Temporal Variations in the Air Quality Index and the Impact of the COVID-19 Event on Air Quality in Western China

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ABSTRACT

This study investigated the AQI (air quality index) and atmospheric pollutants including PM2.5, PM10, CO, SO2, NO2 and O3 in Chongqing, Luzhou and Chengdu from 2017 to 2019. In addition, the impacts of the COVID-19 event on the air quality in the three cities in 2020 were compared and discussed. For the combined AQIs for the three cities, in spring, the daily AQIs ranged between 25 and 182 and averaged 72.1. In summer, the daily AQIs ranged between 24 and 206 and averaged 77.5. In autumn, the daily AQIs ranged between 22 and 170 and averaged 61.1, and in winter, the daily AQIs ranged between 28 and 375 and averaged 99.6. The average AQIs, in order, were Chengdu (85.4) > Chongqing (79.4) > Luzhou (73.2). Both the highest AQIs and PM2.5 (as the major indicator air pollutant) occurred mainly in the low temperature season (January, December, and February), while O3 was the main air pollutant in June and August when the weather was hot. In February 2020, during the epidemic prevention and control actions taken in response to COVID-19 for the three cities, the combined AQIs for the top five days with the highest AQIs in February 2020 was 79.4, which was 23.6% lower than that from 2017–2019 (AQI = 100.7), and the average concentrations of PM2.5, PM10, SO2, CO, and NO2 were 89.4 µg m⁻³, 106 µg m⁻³, 2.31 ppb, 0.72 ppm, and 12.3 ppb, respectively, and were 17.9%, 30.8%, 83.8%, 19.8%, and 62.1%, lower than those in February 2017–2019. However, the average O3 concentration (31.8 ppb) in February 2020 rather than decreasing, increased by 62.2%. This is because a lower NO2 concentration hindered the NO + O3 reaction and led to increase O3 concentration in the ambient air.

Keywords: COVID-19; AQI; PM2.5; PM10; SO2; NOX; CO; O3.

INTRODUCTION

Over the past few decades, China has developed rapidly in terms of economic growth and urbanization. Automobile exhaust, industrial activities, and biomass combustion have released a significant amount of pollutants into the atmosphere. Air pollution was a serious issue many cities (Liu et al., 2012; Liu and Wang, 2014; Li et al., 2017a).

An estimated 2.5 million people are killed each year by indoor and outdoor air pollution in China (Kulmala, 2015). Previous research investigated the relationship between air pollutants and human health (Pope and Dockery, 2006; Cao et al., 2012; Heal et al., 2012; Pope and Dockery, 2013; Jin et al., 2017). Studies have shown that inhaling PM2.5 can cause pneumonia and that it can dissolve in the bloodstream and cause heart and reproductive system diseases (Yang et al., 2017). PM10 also has a significant impact on the mortality related to cardiovascular diseases and respiratory diseases (Abe et al., 2018). PM2.5 is more harmful than PM10 (Deng et al., 2013a, b). SO2 is a common air pollutant that can cause health damage such as bronchitis and bronchial asthma and thus damage health (Hansell et al., 2011; Cerón-Bretón et al., 2018). CO in the atmosphere not only destroys the nerve function of the heart, but also affects the central nervous system and even leads to death from asphyxia (Yang et al., 2012). NO2 can hurt the function of the human respiratory...
system and significantly decrease the lung function index of the human body (Chen et al., 2011). A high atmospheric content of O$_3$ is highly oxidizing and phytotoxic, which can adversely affect plant growth and human health (Monks et al., 2015). In addition, as the third largest greenhouse gas, O$_3$ may play an important role in global warming (Stocker et al., 2013). The impact of air pollution on human health and the environment makes air quality a significant issue for the Chinese government and the public.

A novel coronavirus outbreak occurred in December 2019. It gradually spread all over the world after Spring 2020. It has been confirmed that this pneumonia is an acute respiratory infectious disease, and it considered new coronavirus pneumonia. On February 11, 2020, the World Health Organization (WHO) named it "COVID-19." On January 31st, 2020, novel coronavirus pneumonia was declared an "international emergency public health incident" by WHO’s director general, Tedros Adhanom Ghebreyesus. According to real-time statistical data from Johns Hopkins University in the United States, as of 05:30 on June 5, 2020, Beijing time, the number of confirmed cases of COVID-19 globally was 6,589,090 cases and there had been 388,499 deaths (https://news.sina.com.cn/world/). The Chinese government took prompt measures to suspend all types of transportation channels in Wuhan on January 23, 2020, which greatly restricted the flow of people in the area. Subsequently, various provinces and cities launched a first-class emergency response to major public health emergencies, and human activities such as commercial trade, industrial production and transportation decreased dramatically. In order to understand the impact of the COVID-19 epidemic on air quality, this study investigated changes in air quality in Chongqing, Luzhou and Chengdu during the non-epidemic period (January and February 2017–2019) and compared them to the air quality during the epidemic prevention and control period (January and February 2020).

The AQI (Air Quality Index), describes the level of air cleanliness or pollution as well as the impact of air quality on health. This study investigated, compared, and discussed the AQIs and air pollutants PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, CO, O$_3$, and in Chongqing, Luzhou and Chengdu, near western China from 2017 to 2020 focusing on the impacts of epidemic prevention and control actions on air quality.

**METHODS**

In this study, the air quality in three cities in western China, the Chongqing municipality (longitude 106.54, latitude 29.40), Luzhou in Sichuan province (longitude 105.44, latitude 28.88) and Chengdu (longitude 104.10, latitude 30.66) (Fig. 1) was studied and analyzed for the months of January and February from 2017 to 2020. Chongqing is located in the upper reaches of the Yangtze river, and is characterized by a mild climate and subtropical monsoon humid climate. Chongqing is foggy, and is known as "fog Chongqing." In this study, Spring is defined as the months of March, April, and May; summer includes June, July, and August, and autumn includes September, October, and November, and winter includes January, February and December. The average temperature in Chongqing from 2017 to 2019 ranged between 2.0 and 40℃ and averaged 19.6℃; the temperature in spring ranged between 6.0 and 37℃ and averaged 20℃; in summer, the temperature ranged between 18 and 40℃ and averaged 29℃; in autumn, the temperature ranged between 7.0 and 39℃ and averaged 19℃; and in winter, the temperature ranged between 2.0 and 20℃ and averaged 10℃. Located southeast of Sichuan province, Luzhou has a mild subtropical humid climate and four distinct seasons. The average temperature in Luzhou from 2017 to 2019 ranged between –2.0 and 39℃ and averaged 18.7℃; the temperature in spring ranged between 4.0 and 36℃ and averaged 20℃; in summer, the temperature ranged between 17 and 39℃ and averaged 29℃; in autumn, the temperature ranged between 7.0 and 39℃ and averaged 19℃; and in winter, the temperature ranged between 2.0 and 20℃ and averaged 10℃.
averaged 28°C; in autumn, the temperature ranged between 6.0 and 35°C and averaged 18.5°C; and in winter, the temperature ranged between −2.0 and 22°C and averaged 9.0°C.

Chengdu is located in the central part of Sichuan province and the western part of the Sichuan basin. It has a subtropical monsoon climate and a warm winter climate. The average temperature in Chengdu from 2017 to 2019 ranged between −5.0 and 36°C and averaged 17.3°C; the temperature in spring ranged between 4.0 and 35°C and averaged 18°C; in summer, the temperature ranged between 17 and 36°C and averaged 26°C; in autumn, the temperature ranged between 1.0 and 34°C and averaged 17°C, and in winter, the temperature ranged between −5.0 and 21°C and averaged 8.0°C.

**Air Quality Index (AQI)**

The AQI is a dimensionless index that quantitatively describes the air quality status. First, the sub-AQI of six standard pollutants (PM_{2.5}, PM_{10}, SO_{2}, CO, NO_{2}, and O_{3}) is calculated based on the observed concentration, as shown in Eq. (1) (Shen et al., 2017; She et al., 2017). The overall AQI represents the maximum value of the sub-AQI of all pollutants. When the AQI is higher than 50, the highest contributor of the sub-AQI of the day is defined as the primary pollutant, as shown in Eq. (2) (Shen et al., 2017; She et al., 2017):

$$IAQI_p = \frac{I_{\text{high}} - I_{\text{low}}}{C_{\text{high}} - C_{\text{low}}} (C_p - C_{\text{low}}) + I_{\text{low}}$$

$$AQI = \max(I_1, I_2, \ldots, I_6)$$

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 ≤ C_p; C_{high}: the concentration breakpoint that is ≥ C_p; I_{low}: the index breakpoint corresponding to C_{low}; I_{high}: the index breakpoint corresponding to C_{high}.

The six standards for air pollutants have serious implications for human health. The daily AQI value is calculated from the average concentration of PM_{2.5}, PM_{10}, SO_{2}, NO_{2}, and CO for 24 hours, and the maximum concentration of O_{3} eight hours per day. According to the U.S. Environmental Protection Agency (U.S. EPA) AQI, the range of AQI values related to air quality can be divided into six classes (Hu et al., 2015; Lanzafame et al., 2015; She et al., 2017; Zhao et al., 2018): Class I: 0–50 (Green), Good. Class II: 51–100 (Yellow), Moderate. Class III: 101–150 (Orange), Unhealthy for Sensitive Groups. Class IV: 151–200 (Red), Unhealthy. Class V: 201–300 (Purple), very Unhealthy. Class VI: 300–500 (Maroon), Hazardous.

**Wind Streamline and Wind Speed**

In order to understand the pathway of airflow in Chongqing Municipality and Sichuan Province from January to March, we chose GrADS (Grid Analysis and Display System, http://cola.gmu.edu/grads/) to compute and draw the distribution of the monthly average near-surface streamlines and wind speed with NCEP GDAS/FNL 0.25 Degree Global Tropospheric Analyses data (https://rda.ucar.edu/datasets/ds 083.3/).

**RESULTS AND DISCUSSION**

**Distribution of AQI Values**

As showed in Fig. 2, in Chongqing, the monthly AQI averages from 2017–2019 ranged between 54.0–98.8, and averaged 73.8, where the three months with the highest average AQIs in order were 98.8, 93.0, and 89.9 in January, August, and December, respectively. In January, the proportions of AQI classes I, II, III, IV, V, and VI were 0%, 42%, 58%, 0%, 0% and 0%, respectively. In August, they were 3%, 55%, 42%, 0%, 0%, and 0%, respectively. and in December, they were 0%, 65%, 35%, 0%, 0%, and 0%, respectively. The three months with the lowest AQIs in order were 65.2, 59.2 and 54.0 in March, September and October, respectively. In March, the proportions of AQI classes I, II, III, IV, V, and VI were 3%, 97%, 0%, 0%, 0% and 0%, respectively; in September, they were 37%, 63%, 0%, 0%, 0%, and 0%, and in October were 42%, 58%, 0%, 0%, 0% and 0%, respectively. It can be seen that the average monthly average AQI of the highest three months was 93.6, which was 36.5% higher than the average monthly average AQI of the lowest three months (59.5). During the three months with the highest average AQIs, the average proportions of AQI class I, II, III, IV, V, and VI were 1%, 54%, 45%, 0%, 0%, and 0% respectively; those were 27.3%, 72.7%, 0%, 0%, 0%, and 0% during the three months with the lowest average AQIs, compared with the three months with the highest average AQI, the combined average proportions of class I and II in the three months with the lowest average AQI increased by 45.0%, and the class III decreased to zero.

As shown in Fig. 3, in Luzhou, the monthly average AQI values in 2017–2019 ranged between 46.6 and 115, and averaged 73.2, where the three months with the highest average AQIs in order were 115, 89.1, and 88.9 in January, February and December, respectively. The proportions of AQI classes I, II, III, IV, V, and VI in January were 0%, 23%, 74%, 0%, 0% and 0%, respectively; in February, they were 0%, 75%, 25%, 0%, 0% and 0%, respectively, and in December, they were 0%, 77%, 23%, 0%, 0%, and 0%, respectively. The three months with the lowest AQIs in order were 61.6, 52.0, and 46.6 in June, September, and October, respectively. The proportions of AQI classes I, II, III, IV, V, and VI in June were 37%, 60%, 3%, 0%, 0%, and 0%; in September, they were 47%, 53%, 0%, 0%, 0%, and 0%; while those in October were 74%, 26%, 0%, 0%, 0%, and 0%, respectively. It can be seen that the average monthly average AQI of the highest three months was 97.7, and was 45.3% higher than the average monthly average AQI of the lowest three months (53.4). During the three months with the highest average AQIs, the average proportions of AQI class I, II, III, IV, V, and VI were 0%, 58.3%, 40.7%, 0%, 0%, and 0% respectively, those were 52.7%, 46.3%, 1.0%, 0%, 0%, and 0% during the three months with the lowest average
Fig. 2. Average monthly distribution of AQI in Chongqing from 2017 to 2019.
Fig. 3. Average monthly distribution of AQI in Luzhou from 2017 to 2019.
AQIs, compared with the three months with the highest average AQI, the combined average proportions of class I and II in the three months with the lowest average AQI increased by 41.1%, and the class III decreased by 97.5%.

As shown in Fig. 4, in Chengdu, the monthly average AQI values in 2017–2019 ranged between 58.1 and 128, and averaged 85.4, and the three months with the highest AQIs in order were 128, 113, and 96.1 in January, December, and February, respectively; the proportions of AQI classes I, II, III, IV, V, and VI in January were 0%, 16%, 61%, 23%, 0%, and 0%, respectively; in December, they were 0%, 29%, 71%, 0%, 0%, and 0%, respectively, and in February, they were 0%, 64%, 32%, 4%, 0%, and 0%, respectively. The three months with the lowest AQIs in order were 76.1, 61.2, and 58.1 in June, October, and September, respectively; the proportions of AQI classes I, II, III, IV, V, and VI in June were 13%, 70%, 17%, 0%, 0%, and 0%; in October, they were 19%, 81%, 0%, 0%, 0%, and 0%; and those in September were 30%, 70%, 0%, 0%, 0%, and 0%, respectively. It can be seen that the average monthly average AQI of the highest three months was 112, which was 42.0% higher than the average monthly average AQI of the lowest three months (65.1). During the three months with the highest average AQIs, the average proportions of AQI class I, II, III, IV, V, and VI were 0%, 36.3%, 54.7%, 9%, 0%, and 0% respectively, those were 20.7%, 73.7%, 5.7%, 0%, 0%, and 0% during the three months with the lowest average AQIs. Compared with the three months with the highest average AQI, the combined average proportions of class I and II in the three months with the lowest average AQI increased by 61.5%, the class III decreased by 89.6%, and the class IV decreased to zero.

According to the above results, in 2017–2019, in Chongqing, the daily AQIs ranged between 27 and 204 and averaged 73.8; in Luzhou, the daily AQIs ranged between 22.7 and 208 and averaged 73.2, and in Chengdu, the daily AQIs ranged between 28.2 and 270 and averaged 85.4. The average AQIs in order were Chengdu (85.4) > Chongqing (73.8) > Luzhou (73.2).

In 2017–2019, in Chongqing, in spring, the daily AQIs ranged between 29 and 145 and averaged 66.6; in summer, those ranged between 30 and 203 and averaged 79.9; in autumn, those ranged between 25 and 132 and averaged 59.9, and in winter, those ranged between 28 and 220 and averaged 88.6. It can be seen that the average AQI was the highest in winter and the lowest was in autumn. In Luzhou, in spring, the daily AQIs ranged between 25 and 165 and averaged 69.3; in summer, those ranged between 24 and 177 and averaged 70.2; in autumn, those ranged between 22 and 134 and averaged 55.6, and in winter, those ranged between 28 and 258 and averaged 97.5. It can be seen that the average AQI was the highest in winter and was the lowest in autumn. In Chengdu, in spring, the daily AQIs ranged between 29 and 182 and averaged 80.3; in summer, those ranged between 28 and 206 and averaged 82.3; in autumn, those ranged between 27 and 170 and averaged 67.9, and in winter, those ranged between 32 and 375 and averaged 113. The seasonal distribution of the highest and lowest average AQIs in Chengdu were consistent with those in Chongqing and Luzhou.

In terms of the combined AQIs for the three cities, in spring, the daily AQIs ranged between 25 and 182 and averaged 72.1; in summer, the daily AQIs ranged between 24 and 206 and averaged 77.5; in autumn, the daily AQIs ranged between 22 and 170 and averaged 61.1, and in winter, the daily AQIs ranged between 28 and 375 and averaged 99.6. The distributions of the six AQI classes, in order, in spring were 3%, 94%, 3%, 0%, 0%, and 0%, respectively; in summer were 11%, 74%, 15%, 0%, 0%, and 0%, respectively; in autumn were 29%, 70%, 1%, 0%, 0%, and 0%, respectively; and those in winter were 1%, 52%, 44%, 3%, 0%, and 0%, respectively. According to the data for the three cities, the average AQI in winter was much higher than in other seasons. This is because the temperature in winter is low, and the atmospheric temperature inversion phenomenon is very dominant, which is not conducive to the dispersion, dilution and diffusion of pollutants in the air, so the average AQI in winter is higher (Xu et al., 2020a, b).

The Top Five Days with the Highest AQIs from 2017 to 2019

Tables 1, 2, and 3 show the top five days with the highest AQIs each year from 2017 to 2019 in Chongqing, Luzhou and Chengdu, and the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$, respectively.

In Table 1, the top five days with the highest AQIs in Chongqing in 2017 were 220, 207, 202, 202 and 202, on January 4, January 3, January 5, December 27, and December 28, respectively. On January 4, 2017, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 171 µg m$^{-3}$, 231 µg m$^{-3}$, 11.2 ppb, 1.36 ppm, 36.5 ppb, respectively, and on December 28, they were 156 µg m$^{-3}$, 229 µg m$^{-3}$, 4.9 ppb, 1.52 ppm, 33.1 ppb, and 9.33 ppb, respectively. The indiatory air pollutant on all of these days was PM$_{2.5}$. The highest AQIs in 2018 were 190, 178, 172, 168, and 163, on January 13, December 19, June 7, January 15, and January 14, respectively. On January 13, 2018, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 143 µg m$^{-3}$, 205 µg m$^{-3}$, 7.35 ppb, 1.12 ppm, 37.5 ppb, and 3.73 ppb, respectively, and on January 14, they were 124 µg m$^{-3}$, 174 µg m$^{-3}$, 5.95 ppb, 1.04 ppm, 35.1 ppb and 21.5 ppb respectively. The indiatory air pollutants on these five days were PM$_{2.5}$, PM$_{10}$, O$_3$, PM$_{2.5}$, and PM$_{10}$, respectively. The highest AQIs in 2019 were 203, 179, 175, 172, and 166, on August 12, August 15, January 26, August 17, and August 16, respectively. On August 12, 2019, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 26 µg m$^{-3}$, 55 µg m$^{-3}$, 2.8 ppb, 0.64 ppm, 21.4 ppb, and 129 ppb, respectively, and on August 16, they were 28 µg m$^{-3}$, 57 µg m$^{-3}$, 3.50 ppb, 0.56 ppm, 21.9 ppb, and 108 ppb, respectively, and the indiatory air pollutants for these five days were O$_3$, O$_3$, PM$_{2.5}$, O$_3$ and O$_3$, respectively. The most common indiatory air pollutant in summer was O$_3$, but, in winter, it was PM$_{2.5}$. Previous studies have shown that atmospheric relative humidity is negatively correlated with O$_3$ concentration and that a lower relative humidity is conducive to the formation of O$_3$ (Kato et al., 2016; Li et al., 2017b; Gong et al., 2018). In summer, low relative humidity and high temperatures and
Fig. 4. Average monthly distribution of AQI in Chengdu from 2017 to 2019.
wind speeds are conducive to the dispersion, diffusion, and dilution of air pollutants. Precursors (VOCs) also promote the formation of O₃. In addition, high temperatures and strong ultraviolet radiation will increase the production rate of O₃ in summer; therefore, the concentration of O₃ in summer is much higher. In winter, a large amount of coal was used, and the exhaust gas from combustion greatly contributed to an increase in the concentration of atmospheric particulate matter. By contrast, the temperature in winter is low, and the inverse temperature phenomenon is prominent, which hinders the dilution and diffusion of pollutants in the air. Therefore, the PM₂.₅ concentration in winter is higher.

In Table 2, for the top five days with the highest AQIs in Luzhou, in 2017, the AQIs were 258, 247, 237, 233, and 224, on January 24, January 4, January 26, December 27, and January 3, respectively. On January 24, 2017, the concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 208 µg m⁻³, 266 µg m⁻³, 8.75 ppb, 0.96 ppm, 21.9 ppb, and 22.4 ppb, respectively, and on January 3, they were 174 µg m⁻³, 236 µg m⁻³, 12.0 ppb, 0.80 ppm, 28.2 ppb, and 5.13 ppb, respectively, where the indicatory air pollutant for all five days was PM₂.₅. The highest AQIs in 2018 were 188, 183, 168, 166, and 165, on January 15, January 13, January 12, December 19, and February 16, respectively. On January 15, 2018, the concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 141 µg m⁻³, 188 µg m⁻³, 11.6 ppb, 0.88 ppm, 27.3 ppb, and 7.93 ppb, respectively, and on February 16, they were 125 µg m⁻³, 171 µg m⁻³, 6.65 ppb, 0.64 ppm, 14.6 ppb, and 42.9 ppb, respectively, where the indicatory air pollutant on all five days was PM₂.₅. The highest AQIs in 2019 were 179, 177, 165, 159, and 156 on January 28, August 17, March 13, January 25, and January 8, respectively. On January 28, 2019, the concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 135 µg m⁻³, 164 µg m⁻³, 3.85 ppb, 0.80 ppm, 22.9 ppb, and 10.3 ppb, respectively, and on January 8, they were 119 µg m⁻³, 147 µg m⁻³, 8.75 ppb, 0.80 ppm, 21.9 ppb, and 9.33 ppb, respectively. The indicatory air pollutants for these five days were PM₂.₅, O₃, PM₂.₅, PM₁₀, and PM₂.₅, respectively. According to an analysis of the observation data for three years in Luzhou, the days with higher AQIs were mainly in winter, particularly in January, and the indicatory air pollutant was mainly PM₂.₅, which is consistent with the findings for Chongqing.

In Table 3, the highest AQIs in Chengdu in 2017 were 375, 308, 294, 274, and 248, on January 5, January 4, January 6, January 26, and January 27, respectively. On January 5, 2017, the concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 313 µg m⁻³, 480 µg m⁻³, 7.00 ppb, 2.24 ppm, 58.9 ppb, and 21.5 ppb, respectively, and on January 27, they were 198 µg m⁻³, 308 µg m⁻³, 4.55 ppb, 1.28 ppm, 25.3 ppb, and 32.2 ppb, respectively. The indicatory air pollutant for all five days was all PM₂.₅. The highest AQIs in 2018 were 251, 207, 206, 205, and 192 on January 15, January 14, February 16, December 20, and December 19, respectively. On January 15, 2018, the concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 201 µg m⁻³, 269 µg m⁻³, 6.65 ppb, 1.28 ppm, 42.9 ppb, and 7.93 ppb, respectively, and on December 19, they were 144 µg m⁻³, 195 µg m⁻³, 2.80 ppb, 0.96 ppm, 33.6 ppb, and 11.2 ppb, respectively. The indicatory air pollutant for all five days was PM₂.₅. The highest AQIs in 2019 were 185, 183, 178, 174, 173, and 173 on six days comprising August 12, December 13, December 11, August 17, December 12, and December 14, respectively. On August 12, 2019, the concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 40 µg m⁻³, 80 µg m⁻³, 2.80 ppb, 0.72 ppm, 26.3 ppb, and 117 ppb, respectively; on December 12, they were 131 µg m⁻³, 167 µg m⁻³, 4.20 ppb, 0.96 ppm, 28.7 ppb, and 9.80 ppb, respectively, and on December 14, they were 131 µg m⁻³, 171 µg m⁻³, 3.50 ppb, 0.96 ppm, 31.7 ppb, and 7.00 ppb, respectively. The indicatory air pollutants on these six days were O₃, PM₂.₅, PM₁₀, O₃, PM₂.₅, and PM₁₀, respectively. According to the analysis of the observation data for three years, in Chengdu, the days with higher AQI occurred mainly in winter, particularly in January and December, where the indicatory air pollutant was mainly PM₂.₅, which was consistent with the findings for both Chongqing and Luzhou.

According to Table 3, in Chongqing, the top five highest AQIs in 2017 occurred mainly in January and December. In 2018, they occurred mainly in January, June, and December,
Table 2. The five days with the highest AQIs in each year in Luzhou in 2017–2019.

| Date       | AQI | PM$_{2.5}$ (µg m$^{-3}$) | PM$_{10}$ (µg m$^{-3}$) | SO$_2$ (ppb) | CO (ppm) | NO$_2$ (ppb) | O$_3$ (ppb) |
|------------|-----|-------------------------|-------------------------|--------------|----------|-------------|-------------|
| Jan. 24, 2017 | 258 | 208                     | 266                     | 8.75         | 0.96     | 21.9        | 22.4        |
| Jan. 4, 2017 | 247 | 200                     | 257                     | 6.8          | 0.56     | 21.9        | 5.13        |
| Jan. 26, 2017 | 237 | 190                     | 243                     | 8.05         | 0.96     | 23.4        | 4.67        |
| Dec. 27, 2017 | 233 | 183                     | 256                     | 9.8          | 1.52     | 40.9        | 4.67        |
| Jan. 3, 2017 | 224 | 174                     | 236                     | 12.0         | 0.80     | 28.2        | 5.13        |
| Jan. 15, 2018 | 188 | 141                     | 188                     | 11.6         | 0.88     | 27.3        | 7.93        |
| Jan. 13, 2018 | 183 | 138                     | 187                     | 14.0         | 0.80     | 27.3        | 7.93        |
| Jan. 12, 2018 | 168 | 127                     | 177                     | 12.0         | 0.80     | 31.7        | 7.47        |
| Dec. 19, 2018 | 166 | 126                     | 149                     | 10.1         | 0.80     | 21.4        | 5.60        |
| Feb. 16, 2018 | 165 | 125                     | 171                     | 6.65         | 0.64     | 14.6        | 42.9        |
| Jan. 28, 2019 | 179 | 135                     | 164                     | 3.85         | 0.80     | 22.9        | 10.3        |
| Aug. 17, 2019 | 177 | 40                      | 67                      | 6.30         | 0.56     | 21.4        | 113         |
| Mar. 13, 2019 | 165 | 125                     | 152                     | 6.65         | 0.80     | 25.8        | 8.40        |
| Jan. 25, 2019 | 159 | 121                     | 147                     | 6.65         | 0.80     | 23.4        | 14.0        |
| Jan. 8, 2019  | 156 | 119                     | 147                     | 8.75         | 0.80     | 21.9        | 9.33        |

Table 3. The five days with the highest AQIs each year in Chengdu in 2017–2019.

| Date       | AQI | PM$_{2.5}$ (µg m$^{-3}$) | PM$_{10}$ (µg m$^{-3}$) | SO$_2$ (ppb) | CO (ppm) | NO$_2$ (ppb) | O$_3$ (ppb) |
|------------|-----|-------------------------|-------------------------|--------------|----------|-------------|-------------|
| Jan. 5, 2017 | 375 | 313                     | 480                     | 7.0          | 2.24     | 58.9        | 21.5        |
| Jan. 4, 2017 | 308 | 258                     | 399                     | 10.2         | 1.92     | 54.5        | 5.13        |
| Jan. 6, 2017 | 294 | 243                     | 360                     | 6.30         | 1.84     | 41.4        | 7.93        |
| Jan. 26, 2017 | 274 | 227                     | 316                     | 4.90         | 1.36     | 34.1        | 20.1        |
| Jan. 27, 2017 | 248 | 198                     | 308                     | 4.55         | 1.28     | 25.3        | 32.2        |
| Jan. 15, 2018 | 251 | 201                     | 269                     | 6.65         | 1.28     | 42.9        | 7.93        |
| Jan. 14, 2018 | 207 | 157                     | 213                     | 6.30         | 1.04     | 37.0        | 35.5        |
| Feb. 16, 2018 | 206 | 156                     | 193                     | 3.85         | 1.04     | 18.0        | 49.5        |
| Dec. 20, 2018 | 205 | 155                     | 207                     | 3.50         | 0.96     | 27.8        | 10.3        |
| Dec. 19, 2018 | 192 | 144                     | 195                     | 2.80         | 0.96     | 33.6        | 11.2        |
| Aug. 12, 2019 | 185 | 40                      | 80                      | 2.80         | 0.72     | 26.3        | 117         |
| Dec. 13, 2019 | 183 | 138                     | 170                     | 3.50         | 0.96     | 27.3        | 7.93        |
| Dec. 11, 2019 | 178 | 134                     | 178                     | 3.15         | 1.04     | 33.1        | 21.0        |
| Aug. 17, 2019 | 174 | 43                      | 80                      | 2.80         | 0.72     | 28.2        | 112         |
| Dec. 12, 2019 | 173 | 131                     | 167                     | 4.20         | 0.96     | 28.7        | 9.80        |
| Dec. 14, 2019 | 173 | 131                     | 171                     | 3.50         | 0.96     | 31.7        | 7.00        |

While in 2019, they were mainly in January and August. In Luzhou, the top five highest AQIs in 2017 occurred mainly in January and December. In 2018, they occurred mainly in January, February, and December, while in 2019, they were mainly in January, March, and August. In Chengdu, the top five highest AQIs in 2017 occurred mainly in January, in 2018, they were mainly in January, February, and December, and in 2019, the top six highest AQIs were mainly in August and December.

Among the 46 days with the highest AQIs over the three years under observation (2017–2019), the distributions were 52.0%, 24.0%, 17.0%, 4.30%, and 2.20% in January, December, August, February, and June, respectively. It can be seen that the highest AQIs occurred mainly in the season with lower temperatures (January, December, and February), which was consistent with the conclusion made earlier that PM$_{2.5}$ was the main indicator air pollutant in January, February, and December due to low temperatures, and O$_3$ was the main air pollutant in June and August due to hot temperatures. In winter, a lower ground temperature will hinder the dispersion of air pollutants and lead to an increase in PM$_{2.5}$ concentrations in the atmosphere (Tang et al., 2017; Xing et al., 2017; Lee et al., 2018; Wang et al., 2018). Under sufficient solar radiation intensity, NO$_2$ acts as the precursor of a photochemical reaction, and first decomposes into NO and O (3P):

$$\text{NO}_2 + \text{hv} (\lambda \leq 430 \text{ nm}) \rightarrow \text{NO} + \text{O} (3\text{P})$$

$$\text{O} (3\text{P}) + \text{O}_2 \rightarrow \text{O}_3$$

$$\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$$

It can be seen that NO$_2$ is one of the important precursors of O$_3$, and NO is a direct reactant with O$_3$. A lower NO$_2$ concentration in the atmosphere will lead to a decrease in the level of NO, which will reduce the possibility of NO reacting with O$_3$, and in turn will lead to an accumulation of O$_3$. Due to strong solar radiation and a dominant photochemical reaction, summer is more suitable for the accumulation of O$_3$. Therefore, O$_3$ concentrations in summer are much higher. The average AQIs during the 15 days with highest

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AQIs were 187, 194, and 227 in Chongqing, Luzhou, and Chengdu, respectively. These results indicate that Chengdu had the highest average AQI during the observation period, and thus more attention should be paid to improving the air quality in this city.

It can be seen that the average AQIs in Chengdu (227) were far greater than the average AQI values in Chongqing and Luzhou, while the results in Chongqing (187) and Luzhou (194) were very close. It can be concluded that the air quality in Chengdu was the worst, and the air quality in Chongqing and Luzhou were, in order, the second and the third. This result is consistent with conclusions drawn above.

In Chongqing, the average AQI values for the highest five days were 207, 174, and 179 in 2017, 2018, and 2019, respectively; in Luzhou, they were 240, 174, and 167, and in Chengdu, they were 300, 212 and 178 in 2017, 2018 and 2019, respectively. It can be seen that in Chongqing, the air quality was the worst in 2017, followed by 2019, and was the best in 2018; in Luzhou, the air quality was the worst in 2017, followed by 2018, and was the best in 2019; in Chengdu, the air quality was the worst in 2017, followed by 2018, and was the best in 2019. From 2017 to 2019, in general, the air quality of the three cities were all improved.

**Impact of the COVID-19 Event on Air Quality**

Figs. 2, 3, and 4 show the average monthly AQI distribution for Chongqing, Luzhou and Chengdu in January and February 2017–2019 during the non-epidemic period, respectively, and Fig. 5 shows the monthly AQI distribution in Chongqing, Luzhou and Chengdu in January and February 2020 for the epidemic prevention and control period.

As shown in Figs. 2 and 5, in Chongqing, the proportion of classes I, II, III, IV, V, and VI with the average AQI from January 2017–2019 were 0%, 42%, 58%, 0%, 0%, and 0%, respectively, and those in January 2020, were 19%, 74%, 7%, 0%, 0%, and 0% respectively. It can be seen that compared with the average AQI from January 2017–2019, the proportion of Class I in January 2020 increased to 19.0%; that of Class II increased to 74.0%, and that of Class III decreased to 7.00%. In addition, the average AQI in January 2020 was 69.8, which was 35.7% lower than that in 2017–2019 (AQI = 98.8). In February 2017–2019, in Chongqing, the proportion of classes I, II, III, IV, V, and VI with the average AQI was 7%, 82%, 11%, 0%, 0%, and 0% respectively, and in February 2020, the proportion of classes I, II, III, IV, V, and VI with the average AQI was 21%, 65%, 14%, 0%, 0%, and 0%, respectively. It can be seen that compared with the average AQI in February 2017–2019, Class I in February 2020 increased to 21.0%, and Class II decreased to 65.0%. The average AQI in February 2020 was 68.8, which was 11.5% lower than that from 2017–2019 (AQI=77.2). It can be seen that the air quality in January and February 2020 (during the epidemic prevention and control period) improved significantly compared with January and February 2017–2019 (the non-epidemic period).

As shown in Figs. 3 and 5, in Luzhou, the proportion of classes I, II, III, IV, V and VI with the average AQI in January 2017–2019 was 0%, 23%, 74%, 3%, 0%, and 0%, respectively, and these classes in January 2020, were 10%, 61%, 29%, 0%, 0%, and 0%, respectively. It can be seen that compared with the average AQI in January 2017–2019, the AQI Class I in January 2020 increased to 10.0%; Class II increased to 61.0%; Class III decreased to 29.0%, and Class IV decreased to zero. The average AQI in January 2020 was 87.0, which was 27.4% lower than that in the period 2017–2019 (AQI = 115). In February 2017–2019, the proportions of classes I, II, III, IV, V, and VI were 0%, 75%, 25%, 0%, 0%, and 0%, respectively, and those in February 2020, were 7%, 62%, 31%, 0%, 0% and 0%, respectively. It can be seen that compared with the average AQI in February 2017–2019, AQI Class I in February 2020 increased to 7.00%, and AQI Class II decreased to 62.0%. The average AQI in February 2020 was 83.5, which was 6.50% lower than that in the period 2017–2019 (AQI=89.1). It can be seen that the air quality in January and February 2020 (during the epidemic prevention and control period) improved significantly compared with January and February 2017–2019 (the non-epidemic period).

As shown in Figs. 4 and 5, in Chengdu, the proportion of classes I, II, III, IV, V, and VI with the average AQI in January 2017–2019 was 0%, 16%, 61%, 23%, 0%, and 0%, respectively, and the proportion of classes I, II, III, IV, V and VI with the average AQI in January 2020 was 0%, 58%, 39%, 3%, 0%, and 0%, respectively. It can be seen that compared with the average AQI in January 2017–2019, the proportion of AQI Class II in January 2020 increased to 58.0%, and that of Class III decreased to 39.0%. The average AQI in January 2020 was 92.9, which was 32.0% lower than that from 2017–2019 (AQI=128). In Chengdu, the proportion of classes I, II, III, IV, V, and VI with the average AQI in February 2017–2019 was 0%, 64%, 32%, 4%, 0%, and 0%, respectively, and the proportion in February 2020 was 17%, 59%, 24%, 0%, 0%, and 0%, respectively. It can be seen that compared with the average AQI in January 2017–2019, AQI Class I in February 2020 increased to 17.0%; Class II decreased to 59.0%; Class III decreased to 24.0%, and Class IV decreased to zero. The average AQI in February 2020 was 74.7, which was 25.0% lower than that during the period from 2017–2019 (AQI=96.0). It can be seen that the AQI in January and February 2020 (during the epidemic prevention and control period) decreased significantly compared with January and February 2017–2019 (during the non-epidemic period).

According to the above analysis, for the three cities, the combined AQI in February 2020 was 79.4, which was 23.6% lower than that in the period from 2017–2019 (AQI = 101). These results indicated that the prevention and control measures for COVID-19 greatly restricted the movement of people, transportation, engineering construction, industrial production and commercial trading activities Therefore, the stationary emissions, automobile exhaust, and fugitive emissions were also been greatly reduced, so the air quality was significantly improved.

**The Five Days with the Highest AQIs in February 2017–2020**

Tables 4–6 shows the top five days with the highest AQIs in Chongqing, Luzhou and Chengdu in February 2017–2020.

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As shown in Table 4, in Chongqing, the highest AQIs in February 2017 were 164, 162, 149, 130, and 129 on February 15, February 14, February 18, February 17, and February 19, respectively. On February 15, 2017, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 126 µg m$^{-3}$, 169 µg m$^{-3}$, 6.30 ppb, 1.28 ppm, 34.1 ppb, and 20.1 ppb, respectively, and on February 19, they were 98 µg m$^{-3}$, 131 µg m$^{-3}$, 4.20 ppb, 1.04 ppm, 23.9 ppb, and 38.3 ppb respectively. The indicatory air pollutant on five days was PM$_{2.5}$.

The highest AQIs in February 2018 in Chongqing were 156, 134, 125, 119, and 112 on February 16, February 7, February 17, February 8 and February 2, respectively. On February 16, 2018, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 119 µg m$^{-3}$, 150 µg m$^{-3}$, 3.50 ppb, 0.96 ppm, 13.6 ppb, and 24.4 ppb, respectively, and on February 2, those were 84 µg m$^{-3}$, 128 µg m$^{-3}$, 4.90 ppb, 0.88 ppm, 26.8 ppb, and 22.4 ppb, respectively. The indicatory air pollutant for all five days was PM$_{2.5}$.

In Chongqing, the highest AQIs in February 2019 were 113, 103, 97, 88, and 88 on February 21, February 7, February 22, February 5, and February 20, respectively. On February 16, 2019, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 85 µg m$^{-3}$, 115 µg m$^{-3}$, 3.50 ppb, 0.88 ppm, 24.4 ppb, and 28.0 ppb, respectively, and on February 20, they were 65 µg m$^{-3}$, 92 µg m$^{-3}$, 2.80 ppb, 0.80 ppm, 22.4 ppb, and 24.3 ppb, respectively. The indicatory air pollutant for all five days was PM$_{2.5}$.

The highest AQIs in February 2020 in Chongqing were 113, 113, 105, 102, and 93 on February 19, February 21, February 23, February 14 and February 20, respectively. On February 16, 2020, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 85 µg m$^{-3}$, 104 µg m$^{-3}$, 2.10 ppb, 0.64 ppm, 11.2 ppb, and 35.5 ppb, respectively, and on February 20, they were 69 µg m$^{-3}$, 85 µg m$^{-3}$, 2.10 ppb, 0.56 ppm, 12.7 ppb, and 21.5 ppb, respectively. The indicatory air pollutant on all five days was all PM$_{2.5}$.

The above results indicated that in Chongqing, the average value on the 15 days with the highest AQI in February 2017–2019 (non-epidemic period) was 125, and the corresponding

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**Fig. 5.** AQI distribution in January and February 2020 in Chongqing, Luzhou and Chengdu.
average concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 94.7 µg m$^{-3}$, 129 µg m$^{-3}$, 5.00 ppb, 0.95 ppm, 24.1 ppb, and 25.6 ppb respectively. The average AQI on the five days with the highest AQI in February 2020 (the epidemic prevention and control period) was 105, and the corresponding average concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 78.8 µg m$^{-3}$, 97.2 µg m$^{-3}$, 2.17 ppb, 0.66 ppb, 12.5 ppb, and 24.8 ppb, and were 18.4%, 27.8%, 78.8%, 37.1%, 63.6%, and 3.00%, lower than those in the period from 2017–2019, respectively. In Table 4, the average AQI in 2020 was 105, which was 16.9% lower than that in the period from 2017–2019 (AQI = 125). Compared with the non-epidemic control period, the air quality in the epidemic prevention and control period was improved significantly.

As shown in Table 5, in Luzhou, the highest AQIs in February 2017 were 177, 170, 168, 162, and 161 on February 18, February 16, February 20, February 14, and February 15, respectively. On February 18, 2017, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 139 µg m$^{-3}$, 188 µg m$^{-3}$, 13.3 ppb, 0.72 ppm, 24.4 ppb, and 30.8 ppb, respectively, and on February 15, they were 122 µg m$^{-3}$, 165 µg m$^{-3}$, 11.2 ppb, 0.56 ppm, 23.9 ppb, and 35.5 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$.

The highest AQIs in February 2018 in Luzhou were 165, 148, 139, 134, and 122 on February 16, February 15, February 7, February 9, and February 17, respectively. On February 16, 2018, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 125 µg m$^{-3}$, 171 µg m$^{-3}$, 6.65 ppb, 0.64 ppm, 14.6 ppb, and 42.9 ppb, respectively, and on February 17, they were 92 µg m$^{-3}$, 125 µg m$^{-3}$, 7.00 ppb, 0.80 ppm, 17.0 ppb, and 31.3 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$.

In Luzhou, the highest AQIs in February 2019 were 142, 120, 115, 105, and 105 on February 5, February 22, February 23, February 6, and February 7, respectively. On February 5, 2019, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 108 µg m$^{-3}$, 133 µg m$^{-3}$, 5.60 ppb, 0.72 ppm, 12.7 ppb, and 42.9 ppb, respectively, and on February 7, they were 79 µg m$^{-3}$, 95 µg m$^{-3}$, 4.90 ppb, 0.72 ppm, 13.2 ppb, and 46.2 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$.

The highest AQIs in February 2020 in Luzhou were 150, 134, 133, 129, and 113 on February 22, February 13, February 18, February 14, and February 20, respectively. On February 22, 2020, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 115 µg m$^{-3}$, 127 µg m$^{-3}$, 2.45 ppb, 0.80 ppm, 9.74 ppb, and 18.2 ppb, respectively, and on February 20, they were 85 µg m$^{-3}$, 94 µg m$^{-3}$, 1.75 ppb, 0.72 ppm, 7.79 ppb, and 26.1 ppb respectively. The indicative air pollutant on all five days was PM$_{2.5}$.

According to the above data, it can be seen that in Luzhou, the average AQI on the 15 days with the highest AQI in February 2017–2019 (non-epidemic period) was 142, and the corresponding average concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 108 µg m$^{-3}$, 133 µg m$^{-3}$, 5.60 ppb, 0.72 ppm, 12.7 ppb, and 42.9 ppb, respectively, and on February 7, they were 79 µg m$^{-3}$, 95 µg m$^{-3}$, 4.90 ppb, 0.72 ppm, 13.2 ppb, and 46.2 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$.

As shown in Table 6, in Chengdu, the highest AQIs in February 2017 were 213, 207, 190, 165, and 164, on February 18, 2017, respectively. On February 18, 2017, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 225 µg m$^{-3}$, 295 µg m$^{-3}$, 10.00 ppb, 2.24 ppm, 32.8 ppb, and 57.6 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$. The highest AQIs in February 2018 in Chengdu were 190, 165, 164, 161, and 160 on February 16, February 15, February 7, February 9, and February 17, respectively. On February 16, 2018, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 125 µg m$^{-3}$, 171 µg m$^{-3}$, 6.65 ppb, 0.64 ppm, 14.6 ppb, and 42.9 ppb, respectively, and on February 17, they were 92 µg m$^{-3}$, 125 µg m$^{-3}$, 7.00 ppb, 0.80 ppm, 17.0 ppb, and 31.3 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$.

In Chengdu, the highest AQIs in February 2019 were 142, 120, 115, 105, and 105 on February 5, February 22, February 23, and February 6, and February 7, respectively. On February 5, 2019, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 108 µg m$^{-3}$, 133 µg m$^{-3}$, 5.60 ppb, 0.72 ppm, 12.7 ppb, and 42.9 ppb, respectively, and on February 7, they were 79 µg m$^{-3}$, 95 µg m$^{-3}$, 4.90 ppb, 0.72 ppm, 13.2 ppb, and 46.2 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$.

The highest AQIs in February 2020 in Chengdu were 165, 148, 139, 134, and 122 on February 16, February 15, February 7, February 9, and February 17, respectively. On February 16, 2020, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 125 µg m$^{-3}$, 171 µg m$^{-3}$, 6.65 ppb, 0.64 ppm, 14.6 ppb, and 42.9 ppb, respectively, and on February 17, they were 92 µg m$^{-3}$, 125 µg m$^{-3}$, 7.00 ppb, 0.80 ppm, 17.0 ppb, and 31.3 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$. The highest AQIs in February 2020 in Chengdu were 190, 165, 164, 161, and 160 on February 16, February 15, February 7, February 9, and February 17, respectively. On February 16, 2020, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 125 µg m$^{-3}$, 171 µg m$^{-3}$, 6.65 ppb, 0.64 ppm, 14.6 ppb, and 42.9 ppb, respectively, and on February 17, they were 92 µg m$^{-3}$, 125 µg m$^{-3}$, 7.00 ppb, 0.80 ppm, 17.0 ppb, and 31.3 ppb, respectively. The indicative air pollutant on all five days was PM$_{2.5}$.
respectively. The indicatory air pollutant for all five days was PM$_{2.5}$.

The highest AQIs in February 2018 in Chengdu were 163, 104, 2.45 ppb, 0.80 ppm, and on February 8, they were 104 µg m$^{-3}$, 125 µg m$^{-3}$, 17.0 µg m$^{-3}$, 9.25 µg m$^{-3}$, and 14.2 µg m$^{-3}$, respectively. On February 22, 2020, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 156 µg m$^{-3}$, 193 µg m$^{-3}$, 3.85 µg m$^{-3}$, 2.80 µg m$^{-3}$, 3.15 µg m$^{-3}$, and 2.10 µg m$^{-3}$, respectively. On February 14, 2020, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 104 µg m$^{-3}$, 140 µg m$^{-3}$, 3.50 µg m$^{-3}$, 0.72 ppm, and on February 8, they were 109 µg m$^{-3}$, 132 µg m$^{-3}$, 2.45 ppb, 0.80 ppm, and 23.9 ppb, respectively. The indicator air pollutant for all five days was PM$_{2.5}$.

The highest AQIs in February 2018 in Chengdu were 206, 160, 159, 147, and 143 on February 16, February 14, February 7, February 15, and February 8, respectively. On February 16, 2018, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 156 µg m$^{-3}$, 193 µg m$^{-3}$, 3.85 ppb, 1.04 ppm, 18.0 ppb, and 49.5 ppb, respectively, and on February 8, they were 109 µg m$^{-3}$, 132 µg m$^{-3}$, 2.45 ppb, 0.80 ppm, 23.9 ppb, and 24.7 ppb, respectively. The indicator air pollutant on all five days was PM$_{2.5}$.

The highest AQIs in February 2019 in Chengdu were 137, 120, 122, 108, and 105 on February 5, February 22, February 6, February 23 and February 2, respectively. On February 5, 2019, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 104 µg m$^{-3}$, 140 µg m$^{-3}$, 3.50 ppb, 0.72 ppm, 26.8 µg m$^{-3}$, and 14.5 µg m$^{-3}$, respectively. On February 13, 2019, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 156 µg m$^{-3}$, 120 µg m$^{-3}$, 2.80 µg m$^{-3}$, 2.10 µg m$^{-3}$, 3.50 µg m$^{-3}$, and 0.72 ppm, respectively.

The highest AQIs in February 2020 in Chengdu were 125, 122, 97, and 80 on February 14, February 15, and February 8, respectively. On February 13, 2020, the concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, NO$_2$, and O$_3$ were 156 µg m$^{-3}$, 120 µg m$^{-3}$, 2.80 µg m$^{-3}$, 2.10 µg m$^{-3}$, 3.50 µg m$^{-3}$, and 0.72 ppm, respectively.
17.5 ppb, and 51.8 ppb, respectively, and on February 2, they were 79 µg m⁻³, 98 µg m⁻³, 2.10 ppb, 0.80 ppm, 17.5 ppb, and 15.9 ppb respectively. The indicative air pollutant for all five days was PM₂.₅.

In Chengdu, the highest AQIs in February 2020 were 138, 115, 114, 113, and 110 on February 27, February 13, February 26, February 12, and February 24, respectively. On February 27, 2020, the concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 105 µg m⁻³, 125 µg m⁻³, 2.10 ppb, 0.80 ppm, 16.6 ppb, and 25.2 ppb, respectively, and on February 24, they were 83 µg m⁻³, 108 µg m⁻³, 2.45 ppb, 0.64 ppm, 18.5 ppb, and 44.3 ppb, respectively. The indicative air pollutant on all five days was PM₂.₅.

According to the above data, the average of the 15 days with the highest AQI in February from 2017 to 2019 (the epidemic prevention and control period) was 118, and the corresponding average concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 118.1 µg m⁻³, 162 µg m⁻³, 4.22 ppb, 0.99 ppm, 27.9 ppb, and 32.3 ppb, respectively. The average of the top five days with the highest AQI in February 2020 (the epidemic prevention and control period) was 118, and the corresponding average concentrations of PM₂.₅, PM₁₀, SO₂, CO, NO₂, and O₃ were 89.2 µg m⁻³, 108 µg m⁻³, 2.38 ppb, 0.74 ppm, 15.7 ppb, and 40.5 ppb, which were 27.9%, 40.2%, 55.8%, 29.6%, 55.9%, and -22.5% lower than those in the period from 2017–2019, respectively. In Table 6, the average AQI in 2020 was 118, which was 27.6% lower than that in the period from 2017–2019 (AQI = 155.7). Compared with the non-epidemic period, during the epidemic prevention and control period, the air quality was improved significantly.

In the combined results of three cities, during the 5 days with the highest AQI during the epidemic prevention and control action period (February 2020), the average concentrations of PM₂.₅, PM₁₀, SO₂, CO, and NO₂ were 89.4 µg m⁻³, 106 µg m⁻³, 2.31 ppb, 0.72 ppm, and 12.3 ppb, and which were 17.9%, 30.8%, 83.8%, 19.8%, and 62.1%, lower than those in February 2017–2019, respectively. However, the average O₃ concentration (31.8 ppb) in February 2020 did not show a significant decrease, but rather increased by 6.2%. This decrease in the average concentration of PM₂.₅, PM₁₀, SO₂, CO, and NO₂ was attributed to the “lockdown” of the cities during the epidemic prevention and control action period (2020). The O₃ concentration increased because a lower NO₂ concentration hindered the NO + O₃ reaction and resulted in an accumulation of O₃ in the air.

### The Wind Streamline and Wind Speed

During this period, the airflow pathway is usually affected by Siberia High (Siberia Anticyclone). Fig. 6 shows the distribution of monthly average near-surface streamlines in Chongqing Municipality and Sichuan Province (including Chengdu and Luzhou City) from January to March in 2019 and 2020, respectively.

Fig. 7 shows the distribution of the monthly average near-surface wind speed in the same regions. The results indicated that the monthly average wind speed in this region from January to March of 2019 was generally higher than the same period in 2020, and the monthly average wind speed in February 2019 was significantly higher than that in January and March of 2019 (about 0.5 m s⁻¹ higher). From January to March of 2020, the monthly average wind speed in March was just slightly higher than that in January and

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**Fig. 6.** The wind streamline at Chongqing Municipality and Sichuan Province, China, during January to March in 2019–2020.
February of 2020, and the difference between these three months was not obvious. In terms of geographical distribution, Chongqing Municipality is located on the east side of Sichuan province; Luzhou City is located on the southeast corner of Sichuan Province close to the southwest side of Chongqing Municipality, and Chengdu City is located east of the center of Sichuan Province. Due to the influence of the terrain, western Sichuan Province (relatively higher terrain) experiences relatively stronger wind speed compared to Chongqing, Chengdu, and Luzhou (relative lower terrain) in which the monthly average wind speed was below 2.5 m s\(^{-1}\) in 2019 and even less than 2.0 m s\(^{-1}\) in 2020. According to the distribution of the monthly average streamlines, based on the places where the confluences of streamlines generally have lower wind speed, these three cities are located in lower wind speed regions. In Chongqing, from January to March, the prevailing winds in the southeastern corner are usually southeasterly (SE) to easterly (E) wind, while the prevailing winds in the northern corner (relatively upwind) and southwestern corners (relatively downwind) are usually northeasterly (NE) to east-northeasterly (ENE), and the wind speed is usually lower at the streamline confluence where air pollution is easily accumulated. The prevailing wind in Luzhou from January to March is northerly (N). Luzhou is located downwind of Chongqing, which it means that the air pollutants from Chongqing were easily transported and passes through Luzhou in a northerly to southerly direction with the air flow. Between Chengdu (west side) and Chongqing and Luzhou (east side), there is a banded wind zone with relatively stronger wind speed from January to March, and the wind direction is generally northeasterly to northerly. In Chengdu, the western corner is affected by a relatively stronger wind zone as mentioned above. The prevailing winds are northeasterly to easterly, so it is not as easy for this banded zone to accumulate air pollutants as it is in the surrounding regions. In other parts of Chengdu, the wind direction is generally more chaotic, resulting in relatively lower wind speed, but it tends toward a northerly wind. Because of this lower wind speed, it is relatively easy for Chengdu to accumulate air pollutants. Generally speaking, because it is affected by Siberia High (Siberia Anticyclone) during the winter, the airflow transport in Chongqing Municipality and the eastern half of Sichuan Province (including Chengdu and Luzhou City) from January to March is dominated by a weaker northeasterly wind (entering from the northeast and leaving from the southwest), and the monthly average wind speed is less than 2.5 m s\(^{-1}\). The wind streamline and wind speed data provide insights into the air transport of pollutants and their effects on the surrounding environment.

CONCLUSIONS

1. In 2017–2019, in Chongqing, the daily AQIs ranged between 27 and 204 and averaged 73.8; in Luzhou, the daily AQIs ranged between 22.7 and 208 and averaged 73.2; while in Chengdu, the daily AQIs ranged between 28.2 and 270 and averaged 85.4. The average AQIs, in order, were Chengdu (85.4) > Chongqing (73.8) > Luzhou (73.2).

2. For the combined AQIs for the three cities, in 2017–2019 in spring, the daily AQIs ranged between 25 and 182 and averaged 72.1; in summer, the daily AQIs ranged between 24 and 206 and averaged 77.5; in autumn, the daily AQIs ranged between 22 and 170 and averaged 61.1, and in winter, the daily AQIs ranged between 28 and 375 and averaged 99.6. The distributions
of the six AQI classes in spring were 3%, 94%, 3%, 0%, and 0%, respectively; those in summer were 11%, 74%, 15%, 0%, 0%, and 0%, respectively; those in autumn were 29%, 70%, 1%, 0%, 0%, and 0%, respectively, and those in winter were 1%, 52%, 44%, 3%, 0%, and 0%, respectively. The average AQI in winter was much higher than in the other seasons. This is because the temperature in winter is low, and the atmospheric temperature inversion phenomenon is prominent, which is not conducive to the dispersion and dilution of pollutants in the air, so the average AQI in winter tends to be higher.

3. In Chongqing, the average AQI values on the highest 5 days were 207, 174, and 179 in 2017, 2018, and 2019, respectively; in Luzhou, they were 240, 174, and 167; in Chengdu, those were 300, 212, and 178, in 2017, 2018, and 2019, respectively. It can be seen that in Chongqing, the air quality was the worst in 2017, followed by 2019, and was the best in 2018; in Luzhou, the air quality was the worst in 2017, followed by 2018, and was the best in 2019; in Chengdu, the air quality was the worst in 2017, followed by 2018, and was the best in 2019. From 2017 to 2019, in general, the air quality improved on an annual basis.

4. For the three cities, the combined AQI in February 2020 was 79.4, which was 23.6% lower than that in the period from 2017–2019 (AQI=101). These results indicated that the prevention and control measures for COVID-19 greatly restricted the movements of people, transportation, engineering construction, industrial production, and commercial trading activity. Therefore, stationary emissions, automobile exhaust, and fugitive emissions were also greatly reduced, so the air quality was significantly improved.

5. The combined results for the three cities on the 5 days with the highest AQIs during the epidemic prevention and control action period (February 2020) reveal, the average concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, and NO$_2$ of 89.4 µg m$^{-3}$, 106 µg m$^{-3}$, 2.31 ppb, 0.72 ppm, and 12.3 ppm, which were 17.9%, 30.8%, 83.8%, 19.8%, and 62.1%, lower than those in February 2017–2019, respectively. However, the average O$_3$ concentration (31.8 ppb) in February 2020 did not show a significant decrease, but rather increased by 6.2%. The decrease in the average concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO, and NO$_2$ was attributed to the "lockdown" of the cities during the epidemic prevention and control action period (February 2020). An increase in the O$_3$ concentration was because a lower NO$_2$ concentration hindered the NO + O$_3$ reaction and resulted in an accumulation of O$_3$ in the air.

6. In general, due to effects of the Siberia High (Siberia Anticyclone) during winter, the airflow transport features in Chongqing Municipality and the eastern half of Sichuan Province (including Chengdu and Luzhou City) from January to March was dominated by a weaker northeasterly wind (entering from the northeast and leaving from the southwest), and the monthly average wind speed was below 2.5 m s$^{-1}$. The wind streamline and wind speed data provides insights into the air transport of pollutants and their effects on the air quality in the surrounding environment.

7. This study provides useful information for the development of air pollution control strategies and adds to the body of research on this topic in the literature.

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