQI average of 112.6) was in winter, for which the proportions were 7.4%, 39.5%, 33.3%, 12.5%, 7.2%, and 0.1%, respectively. $PM_{2.5}$, PM_{10}, and NO_2 in order were the most important indicatory air pollutants for AQI classes IV, V, and VI, which all prevailed in winter and spring, while O_3 was the indicatory air pollutant that occurred most in summer.

The COVID-19 event, which triggered global attention, broke out at the end of 2019. This study also investigated and compared the air quality levels in the three cities from January to March 2017–2019 with those in 2020. The results showed that during February 2020, in the three cities, the average ambient air concentrations of $PM_{2.5}$, PM_{10}, SO_2, CO, and NO_2 were 41.9 µg m^{-3}, 50.1 µg m^{-3}, 2.18 ppb, 0.48 ppm, and 8.97 ppb, and were 46.5%, 48.9%, 52.5%, 36.2%, and 52.8%, respectively, lower than those in the same month in 2017–2019, respectively. However, the O_3 average concentration (80.6 ppb) did not show significant fluctuations and even slightly increased by 3.6%. This is because a lower concentration of NO_2 resulted in constraints on the reaction of $NO + O_3$, so the O_3 level could not be effectively further reduced. In addition, this study also analyzed and compared the five highest daily AQIs from February 2017–2019 with those of 2020 for the three cities. The mean AQI for the 5 days with the highest daily AQI (averaged 122.6) in February 2020 was 45.1% lower than that for February 2017–2019 (averaging 223.2), and the indicatory air pollutant was always $PM_{2.5}$, which decreased by 46.7% (from 173.6 to 92.6 µg m^{-3}). It is clear that during the COVID-19 epidemic prevention and control action periods, the air quality near central China improved significantly.

Keywords: COVID-19; AQI; $PM_{2.5}$; PM_{10}; SO_2; CO; NO_2; O_3.

INTRODUCTION

With the progress of society and the continuous improvement of the level of industrialization, air pollution is becoming increasingly serious. It poses harm to human health and has become a global environmental problem that is difficult to solve or irreversible (Chatterton *et al.*, 2000).

In January 2013, a continuous haze air quality crisis million people. It is considered to be the worst air pollution occurred across a large area of China, affecting more than 8 event in China since the 20th century (Wang *et al.*, 2014). In recent years, large amounts of polluted air stream and frequent environmental pollution problems have affected human health and reduced average human life expectancy. Therefore, environmental awareness and the demand for a healthy environment are also increasing. A World Health Organization (WHO) report states that in 2012, seven million deaths were caused by air pollution worldwide (WHO, 2014). Studies have shown that fine particulate pollution ($PM_{2.5}$) is highly correlated with population mortality and morbidity (Shen *et al.*, 2017). Sulfur dioxide in the atmosphere can affect the respiratory system and lung function and can stimulate the respiratory tract, thereby aggravating asthma and chronic bronchitis in humans, and making people more vulnerable

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to diseases such as respiratory infections. O_3 pollution, which has become increasingly prominent in recent years, can also cause respiratory diseases and increase the possibility of lung infections. Therefore, the risk of death in patients with heart and lung diseases is also greater (Turner *et al.*, 2016). In recent years, various diseases caused by air pollution have been on the rise. It is estimated that 2.5 million deaths are caused by indoor and outdoor air pollution each year (Kulmala, 2015).

At the end of 2019, a novel pneumonia broke out, which the World Health Organization named "COVID-19" (Corona Virus Disease-19). The COVID-19 pathogen was found to be a novel coronavirus similar to SARS-CoV-2. The COVID-19 is a new type of acute respiratory infectious disease, which has characteristics that include rapid transmission, a wide range, and strong infectivity. According to data released by the World Health Organization, as of May 6, 2020, the cumulative number of confirmed cases of COVID-19 in the world reached 3,525,116 cases and there were 243,540 deaths (Data were obtained from the platform: http://news.cctv.com/). In order to prevent the spread of the epidemic on a large scale, on January 23, 2020, the Chinese government imposed a travel ban on Wuhan and other provinces, which significantly restricted population movement. Since then, all of the provinces and cities have successively initiated first-level responses to major public health emergencies, and human activities such as industrial production and transportation have sharply decreased. According to previous studies, in central China, winter is the season when air pollution is most serious, and $PM_{2.5}$ pollution is particularly prevalent (Wang *et al.*, 2018). This is because the temperature is relatively low, and the vertical convection in the atmosphere is weak, which leads to a temperature inversion that is not conducive to the dispersion of pollutants. On the other hand, a large number of coal-fired emissions are caused by residential heating and industries

(Lee *et al.*, 2018; Zhao *et al.*, 2018). However, February 2020 was different. Due to the impact of the COVID-19 event, industrial, construction, and transportation activities in China almost stopped. These prevention and control actions for COVID-19 were closely related to variations in air quality. Therefore, in this study, the air quality levels of three cities (Anqing, Hefei, and Suzhou) in Anhui Province were investigated, compared, and discussed for the non-epidemic period and the epidemic prevention and control period in order to gain more insight into the variations in air quality during that period.

The Air Quality Index (AQI) is used by government agencies to communicate to the public how polluted the air currently is and provides short-term or long-term effects of air pollution on public health. The establishment of ambient air quality standards can provide a basis for and guarantee the management of ambient air quality in order to protect human health, maintain ecological environmental safety, and promote harmonious, sustainable development that protects people, society, and nature (Fang *et al.*, 2009).

METHODS

The air quality in three cities in Anhui Province (near central China) was analyzed: Anqing (31°52′N, 117.17E), Hefei (31°52′N, 117°17′E), and Suzhou (33°38′N, 116.58E) (Fig. 1), from January to March, 2017–2020.

Anqing City is located in the southwestern part of Anhui Province and on the north bank of the lower reaches of the Yangtze river. There is a subtropical wet monsoon climate along the river. Hefei City is located in the central part of Anhui Province with a subtropical humid monsoon climate. Suzhou City is located in the northernmost part of Anhui with a warm temperate and semi-humid monsoon climate. In recent years, the economy of central China has developed rapidly, people's living standards have improved, and at the
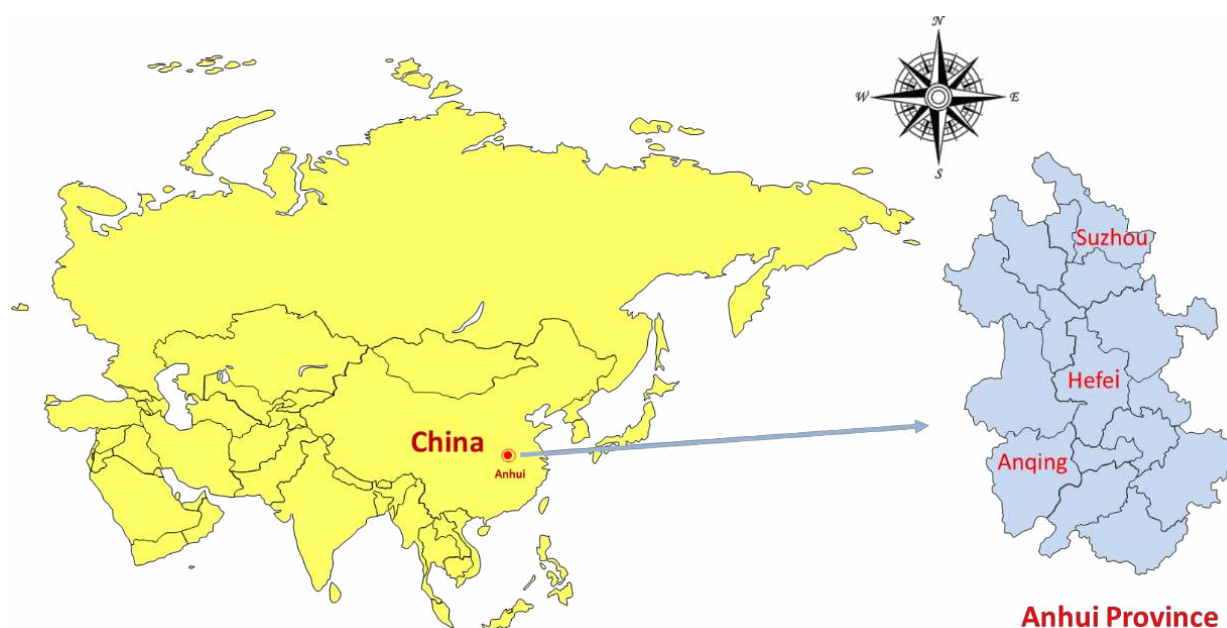

Fig. 1. Location of Anqing, Hefei, Suzhou in Anhui Province, near central China.

same time, the public's requirements for environmental quality have also increased. This study has important reference significance for human health and urban environmental protection. Data were obtained from the platform: http://www.aqistudy.cn/.

Air Quality Index (AQI)

The AQI is a dimensionless index that quantitatively describes the status of air quality. As indicated in Eq. (1), the sub-AQI of the six criteria pollutants ($PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3) were first calculated with the observation concentrations. The AQI comes from the maximum of the sub-AQI of all pollutants, as shown in Eq. (2), where when the AQI is higher than 50, the contributor of the maximum sub-AQI is defined as the primary pollutant on that day (She *et al.*, 2017; Shen *et al.*, 2017).

$$IAQI_P = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C_P - C_{low}) + I_{low} \qquad (1)$$

$$AQI = max\ (I_1, I_2, \ldots, I_n) \qquad (2)$$

$IAQI_P$: the air quality sub index for air pollutant p.
C_P: the concentration of pollutant p.
C_{low}: the concentration breakpoint that is $\leq C_P$.
C_{high}: the concentration breakpoint that is $\geq C_P$.
I_{low}: the index breakpoint corresponding to C_{low}.
I_{high}: the index breakpoint corresponding to C_{high}.

Air quality is closely related to human health. The daily AQIs are calculated based on the 24-hour average concentrations of $PM_{2.5}$, $PM_{10,}$ SO_2, CO, NO_2, and the daily average 8-hour maximum concentration of O_3. According to the United States Environmental Protection Agency (US EPA) AQI, the ranges of AQI values related to air quality can be classified into six classes (Zhao *et al.*, 2018):
Class I: 0–50, Good, Green.
Class II: 51–100, Moderate, Yellow.
Class III: 101–150, Unhealthy for sensitive Groups, Orange.
Class IV: 151–200, Unhealthy, Red.
Class V: 201–300, Very unhealthy, Purple.
Class VI: 300–500, Hazardous, Maroon.

RESULTS AND DISCUSSION

AQI Distribution

The Air Quality Index (AQI) is used to assess the state of air quality and its impact on human health, thereby providing guidance.

The proportions of the six AQI classes in different seasons for Anqing, Hefei and Suzhou in 2017–2019 are shown in Figs. 2(a)–2(d).

The combined data for the three years in Anqing from 2017–2019, in spring, summer, fall, and winter (Fig. 2(a)) show that the daily AQI ranged between 22 and 157, 20 and 170, 20 and 182, and 22 and 303, and averaged 76.3, 64.6, 75.5, and 108.5, respectively. In the meanwhile, in spring, the proportions of AQI classes I, II, III, IV, V, and VI were 13.5%, 74.5%, 11.7%, 0.4%, 0%, and 0%, respectively. In

summer, the proportions of classes I, II, III, IV, V, and VI were 39.5%, 48.2%, 11.6%, 0.7%, 0%, and 0%, respectively. In fall, the proportions were 22.7%, 58.2%, 17.6%, 1.5%, 0%, and 0%, respectively, and in winter, they were 10.7%, 41.5%, 28.9%, 10.4%, 8.1%, and 0.4%, respectively. According to the data under investigation from 2017–2019, the most common indicatory air pollutants in Anqing in spring, summer, fall, and winter were $PM_{2.5}$, O_3, O_3, and $PM_{2.5}$, respectively. It can be seen that the air quality in summer was obviously better than that in winter.

The combined data for the three years in Hefei from 2017–2019 in spring, summer, fall, and winter (Fig. 2(b)) show that the daily AQI ranged between 32 and 188, 14 and 200, 29 and 222, and 28 and 285, and averaged 83.7, 79.8, 78.3, and 106.3, respectively. In the meanwhile, in spring, the proportions of AQI classes I, II, III, IV, V, and VI were 10.0%, 67.4%, 21.1%, 1.5%, 0%, and 0%, respectively. In summer, the proportions of classes I, II, III, IV, V, and VI were 21.0%, 52.9%, 23.9%, 2.2%, 0%, and 0%, respectively. In fall, the proportions were 18.1%, 60.9%, 17.7%, 3.0%, 0.4%, and 0%, respectively, and in winter, they were 8.5%, 41.1%, 35.9%, 10.4%, 4.1%, and 0%, respectively. According to the data under investigation from 2017–2019, the most common indicatory air pollutants in Hefei in spring, summer, fall, and winter were $PM_{2.5}$, O_3, NO_2, and $PM_{2.5}$, and it can be seen that the air quality in Hefei was slightly worse than that in Anqing. The data shows that Hefei's vehicle ownership (2.0 million, 2018) is much higher than that of Anqing (0.9 million, 2018) (http://www.yearbookchina.com/), and motor vehicle exhaust is an important contributor of ambient NO_2 and $PM_{2.5}$, which may be the reason for the poor air quality in Hefei in summer and fall.

The combined data for the three years in Suzhou from 2017–2019 in spring, summer, fall, and winter (Fig. 2(c)) show that the daily AQI ranged between 35 and 500, 21 and 187, 33 and 431, and 39 and 300, and averaged 93.4, 89.8, 89.8, and 123.1, respectively. In the meanwhile, in spring, the proportions of AQI classes I, II, III, IV, V, and VI were 4.4%, 63.3%, 26.3%, 5.2%, 0.4%, and 0.4%, respectively. In summer, the proportions of classes I, II, III, IV, V, and VI were 16.3%, 48.6%, 30.1%, 5.1%, 0%, and 0%, respectively. In fall, the proportions were 9.6%, 58.1%, 27.4%, 3.7%, 0.7%, and 0.4%, respectively, and in winter, they were 3.0%, 35.9%, 35.2%, 16.7%, 9.3%, and 0%, respectively. According to the data under investigation from 2017–2019, the most common indicatory air pollutants in Suzhou in spring, summer, fall, and winter were O_3, O_3, NO_2, and $PM_{2.5}$, and compared with Anqing and Hefei, the air quality in Suzhou was the worst. From 2017–2019, the proportion of AQI class VI in fall was 0.4%, which indicated that serious air pollution incidents occurred. Suzhou is the northernmost of the three cities. Due to the monsoon, there may be many pollutants from northern cities in the atmosphere in Suzhou, including the precursors that form O_3. Weather conditions that are not conducive to the spread of pollutants and the large amount of coal-fired emissions caused by residents' heating are important causes of severe air pollution in winter.

Fig. 2(d) shows the proportions of the six AQI classes for the three cities in spring, summer, fall, and winter from
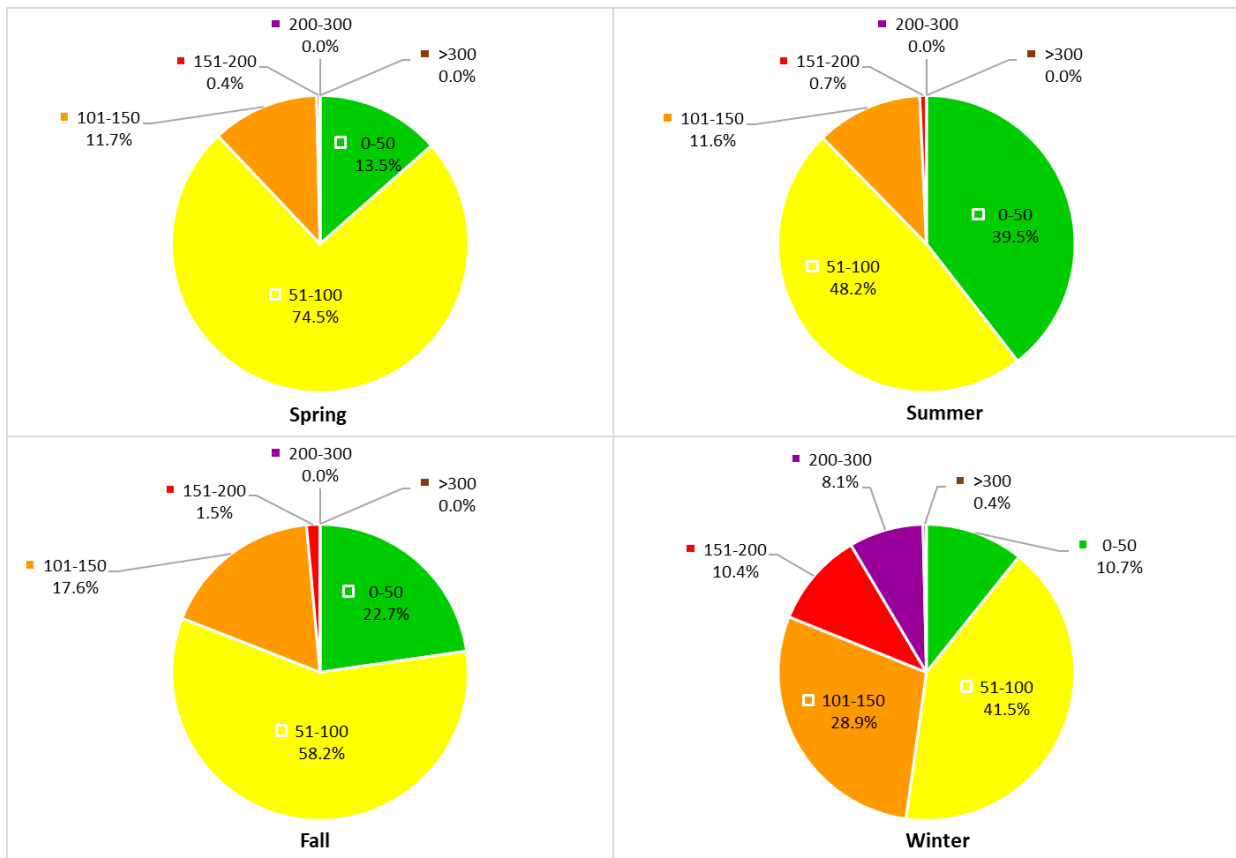
Fig. 2(a). The proportions of the six AQI classes for Anqing in spring, summer, fall, and winter in 2017–2019.
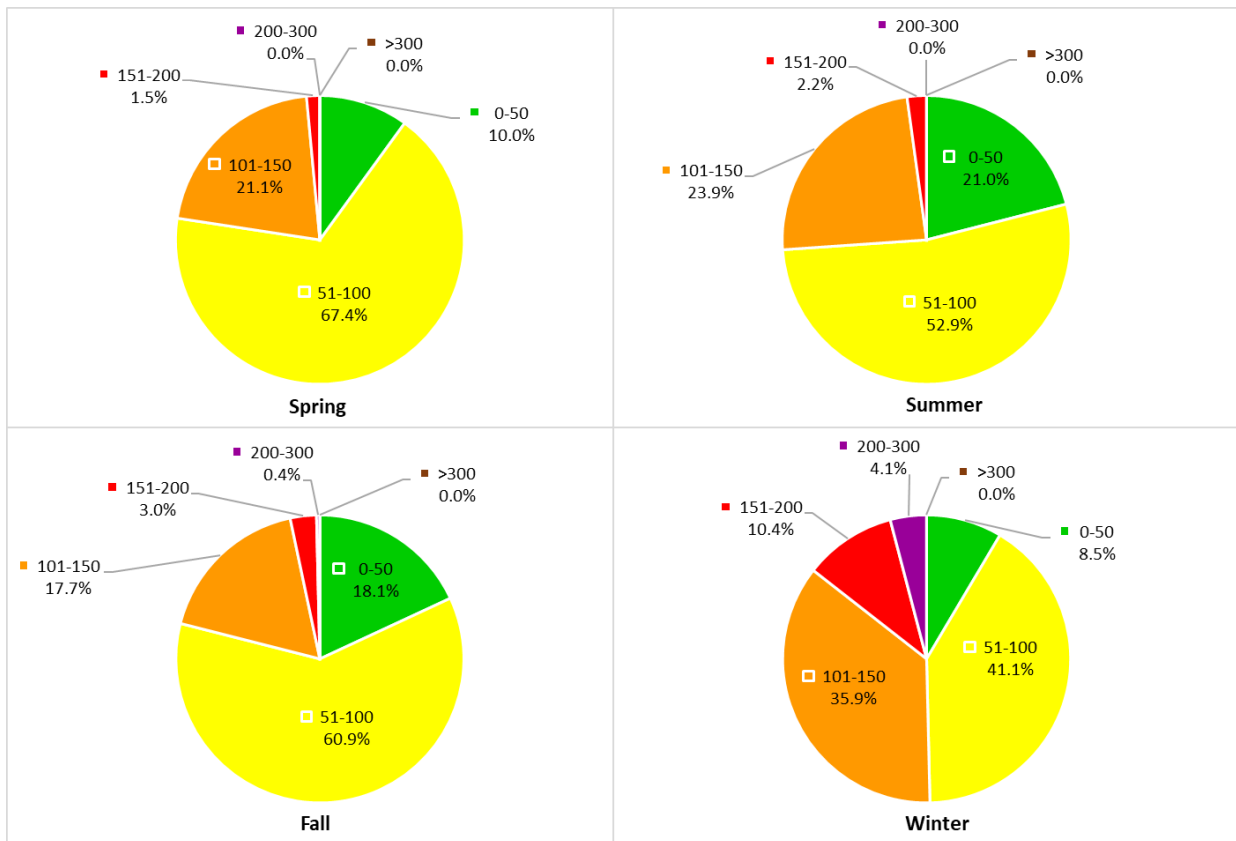

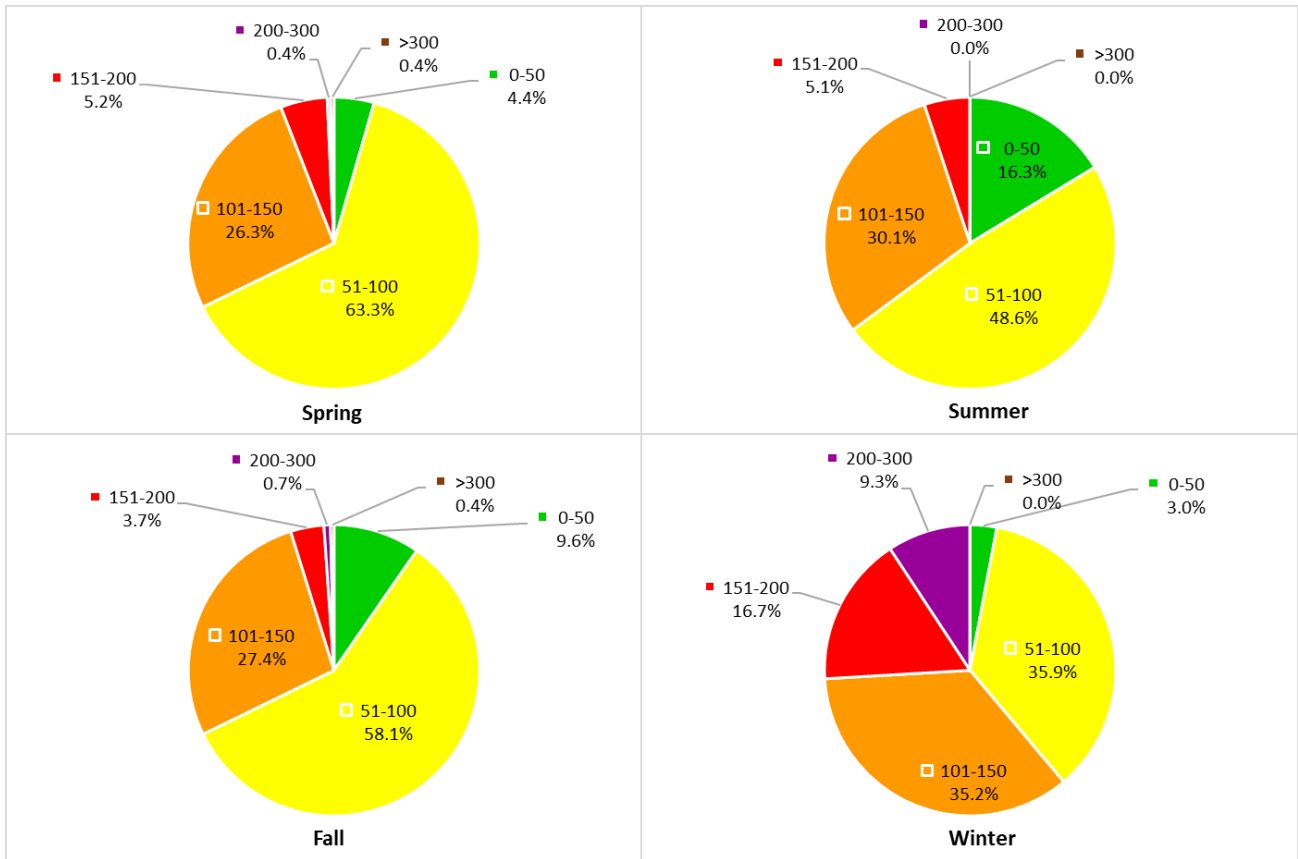**Fig. 2(b).** The proportions of the six AQI classes for Hefei in spring, summer, fall, and winter in 2017–2019.

Fig. 2(c). The proportions of the six AQI classes for Suzhou in spring, summer, fall, and winter in 2017–2019.
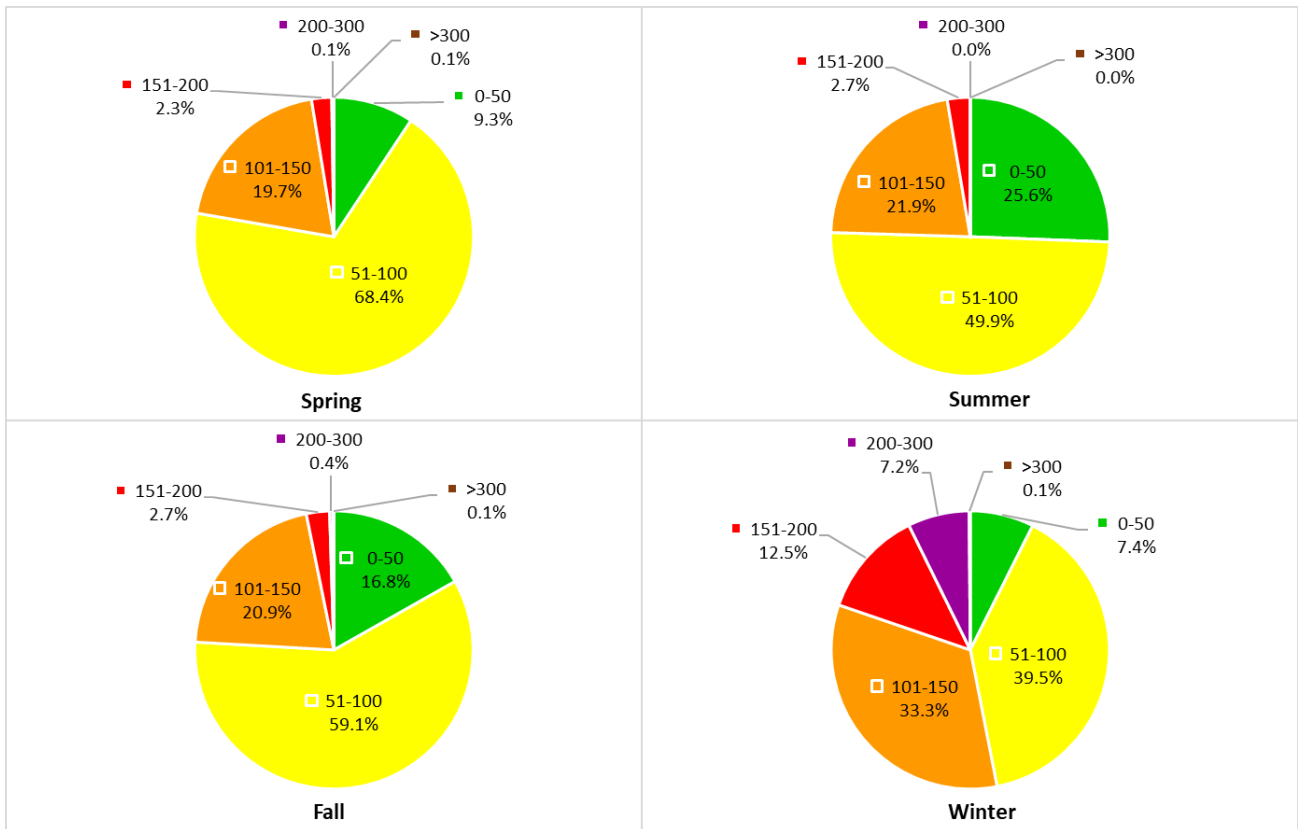

Fig. 2(d). The proportions of the six AQI classes for the three-city in spring, summer, fall, and winter in 2017–2019.

2017–2019. In spring, the proportions of AQI classes I, II, III, IV, V, and VI for the three cities were 9.3%, 68.4%, 19.7%, 2.3%, 0.1%, and 0.1%, respectively. In summer, the proportions of classes I, II, III, IV, V, and VI were 25.6%, 49.9%, 21.9%, 2.7%, 0%, and 0%, respectively. In fall, the proportions were 16.8%, 59.1%, 20.9%, 2.7%, 0.4%, and 0.1%, respectively, and in winter, they were 7.4%, 39.5%, 33.3%, 12.5%, 7.2%, and 0.1%, respectively. In general, the AQI levels of the three cities in the different seasons were in order as follows: winter > spring > fall > summer, which was consistent with the results of Shen *et al.* (2017) indicating that the air quality in summer was much better than that in winter. In summer, higher temperature and air humidity are conducive to the dilution and diffusion of pollutants, and the concentration of particulate matter in the air is much lower than in winter. In winter, a large amount of coal is used for heating, and the exhaust gas produced by combustion greatly contributes to the accumulation of atmospheric particulate matter. Due to the low temperature in winter, the vertical exchange of the atmosphere is weak, and the inverse temperature phenomenon is significant, which is not conducive to the dilution and diffusion of pollutants in the air, so the air quality in winter is poor.

In terms of annual AQI characteristics, in Anqing, in 2017, 2018, and 2019, the daily AQI ranged from 21 to 285, 20 to 265, and 20 to 303, respectively, and averaged 83.1, 77.3, and 83.2, respectively. In Hefei, in 2017, 2018, and 2019, the daily AQI ranged from 29 to 285, 24 to 231, and 14 to 216, respectively, and averaged 95.1, 79.5, and 87.6, respectively. As for Suzhou, in 2017, 2018, and 2019, the daily AQI ranged from 32 to 500, 24 to 251, and 21 to 431, respectively, and averaged 109.4, 91.2, and 97.5, respectively. Based on the analysis of the observation data for the three years, the AQI level rankings of the three cities were as follows: Suzhou > Hefei > Anqing, which showed that among the three cities from 2017–2019, Anqing had the best air quality, and Suzhou had the worst.

It can be seen that during the three-year observation period, the air quality in Anqing did not improve significantly, but the air quality in Hefei and Suzhou improved to some extent. Data from the three-year observation period show that the average annual AQI of the three cities reached the lowest in 2018, but the air quality in 2019 showed a certain degree of deterioration. The AQI of Suzhou was higher than that in Anqing and Hefei, which indicates more serious air pollution. In addition, in 2017 and 2019, the maximum AQI in Suzhou reached 500 and 431, respectively, indicating that serious air pollution incidents occurred in Suzhou during this period.

Indicatory Air Pollutants

In this study, the indicatory air pollutants of AQI classes IV, V, and VI in the three cities during the period 2017–2019 were also analyzed.

As shown in Table 1(a), during the three-year period under observation (2017–2019), in Anqing, the daily AQI comprised classes IV, V, and VI for a total of 58 days. There were 35 days for Class IV, where the AQI ranged from 152–199 and averaged 173.6. The main indicatory air pollutant

was $PM_{2.5}$ (30 days), for which the concentration ranged from 89–163 µg m^{-3} and averaged 132.5 µg m^{-3}, and followed by O_3 (5 days), which ranged from 102–110 ppb and averaged 105.2 ppb. There were 22 days for Class V, where the AQI ranged from 201–285 and averaged 222.4. The indicatory air pollutant for those days was $PM_{2.5}$, ranging from 147–235 µg m^{-3} and averaging 170.9 µg m^{-3}. There was 1 day that was Class VI, where the AQI was 303, and the indicatory air pollutant was $PM_{2.5}$ (253 µg m^{-3}).

As shown in Table 1(b), during the three-year period, in Hefei, there were 58 days when the daily AQI fell into classes IV, V, and VI. There were 46 days for Class IV when the AQI ranged from 151–200 and averaged 172.3. The main indicatory air pollutant was $PM_{2.5}$ (33 days), followed by O_3 (10 days), PM_{10} (2 days), and NO_2 (1 day), for which the concentration for each air pollutant ranged from 111–222 µg m^{-3}, 101–126 ppb, 253–308 µg m^{-3}, and 28.7 ppb and averaged 132.5 µg m^{-3}, 109.5 ppb, 280.5 µg m^{-3}, and 28.7 ppb, respectively. There were 12 days that were Class V, where the AQI ranged from 202–285 and averaged 225.6. The indicatory air pollutant for those days was $PM_{2.5}$, ranging 76–235 µg m^{-3} and averaging 167.4 µg m^{-3}. There were no Class VI days in the three year period in Hefei.

As shown in Table 1(c), during the three years, in Suzhou, there were 113 days when the daily AQI comprised classes IV, V, and VI. There were 83 days for Class IV, where the AQI ranged from 151–195 and averaged 169.8. The main indicatory air pollutant was $PM_{2.5}$ (59 days), followed by O_3 (22 days), and PM_{10} (2 days), and the concentrations of each air pollutant ranged from 116–146 µg m^{-3}, 101–120 ppb, and 254–287 µg m^{-3} and averaged 131.2 µg m^{-3}, 106.2 ppb, and 270.5 µg m^{-3}, respectively. There were 28 days that fell into Class V, and the AQI ranged from 201–300 and averaged 232.3. The indicatory air pollutant for those days was $PM_{2.5}$, ranging from 119–250 µg m^{-3} and averaging 176.5 µg m^{-3}. For Class VI, there were 2 days, with the AQI ranging from 431–500 and averaging 465.5, and the indicatory air pollutant was PM_{10} (531 µg m^{-3}), which shows that serious air pollution incidents occurred.

The combined three-year data for the three cities indicated that in classes IV, V, and VI, $PM_{2.5}$ was the most important indicatory air pollutant, followed by O_3, PM_{10}, and NO_2. The vast majority of AQI classes IV, V, and VI occurred in winter and spring, with the exception of the days when the indicatory air pollutant was O_3, which occurred most in summer. This is because the higher temperature and stronger solar radiation in summer are more conducive to the production and accumulation of O_3.

The Impact of the COVID-19 Event on Air Quality
Comparison of Air Pollutants

The average concentrations for $PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3 in January, February, and March 2017–2019 and those for 2020, are shown and compared in Fig. 3(A)–3(F), respectively.

PM$_{2.5}$ Concentration

$PM_{2.5}$ mainly comes from thermal power generation, industrial production, automobile exhaust, the burning of

Table 1(a). Indicatory air pollutants of AQI classes IV, V, and VI in Anqing from 2017–2019 (Units for different air pollutants, $PM_{2.5}$ (µg m^{-3}), O_3 (ppb)).

AQI Class	AQI		Indicatory Air Pollutants		
	Range	Mean		Range	Mean
VI (1 day)	303	303	$PM_{2.5}$	253	253
V (22 days)	201–285	222.4	$PM_{2.5}$	147–235	170.9
IV (35 days)	152–199	173.6	$PM_{2.5}$ (30 days)	89–163	132.5
			O_3 (5 days)	102–110	105.2

Table 1(b). Indicatory air pollutants of AQI classes IV, V, and VI in Hefei from 2017–2019 (Units for different air pollutants, $PM_{2.5}$ (µg m^{-3}), PM_{10} (µg m^{-3}), NO_2 (ppb), O_3 (ppb)).

AQI Class	AQI		Indicatory Air Pollutants		
	Range	Mean		Range	Mean
VI (0 day)	\	\	\	\	\
V (12 days)	202–285	225.6	$PM_{2.5}$	76–235	167.4
IV (46 days)	151–200	172.3	$PM_{2.5}$ (33 days)	111–222	132.5
			O_3 (10 days)	101–126	109.5
			PM_{10} (2 days)	253–308	280.5
			NO_2 (1 day)	28.7	28.7

Table 1(c). Indicatory air pollutants of AQI classes IV, V, and VI in Suzhou from 2017–2019 (Units for different air pollutants, $PM_{2.5}$ (µg m^{-3}), PM_{10} (µg m^{-3}), O_3 (ppb)).

AQI Class	AQI		Indicatory Air Pollutants		
	Range	Mean		Range	Mean
VI (2 days)	431–500	465.5	PM_{10}	531	531
V (28 days)	201–300	232.3	$PM_{2.5}$	119–250	176.5
IV (83 days)	151–195	169.8	$PM_{2.5}$ (59 days)	116–146	131.2
			O_3 (22 days)	101–120	106.2
			PM_{10} (2 days)	254–287	270.5

biomass, secondary generation, road dust, and other processes. $PM_{2.5}$ is composed of primary particles directly discharged into the air and secondary particles generated by photochemical reactions of gaseous pollutants in the air. $PM_{2.5}$ usually accumulates in the human respiratory tract and causes very serious harm to human health (Tao *et al.*, 2009; Xu *et al.*, 2017; Wu *et al.*, 2019b).

As shown in Fig. 3(A)(a), in the month of January 2017–2019, in Anqing, Hefei, and Suzhou, the $PM_{2.5}$ concentrations ranged between 9.0 and 235, between 16 and 202, and between 32 and 250 µg m^{-3} and averaged 92.8, 87.5, and 106.5 µg m^{-3}, respectively. Concentrations in January 2020 were in the range of 9.0–110, 20–138, and 20–223 µg m^{-3}, and averaged 56.0, 64.6, and 100.7 µg m^{-3}, respectively, which was 39.7%, 26.2%, and 5.4% lower than those in January 2017–2019. Based on the data from the three cities, during January 2020, the average $PM_{2.5}$ decreased by 23.8% compared with that in January 2017–2019.

As shown in Fig. 3(A)(b), in Anqing, Hefei and Suzhou, during February 2017–2019, the $PM_{2.5}$ concentrations ranged between 21 and 253, between 17 and 145, and between 31 and 151 µg m^{-3}, and averaged 75.2, 71.7, and 87.0 µg m^{-3}, respectively. Those during February 2020 ranged from 9.0–89, 11–92, and 16–100 µg m^{-3} and averaged 38.7, 36.4, and 50.8 µg m^{-3}, respectively, which was 48.6%, 49.2%, and 41.6% lower than those in February 2017–2019. Based on the data from the three cities, during February 2020, the average $PM_{2.5}$ decreased by 46.5% compared with that in February 2017–2019.

As shown in Fig. 3(A)(c), in Anqing, Hefei and Suzhou, during March 2017–2019, the $PM_{2.5}$ concentrations ranged between 15 and 113, between 9.0 and 110, and between 25 and 149 µg m^{-3}, and averaged 53.0, 54.4, and 68.7 µg m^{-3}, respectively. Concentrations in March 2020 ranged from 8.0–63, 11–59, and 20–78 µg m^{-3} and averaged 37.3, 34.9, and 45.6 µg m^{-3}, respectively, which was 29.7%, 35.8% and 33.5% lower than those in March 2017–2019. Based on the data from the three cities, $PM_{2.5}$ decreased by 33.0% on average compared with March 2017–2019.

The main sources of atmospheric particulate matter include fossil fuel combustion, motor vehicle exhaust emissions, industrial production, construction, road dust, biomass combustion, secondary particulate matter generation, etc. (Song *et al.*, 2007; Kim and Hopke, 2008). It can be seen that compared with the same period in the previous three years, from January to March 2020, the $PM_{2.5}$ concentration decreased significantly. In January 2020, the reason for the drop in $PM_{2.5}$ concentration may have been the Chinese New Year holiday in late January, which led to the temporary closure of most factories. In February and March 2020, the $PM_{2.5}$ concentration decreased significantly. This is because comprehensive strict epidemic prevention and control actions

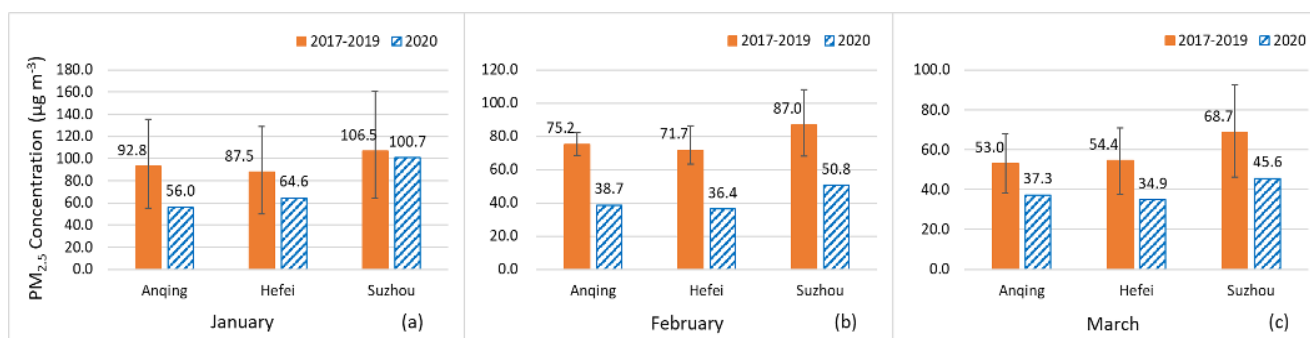**Fig. 3(A).** Average PM$_{2.5}$ concentrations during January, February, and March 2017–2019 and those in 2020, respectively.

were taken in Anhui Province, such as closing factories and restricting traffic. These actions greatly reduced industrial and transportation emissions. In order to prevent the spread of COVID-19, China adopted self-quarantine for residents, which greatly reduced the use of diesel and gasoline vehicles. Therefore, the emissions of fine particulates and PAHs were greatly reduced, which is an important reason for the decrease in atmospheric PM$_{2.5}$ concentrations (Zhou *et al.*, 2009; Wu *et al.*, 2019a; Wu *et al.*, 2019b).

PM$_{10}$ Concentration

PM$_{10}$ refers to solid and liquid particles with an aerodynamic diameters below 10 µm, which can have a direct negative impact on human health (Matus *et al.*, 2012; Liang *et al.*, 2016). PM$_{10}$ in the atmosphere comes from natural factors such as sand storms and soil dust, as well as human factors such as coal combustion and building dust (Matawle *et al.*, 2015; Liu *et al.*, 2020).

As shown in Fig. 3(B)(a), in Anqing, Hefei, and Suzhou, from January 2017–2019, the PM$_{10}$ concentrations ranged between 10 and 258, between 8 and 186, and between 49 and 266 µg m^{-3}, and averaged 100.4, 92.2, and 138.1 µg m^{-3}, respectively. Concentrations in January 2020 ranged from 11–101, 14–119, and 22–253 µg m^{-3} and averaged 53.0, 59.3, and 111.9 µg m^{-3}, respectively, which was 47.2%, 35.7%, and 19.0% lower than those in January 2017–2019. Based on the data from the three cities, during January 2020, the average PM$_{10}$ decreased by 33.9% compared with that in January 2017–2019.

As shown in Fig. 3(B)(b), in Anqing, Hefei, and Suzhou, during February 2017–2019, the PM$_{10}$ concentrations ranged between 15 and 367, between 15 and 179, and between 47 and 254 µg m^{-3}, and averaged 89.2, 83.3, and 120.4 µg m^{-3}, respectively. Concentrations in February 2020 ranged from 11–95, 12–105, and 24–139 µg m^{-3} and averaged 42.9, 43.8, and 63.4 µg m^{-3}, respectively, which was 51.9%, 47.4%, and 47.3% lower than those in February 2017–2019. Based on the data from the three cities, in February 2020, the average PM$_{10}$ decreased by 48.9% compared with that in February 2017–2019.

As shown in Fig. 3(B)(c), in Anqing, Hefei, and Suzhou, in March 2017–2019, the PM$_{10}$ concentrations ranged between 17 and 136, between 15 and 182, and between 47 and 197 µg m^{-3}, and averaged 70.2, 79.3, and 104.2 µg m^{-3}, respectively. Concentrations in March 2020 ranged from

12–134, 22–200, and 39–138 µg m^{-3} and averaged 52.4, 60.2, and 76.8 µg m^{-3}, respectively, which was 25.4%, 24.1%, and 26.3% lower than those in March 2017–2019. Based on the data from the three cities, in March 2020, the average PM$_{10}$ decreased by 25.3% compared with that in March 2017–2019.

PM$_{10}$ mainly comes from the extensive application of fossil fuels in transportation, industrial production, building dust, and wind dust. During the epidemic control period, the residents chose to quarantine at home, which led to the stagnation of industrial production, transportation, and construction. The above control actions were of great importance to the significant reduction in ambient air PM$_{10}$.

SO$_2$ Concentration

SO$_2$ is a major air pollutant and has a wide range of distribution, mainly from the combustion of coal and petroleum and the smelting of sulfur-containing ores. SO$_2$ pollution not only causes environmental problems such as acid rain, but also causes allergic reactions in the human body, causing symptoms such as difficulty with breathing and vomiting.

As shown in Fig. 3(C)(a), in Anqing, Hefei, and Suzhou, in the month of January 2017–2019, the SO$_2$ concentrations ranged between 1.75 and 19.3, between 1.05 and 10.9, and between 2.10 and 24.5 ppb, and averaged 5.02, 3.81, and 6.72 ppb, respectively. Concentrations in January 2020 ranged from 1.75–4.90, 1.40–3.15, and 1.40–3.85ppb and averaged 2.59, 2.00, and 2.21 ppb, respectively, which was 48.5%, 47.6%, and 67.1% lower than those during January 2017–2019. Based on the data from the three cities, during January 2020, the average SO$_2$ decreased by 54.4% compared with that in January 2017–2019.

As shown in Fig. 3(C)(b), in Anqing, Hefei, and Suzhou, in the month of February 2017–2019, the SO$_2$ concentrations ranged between 2.10 and 21.1, between 0.72 and 8.41, and between 1.75 and 18.2 ppb, and averaged 5.14, 3.31, and 5.95 ppb, respectively. Concentrations in February 2020 ranged from 1.45–7.05, 1.41–3.85, and 1.42–3.15 ppb and averaged 2.56, 1.93, and 2.05 ppb, respectively, which was 50.2%, 41.7%, and 65.5% lower than those in February 2017–2019. Based on the data from the three cities, during February 2020, the average SO$_2$ decreased by 52.5% compared with that in February 2017–2019.

As shown in Fig. 3(C)(c), in Anqing, Hefei, and Suzhou, in the month of March 2017–2019, the SO$_2$ concentrations
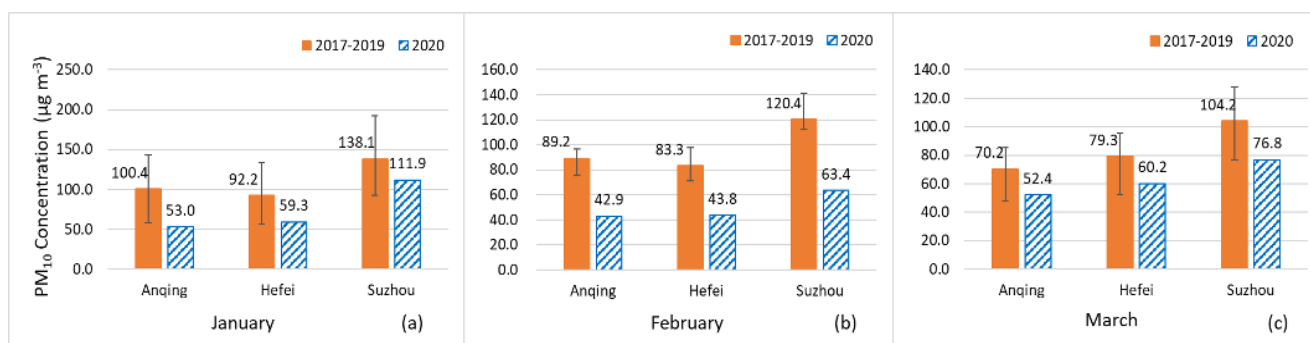
Fig. 3(B). The average concentrations of PM_{10} in January, February and March 2017–2019 and those in 2020, respectively.
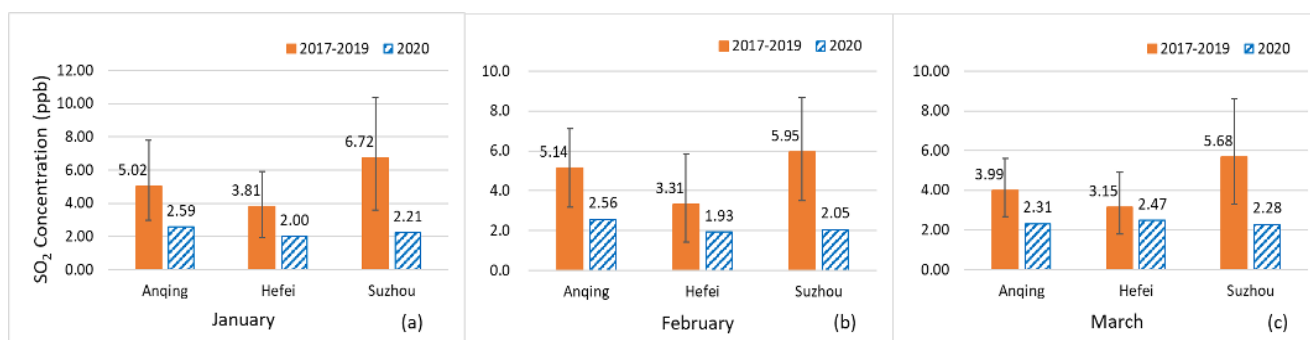

Fig. 3(C). The average concentrations of SO_2 in January, February, and March 2017–2019 and those in 2020, respectively.

ranged between 2.11 and 8.42, between 1.05 and 10.2, and between 1.75 and 13.0 ppb, and averaged 3.99, 3.15, and 5.68 ppb, respectively. Concentrations in March 2020 ranged from 1.45–3.51, 1.40–4.55, and 1.75–3.85 ppb and averaged 2.31, 2.47, and 2.28 ppb, respectively, which was 41.9%, 21.5%, and 59.8% lower than those in March 2017–2019. Based on the data from the three cities, during March 2020, the average SO_2 decreased by 41.1% compared with that in March 2017–2019.

The results indicate that from January to March 2020, the level of SO_2 decreased significantly compared to the same period in 2017–2019, and were far below the WHO air quality regulatory standards (20 µg m^{-3} or 7.0 ppb). Production suspensions due to the Chinese New Year holidays and the restrictions on production activities during the epidemic prevention and control period resulted in a substantial reduction in the burning of fossil fuels, which may be important reasons for the decrease in SO_2 concentration.

CO Concentration

CO (carbon monoxide) is the third smallest component of carbon in the atmosphere, after CO_2 and CH_4. The CO in the atmosphere is mainly from the combustion products resulting when carbonaceous substances are incompletely burned. Factory heating furnaces, power stations, civil boilers, stoves, internal combustion engines, and automobile exhaust gas are the main sources of carbon monoxide.

As shown in Fig. 3(D)(a), in Anqing, Hefei, and Suzhou, in the month of January 2017–2019, the CO concentrations ranged between 0.32 and 1.61, between 0.41 and 2.24, and between 0.48 and 3.04 ppm, and averaged 0.76, 0.92, and

0.91 ppm, respectively. Concentrations in January 2020 ranged from 0.24–1.04, 0.24–1.21, and 0.41–1.84 ppm and averaged 0.61, 0.69, and 0.86 ppm, respectively, which was 19.7%, 24.5%, and 5.8% lower than those in January 2017–2019. Based on the data from the three cities, in January 2020, the average CO decreased by 16.7% compared with that in January 2017–2019.

As shown in Fig. 3(D)(b), in Anqing, Hefei, and Suzhou, in the month of February 2017–2019, the CO concentrations ranged between 0.24 and 1.12, between 0.32 and 1.21, and between 0.41 and 1.84 ppm, and averaged 0.67, 0.77, and 0.80 ppm, respectively. Concentrations in February 2020 ranged from 0.24–0.72, 0.32–0.72, and 0.24–0.88 ppm and averaged 0.46, 0.47, and 0.49 ppm, respectively, which was 31.8%, 38.6%, and 38.2% lower than those in February 2017–2019. Based on the data from the three cities, in February 2020, the average CO decreased by 36.2% compared with that in February 2017–2019.

As shown in Fig. 3(D)(c), in Anqing, Hefei, and Suzhou, in the month of March 2017–2019, the CO concentrations ranged between 0.32 and 0.96, between 0.32 and 1.21, and between 0.24 and 1.23 ppm and averaged 0.59, 0.65, and 0.59 ppm, respectively. Concentrations in March 2020 ranged from 0.32–0.72, 0.32–0.81, and 0.16–0.64 ppm and averaged 0.50, 0.49, and 0.40 ppm, respectively, which was 14.8%, 25.8%, and 32.1% lower than those in March 2017–2019. Based on the data from the three cities, during March 2020, the average CO decreased by 24.2% compared with that in March 2017–2019.

Similar to the SO_2 pattern, in January to March 2020, the CO concentration also showed a significant decrease
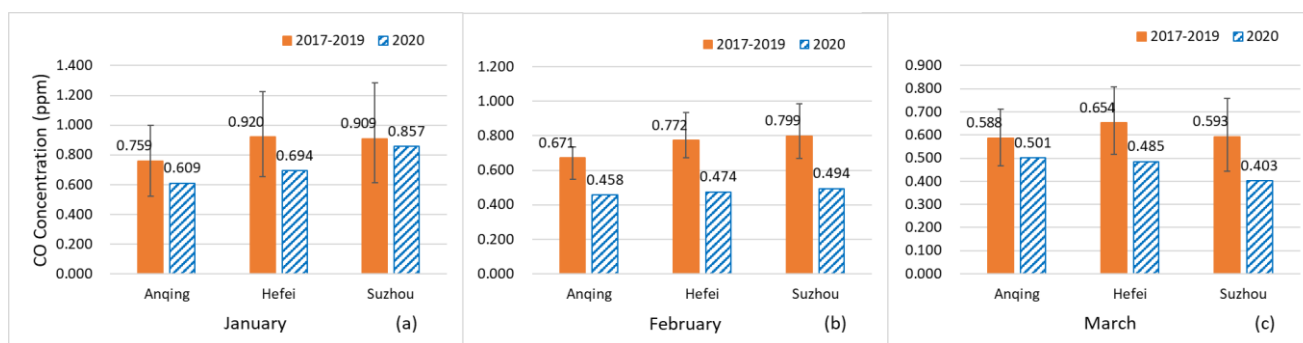
Fig. 3(D). The average concentrations of CO in January, February, and March 2017–2019 and those in 2020, respectively.

compared with the average in the same period in 2017–2019. This shows that during the Lunar New Year holidays and the epidemic control period, fossil fuel burning activities were reduced, thereby greatly reducing the CO emissions.

NO$_2$ Concentration

The main sources of NO$_2$ are the combustion of fossil fuels and the emission of automobile exhaust (Cheng *et al.*, 2018). Compared with the non-epidemic stage, the change in NO$_2$ concentrations was also very obvious.

As shown in Fig. 3(E)(a), in Anqing, Hefei, and Suzhou, in the month of January 2017–2019, the NO$_2$ concentrations ranged between 6.82 and 49.7, between 7.79 and 59.9, and between 7.30 and 47.7 ppb, and averaged 21.2, 26.4, and 23.9 ppb, respectively. Concentrations in January 2020 ranged from 4.87–25.3, 6.82–36.0, and 5.36–30.2 ppb and averaged 13.5, 20.7, and 15.2 ppb, respectively, which was 36.5%, 21.7%, and 36.5% lower than those in January 2017–2019. Based on the data from the three cities, in January 2020, the average NO$_2$ decreased by 31.5% compared with that in January 2017–2019.

As shown in Fig. 3(E)(b), in Anqing, Hefei, and Suzhou, during February 2017–2019, the NO$_2$ concentrations ranged between 5.36 and 36.0, between 5.84 and 53.1, and between 4.87 and 40.4 ppb and averaged 15.9, 22.6, and 18.9 ppb, respectively. Concentrations in the epidemic prevention and control action period (February 2020) ranged from 3.90–17.5, 4.87–16.6, and 2.92–17.5 ppb and averaged 8.91, 11.3, and 6.75 ppb, respectively, which was 43.8%, 50.2%, and 64.4% lower than those in February 2017–2019. Based on the data from the three cities, in February 2020, the average NO$_2$ decreased by 52.8% compared with that in February 2017–2019.

As shown in Fig. 3(E)(c), in Anqing, Hefei, and Suzhou, in March 2017–2019, the NO$_2$ concentrations ranged between 6.82 and 38.0, between 9.74 and 66.7, and between 5.84 and 35.1 ppb, and averaged 17.8, 24.9, and 19.0 ppb, respectively. Concentrations in March 2020 ranged from 5.36–25.3, 8.77–29.7, and 6.82–21.4 ppb and averaged 13.4, 18.1, and 13.4 ppb, respectively, which was 24.8%, 27.0%, and 29.6% lower than those in March 2017–2019. Based on the data from the three cities, during March 2020, the average NO$_2$ decreased by 27.2% compared with that in March 2017–2019.

Compared with that in the period from January to March 2017–2019, in the same period of 2020, the NO$_2$ concentration decreased significantly, especially in February, when strict epidemic prevention and control actions were taken. In the case of relatively similar weather conditions, the decrease in NO$_2$ concentrations in February 2020 fully demonstrated that the epidemic prevention and control action led to a significant improvement in air quality.

O$_3$ Concentration

The formation of urban O$_3$ is a complicated process. O$_3$ has no direct emission source. It is generated by the reaction of precursors such as NO$_x$, CO, and VOCs (volatile organic compounds) under appropriate weather conditions (Saito *et al.*, 2002; Schauer *et al.*, 2007; Biswas *et al.*, 2019). High concentrations of O$_3$ can easily cause urban photochemical smog. The harm from O$_3$ to the human body is mainly caused by the destruction of the respiratory tract mucosa, which results in various respiratory diseases and is also very irritating to the eyes (Monks *et al.*, 2015; Turner *et al.*, 2016).

It is worth noting that the pattern in the O$_3$ concentrations was different from the pattern found for the other five air pollutants. As shown in Fig. 3(F)(a), in Anqing, Hefei, and Suzhou, in the month of January 2017–2019, the O$_3$ concentrations ranged between 9.80 and 65.8, between 4.67 and 44.8, and between 6.53 and 58.8 ppb, and averaged 31.2, 24.8, and 27.1 ppb, respectively. Concentrations in January 2020 ranged from 8.87–56.9, 3.27–45.3, and 13.5–53.2 ppb and averaged 30.4, 21.1, and 29.7 ppb, respectively. In Anqing and Hefei, the O$_3$ concentration decreased slightly by 2.5% and 14.7%, respectively, but in Suzhou, it increased by 9.5% compared with that in January 2017–2019. Based on the data from the three cities, in January 2020, the average O$_3$ decreased by 2.6% compared with that in January 2017–2019.

As shown in Fig. 3(F)(b), in Anqing, Hefei, and Suzhou, in the month of February 2017–2019, the O$_3$ concentrations ranged between 15.4 and 66.7, between 14.5 and 60.7, and between 13.5 and 72.3 ppb and averaged 37.9 33.7, and 37.3 ppb, respectively. Concentrations in February 2020 ranged from 16.8–59.3, 14.9–48.5, and 11.2–54.6 ppb and averaged 41.0, 34.8, and 37.1 ppb, respectively. In Anqing and Hefei, the O$_3$ concentration increased slightly by 8.2% and 3.3%, respectively, but in Suzhou, it decreased by 0.06% compared with that in January 2017–2019. Based on the data from the three cities, om February 2020, the average O$_3$ increased by 3.6% compared with that in February 2017–2019.
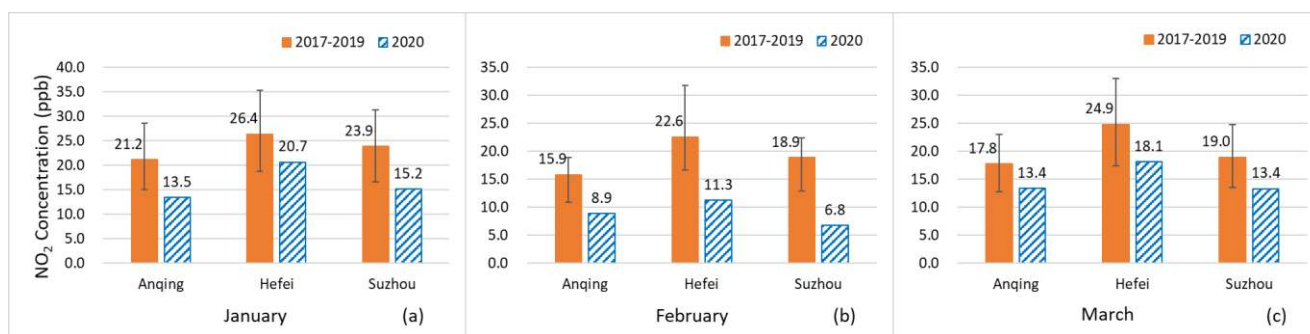
Fig. 3(E). The average concentrations of NO$_2$ in January, February and March 2017–2019 and those in 2020, respectively.
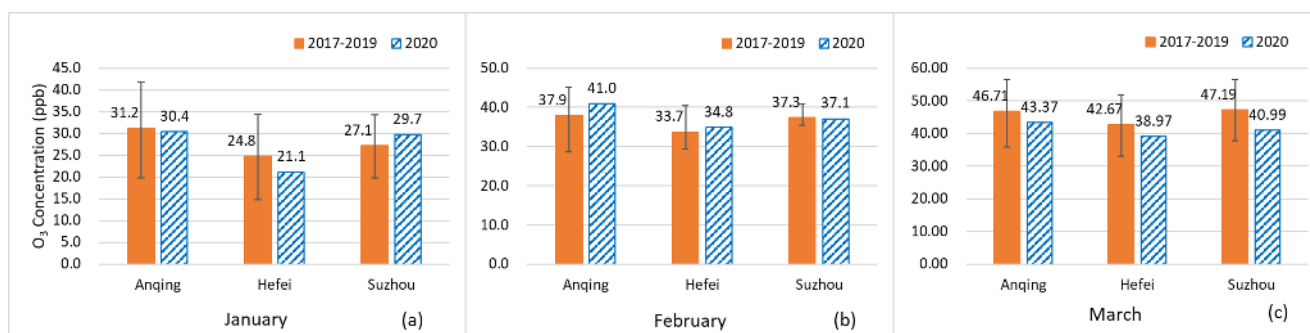

Fig. 3(F). The average concentrations of O$_3$ in January, February and March 2017–2019 and those in 2020, respectively.

As shown in Fig. 3(F)(c), in Anqing, Hefei, and Suzhou, in the month of March 2017–2019, the O$_3$ concentrations ranged between 19.1 and 72.3, between 16.3 and 68.1, and between 20.5 and 82.1 ppb and averaged 46.7, 42.7, and 47.2 ppb, respectively. Concentrations in March 2020 ranged from 19.6–67.2, 11.2–59.3, and 15.4–66.3 ppb and averaged 43.4, 39.0, and 41.0 ppb, respectively, which reflected a decrease of 7.1%, 8.7%, and 13.1% compared with that in March 2017–2019. Based on the data from the three cities, in March 2020, the average O$_3$ decreased by 9.6% compared with that in March 2017–2019.

It can be seen that the fluctuation of O$_3$ concentration was small compared with the obvious downward trend of the other five pollutants, and even showed a small increase (3.6%) in February 2020. This was probably due to a lower concentration of NO$_2$. The role of NOx in atmospheric photochemical processes can be summarized as a basic photochemical cycle:

$$NO_2 + hv \ (\lambda \leq 430 \ nm) \rightarrow NO + M$$

$$M + O_2 \rightarrow O_3$$

$$NO + O_3 \rightarrow NO_2 + O_2$$
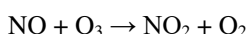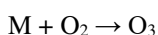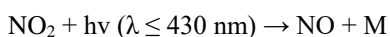
It can be seen that NO$_x$ is one of the important precursors to NO. A lower NO$_2$ concentration will result in a lower level of NO, thus reducing the possibility of NO reacting with O$_3$ and thus preventing accumulation of O$_3$. In general, the change in urban NO$_x$ and O$_3$ concentrations exhibits a negative correlation, where this phenomenon is particularly obvious in winter. This is because in summer, due to strong solar radiation, photochemical reactions are more dominant, which makes the environment more suitable for the accumulation of O$_3$. In winter, the photochemical reaction is relatively weak during the day, so higher NO$_2$ concentrations in a specific range are conducive to the consumption of O$_3$. However, a lower concentration of NO$_2$ makes it impossible for the O$_3$ generated during the day to be further effectively converted (Zhao et al., 2018), which explains why the O$_3$ concentrations in Anqing, Hefei, and Suzhou were not significantly reduced from January to March of 2020.

Distribution of the Six AQI Classes

A statistical analysis was conducted in this study to determine the distribution of the six AQI classes in January, February and March 2017–2019 and those in 2020, respectively.

As Fig. 4(A)(a) shows, in Anqing, in January 2017–2019, the proportions of classes I, II, III, IV, V and VI were 6.5%, 38.7%, 26.9%, 11.8%, 16.1% and 0%, respectively. In January 2020, the proportions of AQI classes I, II, III, IV, V, and VI were 22.6%, 48.4%, 29.0%, 0%, 0%, and 0%, respectively. It can be seen that during January 2020, the combined proportions of Class I and Class II increased from 45.2% to 71.0%, while the combined proportions of classes IV, V, and VI decreased from 28.0% to zero.

In Hefei (Fig. 4(A)(a)), in the month of January 2017–2019, the proportions of AQI classes I, II, III, IV, V and VI were 9.7%, 31.2%, 35.5%, 16.1%, 7.5% and 0%, respectively. However, in January of 2020, the same AQI classes were 12.9%, 48.4%, 29.0%, 9.7%, 0%, and 0%, respectively. The combined proportions of Class I and II increased from 40.9% to 61.3%, and the combined proportion of classes IV,

V, and VI decreased from 23.7% to 9.7%. It can be seen that the air quality in Anqing and Hefei in January 2020 improved compared with the same period in the previous three years.

For Suzhou (Fig. 4(A)(a)), which had no significant change in air quality, in January 2017–2019, the proportions of classes I, II, III, IV, V, and VI were 1.1%, 32.3%, 28.0%, 18.3%, 20.4%, and 0%, respectively. In January 2020, the AQI class proportions were 0%, 32.3%, 29.0%, 29.0%, 9.7%, and 0%. The combined proportion of Class I and Class II slightly decreased by 1.1%, and the combined proportions (38.7%) of classes VI, V, and VI were the same as those in January 2017–2019.

Fig. 4(A)(b) shows the distribution of the AQI classes for the three cities combination in January 2017–2019 and in January 2020, respectively. It can be seen that from 2017 to 2019, the distribution of AQI classes I, II, III, IV, V and VI in the three cities was 5.7%, 34.1%, 30.1%, 15.4%, 14.7% and 0%, respectively, but in January 2020, it was 11.8%, 43.0%, 29.0%, 12.9%, 3.2%, and 0%, respectively. The combined proportions of classes I and II increased from 39.8% to 54.8%, while the proportions of classes VI, V and VI decreased from 30.1% to 16.1%, respectively. According to the data for the three cities, it can be seen that the air quality in Anhui Province in January 2020 improved compared with the same period in the previous three years. This may be because late January 2020 was the lunar New Year holiday in China. During this period, the factories were temporarily closed, resulting in a significant reduction in production and emissions.

As shown in Fig. 4(B)(a), in Anqing, in February 2017–2019, the proportions of classes I, II, III, IV, V, and VI were 14.3%, 38.1%, 35.7%, 8.3%, 2.4%, and 1.2%, respectively. In February 2020, when comprehensive epidemic prevention and control actions were taken, the proportions of classes I, II, III, IV, V, and VI were 37.9%, 58.6%, 3.4%, 0%, 0%, and 0%, respectively. It can be seen that during the epidemic control period, the combined proportions of Class I and Class II increased from 52.4% to 96.6%, while the combined proportions of classes IV, V, and VI decreased from 11.9% to zero, which indicates that the air quality had greatly improved.

In Hefei (Fig. 4(B)(a)), in February 2017–2019, the proportions of classes I, II, III, IV, V, and VI changed to 9.5%, 39.3%, 46.4%, 4.8%, 0%, and 0%, respectively. However, in February of 2020, these proportions were 58.6%, 31.0%, 10.3%, 0%, 0%, and 0%. The combined proportions of classes I and II increased from 48.8% to 89.7% and the combined proportions of classes IV, V, and VI decreased from 4.8% zero.

For Suzhou (Fig. 4(B)(a)), in February 2017–2019, the proportions of classes I, II, III, IV, V, and VI were 2.4%, 39.3%, 32.1%, 25.0%, 1.2%, and 0%, respectively. In February 2020, the proportions changed to 27.6%, 51.7%, 20.7%, 0%, 0%, and 0%. Similar to Anqing and Hefei, in Suzhou, in February 2020, the combined proportions of classes I and II increased from 41.7% to 79.3%, and the combined proportions of classes IV, V, and VI dropped from 26.2% to zero. It was obvious that air quality improved significantly during the epidemic control period.

Fig. 4(B)(b) shows the distribution of the AQIs for the

three cities combination in February 2017–2019 and in February 2020, respectively. It can be seen that from 2017 to 2019, the AQI distribution of classes I, II, III, IV, V, and VI in the three cities was 8.7%, 38.9%, 38.1%, 12.7%, 1.2%, and 0.4%, respectively, but in February 2020, the distribution was 41.4%, 47.1%, 11.5%, 0%, 0%, and 0%, respectively. The combined proportions of classes I and II increased from 47.6% to 88.5%, while the combined proportions of classes IV, V, and VI decreased from 14.3% to 0%. Based on the results from these three cities, it is clear that in February 2020, the air quality improved significantly in the three cities. This is because in February 2020, comprehensive, strict COVID-19 epidemic prevention and control actions were taken in Anhui Province, and measures such as closing factories and restricting traffic greatly reduced the emission of air pollutants.

As shown in Fig. 4(C)(a), in Anqing, in March 2017–2019, the AQI proportions of classes I, II, III, IV, V and VI were 11.8%, 76.3%, 11.8%, 0%, 0% and 0%, respectively. During March 2020, when comprehensive epidemic prevention and control actions were still taken, the proportions of classes I, II, III, IV, V, and VI were 32.3%, 67.7%, 0%, 0%, 0%, and 0%, respectively. The combined proportions of Class I and Class II increased from 88.2% to 100%, which indicated that the air quality greatly improved during the epidemic control period.

In Hefei (Fig. 4(C)(a)), in March 2017–2019, the AQI proportions of classes I, II, III, IV, V and VI were 7.6%, 75.0%, 17.4%, 0%, 0% and 0%, respectively. However, in March of 2020, they were 25.8%, 71.0%, 3.2%, 0%, 0%, and 0%. The combined proportions of Class I and II increased from 82.6% to 96.8%, while the combined proportions of Class IV, V, and VI was zero.

For Suzhou (Fig. 4(C)(a)), in March 2017–2019, the AQI proportions of classes I, II, III, IV, V, and VI were 2.2%, 63.4%, 26.9%, 6.5%, 1.1%, and 0%, respectively. In March 2020, the proportions were 9.7%, 83.9%, 6.5%, 0%, 0%, and 0%. The combined proportions of classes I and II increased from 65.6% to 93.5%, while the combined proportions of classes IV, V, and VI decreased from 7.6% to zero. This indicated that the air quality in the three cities improved significantly during the epidemic control period.

Fig. 4(C)(b) shows the distribution of the AQI classes for three cities combination in March 2017–2019 and in March 2020, respectively. It can be seen that from 2017 to 2019, the AQI distribution of classes I, II, III, IV, V and VI in the three cities was 7.2%, 71.6%, 18.7%, 2.2%, 0.4 % and 0%, respectively, but in March 2020, the distribution was 22.6%, 74.2%, 3.2%, 0%, 0%, and 0%, respectively. The combined proportions of classes I and II increased from 78.8% to 96.8%, while the combined proportion of classes IV, V, and VI decreased from 2.6% to zero. In March 2020, there was a significant improvement in air quality compared to the same period in the previous three years, which was due to the implementation of epidemic prevention and control actions.

Indicatory Air Pollutants

In order to further compare the changes in air quality during the epidemic control period, the five days with the highest daily AQI in February 2017–2019 and those of 2020
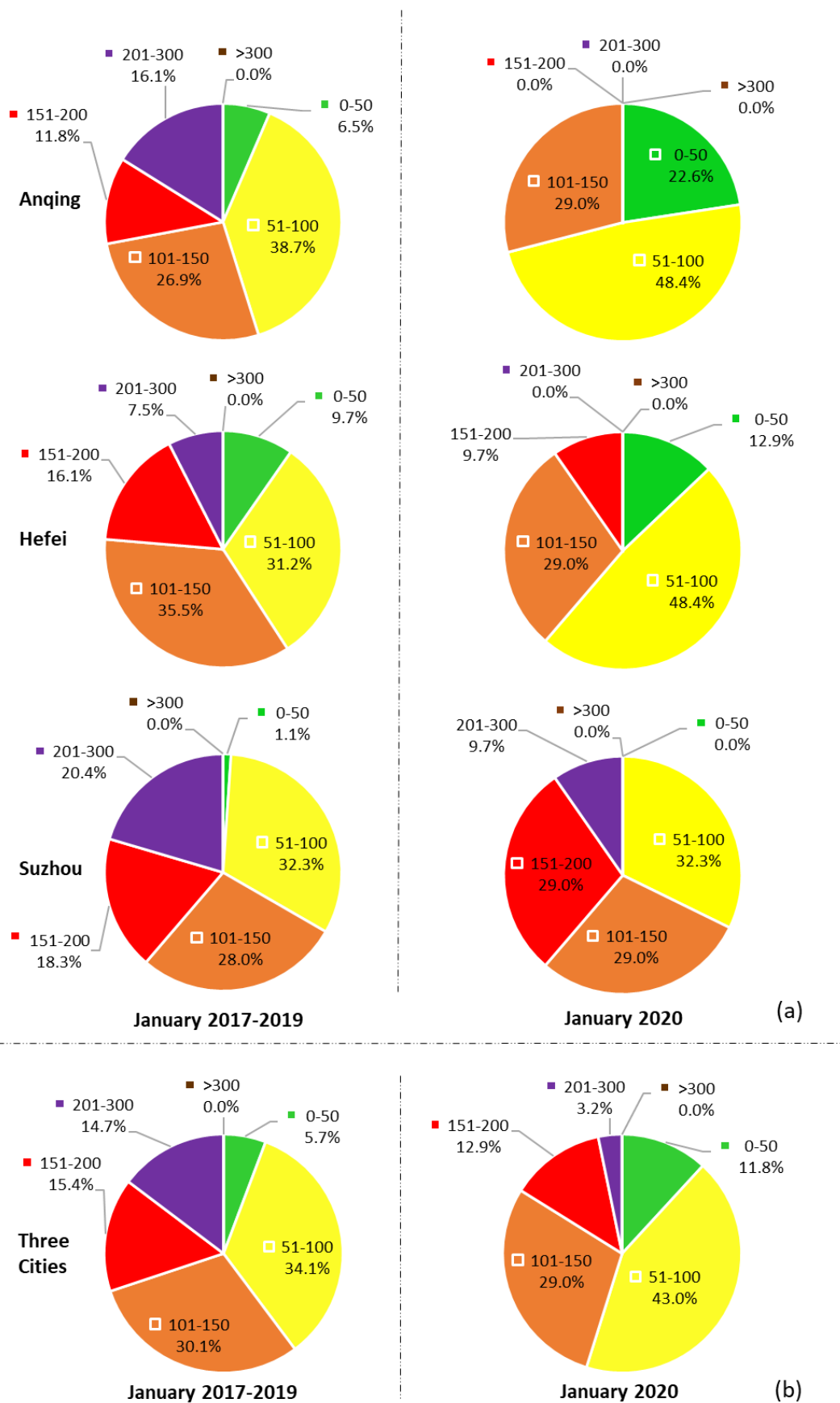
Fig. 4(A). The distribution of the six AQI classes (a) for Anqing, Hefei, and Suzhou in January 2017–2019 and January 2020, respectively and (b) for the three cities under observation.
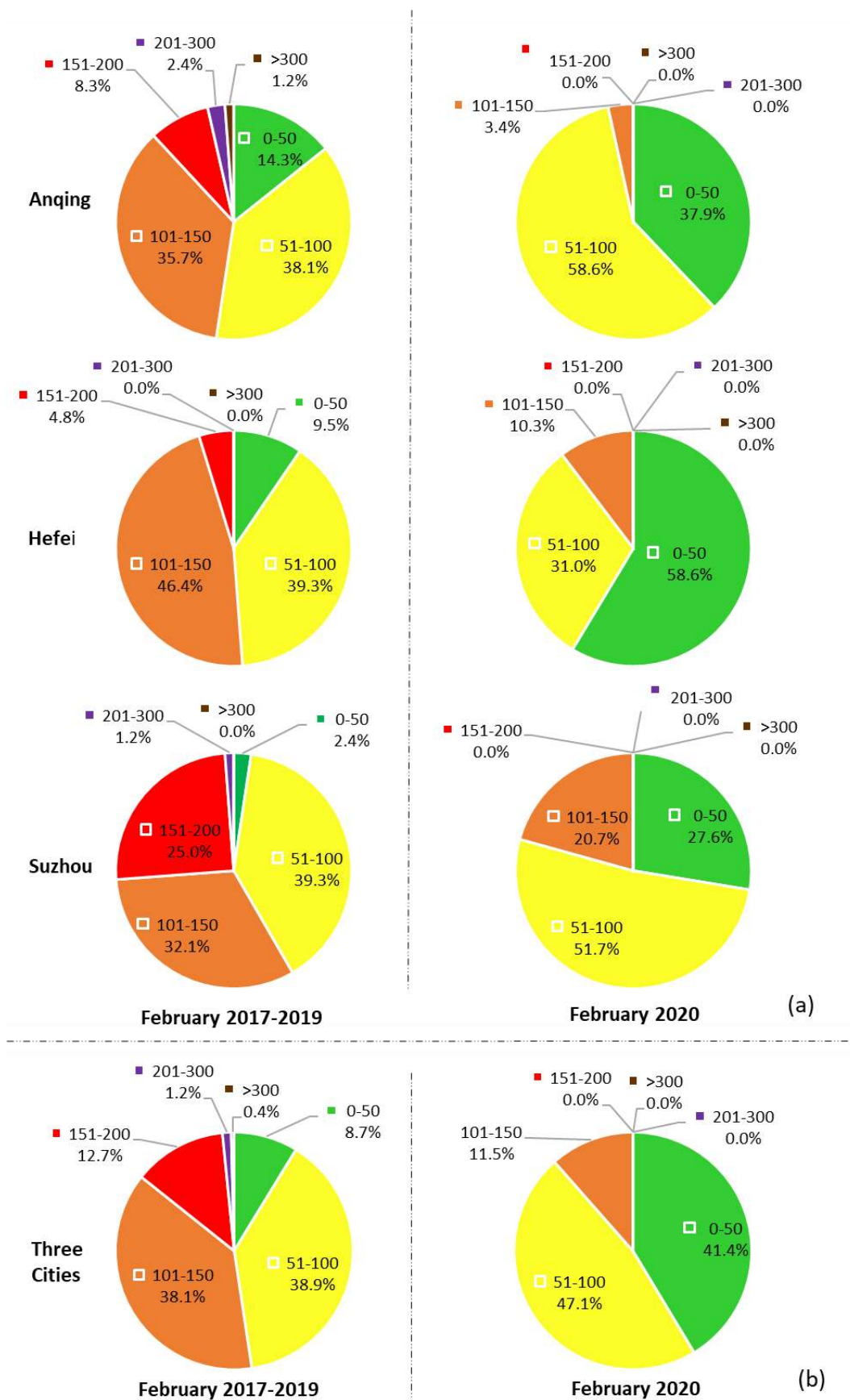
Fig. 4(B). The distribution of the six AQI classes (a) for Anqing, Hefei, and Suzhou in February 2017–2019 and February 2020, respectively and (b) for the three cities under observation.
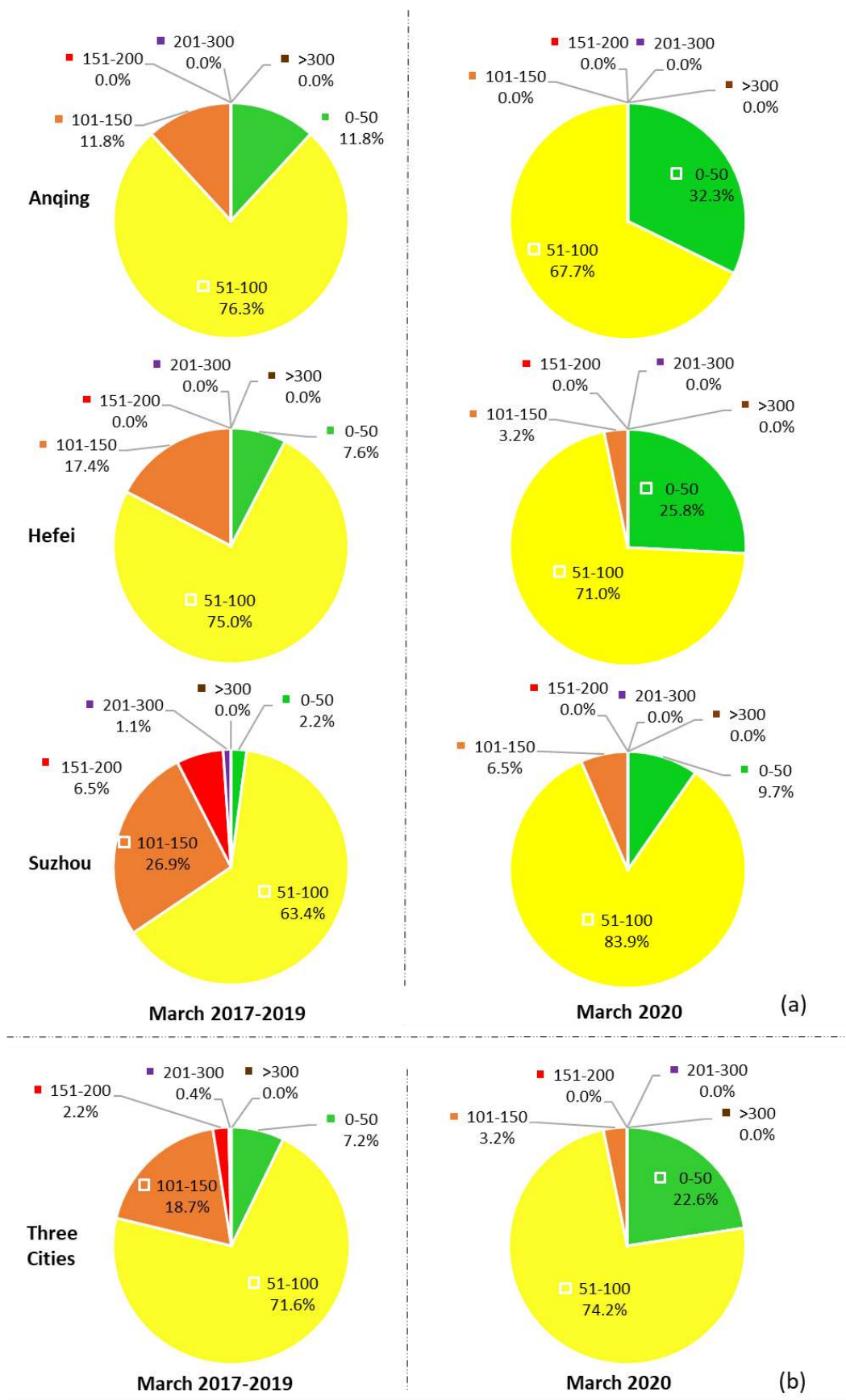
Fig. 4(C). The distribution of the six AQI classes (a) for Anqing, Hefei, and Suzhou in March 2017–2019 and March 2020, respectively and (b) for the three cities under observation.

for the three cities were analyzed and compared, as shown in Table 2.

It can be seen that in February 2017–2019, the AQI on the five days with the highest daily AQI ranged from193–303 and averaged 223.2, while those on the five days in February 2020 ranged from 114–132 and averaged 122.6, which was 45.1% lower than those in February 2017–2019. The indicatory air pollutant on the 10 days under observation was always $PM_{2.5}$. The $PM_{2.5}$ concentrations for the five days with the highest daily AQI in February 2017–2019 ranged from 145–253 µg m^{-3} and in an average of 173.6 µg m^{-3}, while concentrations on the five days in February 2020 ranged from 86–100 µg m^{-3} and averaged 92.6 µg m^{-3}, which was 46.7% lower than those in February 2017–2019. This shows that during the epidemic control period, the air quality near central China improved significantly.

Comparison of Air Quality in Hubei and Anhui Provinces

In a previous study, we investigated, compared, and analyzed the impact of the COVID-19 event on air quality in three cities, Wuhan, Jingmen, and Enshi, in Hubei Province, China (Xu *et al.*, 2020).

In the combined data for the three cities in Hubei Province in the comparison and analysis of the six air pollutants in February 2020 when the comprehensive epidemic prevention and control actions were taken, the average concentrations of atmospheric $PM_{2.5}$, PM_{10}, SO_2, CO, and NO_2 were 46.1 µg m^{-3}, 50.8 µg m^{-3}, 2.56 ppb, 0.60 ppm, and 6.70 ppb and were 30.1%, 40.5%, 33.4%, 27.9%, and 61.4%, respectively, lower than the levels in February 2017–2019. However, the O_3 concentration in February 2020 increased by 14.3% compared with that in February 2017–2019. This was consistent with the conclusions drawn in this study, and more fully demonstrates that the COVID-19 epidemic prevention and control actions reduced the emissions of industrial and transportation exhaust and improved air quality. The increases in the O_3 levels occurred because the lower concentration of NO_2 resulted in constraints on the NO + O_3 reaction, and the O_3 in the air could thus not be effectively further depleted.

For the combined distribution of AQIs in the three cities (Wuhan, Jingmen, and Enshi), in February 2020, when the strict epidemic prevention and control actions were taken, AQI classes I, II, III, IV, V and VI were 33.3%, 54.8%, 9.5%, 2.4%, 0% and 0%, respectively. The combined proportions of classes I and II increased from 63.3% to 88.1%, while the combined proportion of classes IV, V, and VI decreased from 7.2% to 2.4%, compared with that in the month of February 2017–2019 (non-epidemic period). The above results are also consistent with the those in this study. During the epidemic prevention and control period, the air

quality greatly improved.

As for the indicatory air pollutants, the combined data for the three cities (Wuhan, Jingmen, and Enshi) in Hubei Province in February 2020, indicate that during the epidemic prevention and control period, the combined proportion of days during which O_3 was as an indicatory pollutant in classes I and II increased significantly from 1.2% to 17.2%, and the combined proportions of PM_{10} and NO_2 as indicatory air pollutants decreased from 16.5% to 1.1%, and from 7.3% to 0%, respectively, compared with February 2017–2019. A similar conclusion was found in the present study, which indicated that during the epidemic control period, restrictions on transportation and production caused significant reductions in vehicle exhaust and industrial production emissions and improved the air quality.

CONCLUSION

In this study, the proportions of the six AQI classes for the three cities in the spring, summer, fall, and winter of 2017–2019 ranged between 22–500, 20–200, 20–431, and 222–303, and averaged 84.5, 78.1, 81.2, and 112.6, respectively. The AQI levels in the three cities in different seasons were in order as follows: winter > spring > fall > summer, which indicated that the air quality in summer was much better than that in winter.

In terms of annual AQI characteristics, in Anqing, in 2017, 2018, and 2019, the daily AQI averaged 83.1, 77.3, and 83.2, respectively. In Hefei, it averaged 95.1, 79.5, and 87.6, respectively. In Suzhou, it averaged 109.4, 91.2, and 97.5, respectively. Based on an analysis of the observation data for the three years under consideration, the AQI level rankings of the three cities were as follows: Suzhou > Hefei > Anqing. This showed that among the three cities from 2017–2019, Anqing had the best air quality, and Suzhou had the worst. Data from the three-year observation period show that the average annual AQI of the three cities was the lowest in 2018, but the air quality in 2019 deteriorated to a certain degree.

The indicatory air pollutants of AQI classes IV, V, and VI in the three cities from 2017–2019 were also analyzed. In the combined three-year data for the three cities, in classes IV, V, and VI, $PM_{2.5}$ was the most important indicatory air pollutant, followed by O_3, PM_{10}, and NO_2. The vast majority of AQI classes IV, V, and VI occurred in winter and spring, except the days when the indicatory air pollutant was O_3, which occurred most in the summer. This is because the higher temperature and stronger solar radiation in summer are more conducive to the production and accumulation of O_3.

The COVID-19 event has led to a significant improvement in air quality. In the month of January 2020, the average

Table 2. Indicatory air pollutants for the 5 days with the highest daily AQI for the three cities in February 2017–2019 and that in 2020, respectively.

Year	AQI		Indicatory Air Pollutants		
	Range	Mean		Range	Mean
2017–2019	193–303	223.2	$PM_{2.5}$	145–253	173.6
2020	114–132	122.6	$PM_{2.5}$	86–100	92.6

concentrations of atmospheric $PM_{2.5}$, PM_{10}, SO_2, CO, and NO_2 in the three cities (a combination of Anqing, Hefei, and Suzhou) were 23.8%, 33.9%, 54.4%, 16.7%, and 31.5% lower than those in January 2017–2019, respectively. In February 2020, when the epidemic prevention and control actions were taken, the average concentrations of atmospheric $PM_{2.5}$, PM_{10}, SO_2, CO, and NO_2 in three cities were 46.5%, 48.9%, 52.5%, 36.2%, and 52.8% lower than those in February 2017–2019, respectively, and in March 2020, they were 33.0%, 25.3%, 41.1%, 24.2%, and 27.2% lower than those in March 2017–2019, respectively. Restrictions on industrial production and mobile transportation during the epidemic period (February and March 2020) were the main reasons for the significant reduction in air pollutant levels in ambient air.

The fluctuation in the O_3 concentration was small compared with the obvious downward trend of the other five pollutants. In January, February, and March 2017–2019, the O_3 concentrations averaged 27.7, 36.3, and 45.5 ppb, respectively, while in 2020 they were 27.1, 37.6, and 41.1 ppb, respectively. In January 2020 and March 2020, the O_3 concentrations were 2.6% and 9.6%, which was slightly lower than those in 2017–2019, respectively, and in February 2020, there was even a small increase of 3.6%. This is because a lower concentration of NO_2 resulted in a hindering of the $NO + O_3$ reaction, so O_3 was not depleted effectively.

Based on the distribution of the combined AQIs for the three cities, in January, February, and March 2020, the combined proportions of classes I and II increased by 15.1%, 40.9%, and 18.0%, respectively, while the combined proportions of classes IV, V and VI reduced by 14.0%, 14.3%, and 2.6%, respectively. It is clear that during the epidemic prevention and control periods, the air quality near central China improved significantly.

In order to further compare the changes in air quality during the epidemic control period, in this study, the five days with the highest daily AQI in February 2017–2019 and those in 2020 for the three cities were also analyzed and compared. It can be seen that in February 2017–2019, the AQI on the five days averaged 223.2, while during the five days with the highest daily AQI in February 2020 averaged 122.6, which was 45.1% lower than that in February 2017–2019. The indicatory air pollutants on these 10 days was always $PM_{2.5}$. The $PM_{2.5}$ concentrations on the five days with the highest daily AQI in February 2020 averaged 92.6 µg m^{-3}, which was 46.7% lower than those in February 2017–2019 (173.6 µg m^{-3}). This shows that during the epidemic control period, the air quality near central China improved significantly.

This study provides useful information for the establishment of air pollution control strategies and for future research by scientific communities.

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