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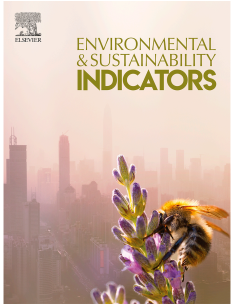

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Surface water quality in the upstream-most megacity of the Yangtze River Basin (Chengdu): 2000-2019 trends, the COVID-19 lockdown effects, and water governance implications

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Surface water quality in the upstream-most megacity of the Yangtze River Basin (Chengdu): 2000-2019 trends, the COVID-19 lockdown effects, and water governance implications

Abstract: Water is essential for a sustainable economic prosperity, but rapid economic growth and intensive agricultural activities usually cause water pollution. The middle and lower reaches of China’s Yangtze River Basin were urbanized and industrialized much earlier than the upper reach and have been suffering from water pollution. In the past two decades, economic growth accelerated in the upper reach due to several national economic initiatives. Based on analyzing water quality changes from 2000 to 2019 and during the COVID-19 lockdown in 2020 for Chengdu in the upper reach, we hope to provide some water governance suggestions. In 2019, water at 66% of 93 sites in Chengdu did not achieve the national III standards using measurements of 23 water quality parameters. The top two pollutants were total nitrogen (TN) and fecal coliform (FC). From 2000 to 2019, water quality was not significantly improved at the non-background sites of Chengdu's Min Basin, and the pollution in this basin was mainly from local pollutants release. During the same period, water quality deteriorated in Chengdu’s Tuo Basin, where pollution was the result of pollutant discharges in Chengdu in addition to inter-city pollutant transport. During the COVID-19 lockdown, water quality generally improved in the Min Basin but not in the Tuo Basin. A further investigation on which pollution sources were shut down or not during the lockdown can help make pollution reduction targets. Based on the results, we provide suggestions to strengthen inter-jurisdictional and inter-institutional cooperation, water quality monitoring and evaluation, and ecological engineering application.

Keywords: water quality index; nitrogen; phosphorus; fecal coliforms; water quality management

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1. Introduction

Water is essential for a sustainable economic prosperity. Many of the world's economic centers and agricultural bases are close to rivers. However, urbanization, industrialization, and intensive agricultural activities require large water quantity and usually cause water pollution. Balancing economic development and water resources protection is one of the key challenges for a sustainable development across the world, particularly the developing countries.

The Yangtze River Economic Belt Initiative (YREBI) is a major engine promoting China's economic development started from 2015 (Sun et al., 2018). As the world's third longest river (6,300 km), having a basin area of 1.78 million km^2, and covering 19 regions at the provincial level, the Yangtze River Basin passes from less to more economic-developed areas from the upstream to downstream (Lijuan et al., 2018; Figures 1a and S1). The river originates on the Qinghai-Tibetan Plateau in West China, where anthropogenic activities are low. In contrast, the downstream Yangtze River Delta in East China is one of the most economically-developed regions in the country. To better protect the basin's ecosystems and environment under the YREBI's implementation, the Standing Committee of China's National People's Congress (SCCNPC) approved the Yangtze River Protection Law in December 2020 (SCCNPC, 2020).

Water pollution is widespread throughout the Yangtze River Basin, and smaller tributaries have more serious water pollution because of their limited flows and closer locations to pollution sources (Chen et al., 2017). The major water pollution problems and their causes have some differences among the headwater, upper, middle, and lower reaches of the basin due to the differences in economic-development stages, natural resource exploitation patterns, climate, vegetation, and geology. In the headwaters, the major water-related problems are soil erosion associated with low vegetation cover and increased discharge triggered by climate warming-accelerated snow-melting (Chen et al., 2017). The upper reach, which is upstream the Yichang city (Figure S1), is heavily affected by hydropower dams, which increases water pollution through altering hydrology (Chen et al., 2017), and characterized by severe soil erosion due to intensive agricultural and other anthropogenic activities. In the middle reach from Yichang to Hukou, the major water pollution problems are related to sand mining, as well as river channel modifications by dams for irrigation and for transportation purposes (Chen et al., 2017). The lower reach, with the highest rates of urbanization, industrialization, channelization, and river bank construction, receives widespread chemical pollution (Chen et al., 2017). As rapid economic growth in the upper and middle reaches owing to the YREBI and other national economic development strategies for West China continues, there is a concern that chemical water pollution may worsen in the upper and middle reaches, thus affected their downstream regions (Chen et al., 2017; Luo et al., 2019; She et al., 2019).

Chengdu Municipality is the upstream-most megacity in the Yangtze River Basin and is one of the transportations, education, and economic centers of West China (Figure 1a). The flourishing of Chengdu Municipality and its Chengdu Plain began with water management through the Dujiangyan (DJY) Irrigation System built in 256 BC. Downstream of the irrigation system, rivers spread out across the Chengdu Plain, which has intensive agricultural activities (Figures 1 and S2). There are two river basins in Chengdu, namely the Min and Tuo Basins (Figure 1).

Anthropogenic pollution is low upstream the Min Basin, while the Tuo Basin is largely affected by pollutants from upstream cities (see section 4.1).

There is a saying about Chengdu’s urban water environment, "the water of Jin River in urban Chengdu could be used for cooking in the 1950s, water quality started to deteriorate in the 1960s, there have been no fish and shrimp since the 1970s, and water quality was so bad that the water could be used only for washing chamber pots since the 1980s". The public started to call for water pollution control in the 1980s; since then, a series of strategies, measures, and regulations have been implemented. The most well-known strategy is the Fu & Nan Rivers Restoration Project implemented mostly within and around the central urban areas between 1992 and 2002, and this project greatly reduced water pollution in urban Chengdu (World Wildlife Fund (WWF), 2012; Xia and Liu, 2001). In 2015, the State Council of China (SCC) issued the Water Pollution Prevention Action Plan, which is the most comprehensive and systematic policy up to date for improving water quality. In contrast, economic growth and urbanization accelerated in Chengdu since 2000s, and this should increase water pollutant generation. Therefore, there is a need to understand water quality change and its driving forces in both urban and rural Chengdu since early 2000s, particularly 2015.

The COVID-19 lockdown in 2020 was an opportunity to investigate if the reduced anthropogenic discharges can quickly improve water quality in Chengdu and explore which pollutant sources have larger effects on water quality. Water quality was obviously improved in many other rivers across the world during the pandemic lockdown, including canals in Venice (Saadat et al., 2020), the Yamuna River in India (Arif et al., 2020), and a site of the Yangtze River in China (Wang and Su, 2020). The officially-required 25-day lockdown in Chengdu was from 24

January to 17 February 2020, which included the seven-day Spring Festival Holiday, the most important Chinese national holiday. After 17 February, many economic and educational activities still were reduced or not allowed to reopen, leading to a hypothesized continued decreased release of water pollutants in Chengdu.

Therefore, this study's major objectives were to investigate Chengdu’s water quality changes during 2000-2019 and the COVID-19 lockdown. Also, we reviewed the water governance in China and Chengdu. Based on the investigation and review, we hope to provide some insights to water governance for not just Chengdu but also other river basins, which are experiencing rapid economic growth and/or intensive agricultural activities.

2. Materials and Methods

2.1. Study area

Chengdu Municipality is in the Sichuan Basin of southwestern China and covers 14,335 km^2 (Chengdu Bureau of Statistics (CBS), 2019). The spatial distributions of land uses in 2000 and 2018 are shown in Figure S2. In western Chengdu are the mountains of the eastern rim of the Qinghai-Tibetan Plateau, including the Qionglai and Longmen mountain ranges. Chengdu’s central urban areas and most of the agricultural regions are in the Chengdu Plain, which is bordered on the west by the Qionglai and Longmen mountain ranges and on the east by the Longquan and Penzhong hills. The plain has elevations of 450-750 meters and is tilted from northwest to southeast. Thus, river water generally flows from northwest to southeast and eventually drains into the Yangtze River. Chengdu has a mean annual total surface runoff of 7.96 billion m^3, and the river systems fall into two basins, the Min and Tuo Basins (Xue et al., 2018; Figure 1). The DJY Irrigation

System, built to irrigate farmland and prevent floods in the Chengdu Plain, is part of the Min Basin. Thus, the Min Basin's river network is heavily artificially modified.

Chengdu experienced rapid economic growth in the past two decades. From 2000 to 2018, the city's gross domestic product (GDP), built-up urban areas, and population increased from RMB 115.7 to 1,534.3 billion Yuan (roughly from US$ 17.1 to 234.4 billion), from 207.8 to 407.3 km^2, and from 10.13 to 14.76 million, respectively (CBS, 2019).

Water pollutant discharges and chemical fertilizer uses varied between 2000 and 2018 (Figure S3). From 2015 to 2018, total discharge of sewage, chemical oxygen demand (COD), and ammonia nitrogen (NH_3-N) from industries and residential activities increased by 32%, 7%, and 5%, respectively (Figure S3a-c). The increased quantities of sewage, COD, and NH_3-N were due to the increases from urban residential activities, which accounted for 92%, 83%, and 88% of the total quantities in 2018, respectively. In contrast, the quantities of sewage, COD, and NH_3-N from industries presented a decreasing trend from 2015 to 2018. The total use of chemical fertilizers decreased by ~28% from 2000 to 2015 and then increased by ~16% from 2015 to 2018. The increase from 2015 to 2018 was probably because Jianyang city (1.17 million population and 2,214 km^2) was incorporated administratively into Chengdu in 2016.

Chengdu's capability to control pollution is enhanced. From 2009 to 2018, total sewage conduit, number of sewage treatment plants, daily treatment capacity of sewage plants, annual total quantity of treated sewage all increased from 1771 to 5328 km, 6 to 28, 1.49 to 2.94 million m^3 per day, and 404 to 979 million m^3, respectively (CBS, 2010 and 2019).

2.2. Water quality measurements

The water monitoring system managed by the Chengdu Environmental Monitoring Station (CEMS) is composed of 93 sites, which can be categorized into long-term, long-term & on-line, on-line, and others (6, 7, 1, and 79 sites, respectively; Figure 1). Water quality was monitored once a month at all the 93 sites. The CEMS collected water samples from the surface layer (less than 20 cm) under the days with no precipitation, and stored each sample in 10 L plastic buckets. The chemical parameters measured were pH, dissolved oxygen (DO), biological oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), Oil Category (OC), Volatile Phenol (VP), Anionic Surfactant (ANS), Fecal Coliform (FC), Chemical Oxygen Demand Chromium (COD_{Cr}), permanganate index (COD_{Mn}), Total Nitrogen (TN), Total Phosphorus (TP), copper (Cu), zinc (Zn), fluoride (F^-), selenium (Se), arsenic (As), cadmium (Cd), Chromium hexad (Cr(VI)), lead (Pb), cyanide (CN), and sulfides (SO_4^{2-}). The chemical analysis methods of these parameters are given in Table S1. Long-term reliable water quality data are available from 2000 to 2019 at thirteen long-term sites (including 201H, JP, DJY, EJS, GNDQ, HLX, LNH, QJDQ, SHM, SYDQ, WFLY, YADQ, and YDZ), with seven and six from the Min and Tuo basins, respectively. Hourly concentrations of DO, TN, NH_3-N, TP, and COD_{Mn} have been collecting since late 2018 at the on-line sites (including 201H, DJY, EJS, HLX, QJDQ, SYDQ, and YDZ), with four and three from the Min and Tuo basins, respectively.

2.3. Water quality evaluation

We evaluated water quality at all the 93 sites in 2019 through classifying water quality grades using the Chinese National Method to Evaluate Surface Water

Quality (CNWQS; Ministry of Ecology and Environment of China (MEE), 2011). In the CNWQS method, each pollutant's concentration is compared with the pollutant's standard for each water quality grade (MEE, 2002, 2011). The worst grade among all the measured pollutants is used as the grade for the monitoring site. The CNWQS method has six grades: I (excellent), II (good), III (moderate), IV (lightly polluted), V (moderately polluted), and VI (heavily polluted). If water is at the I or II levels, it is suitable for drinking water and recreational purposes. At the III level, water is mainly acceptable for fishing, swimming, and other recreational purposes. If water is at the IV and V levels, it is appropriate only for industries and irrigation, but not for domestic or recreational purposes. Water at the VI level cannot be used for any purposes.

Water quality grades were also classified by using the water quality index (WQI) methods (Wu et al., 2018), because the CNWQS method does not consider the comprehensive impacts of multiple water parameters on the overall water quality. WQIs aim at giving a single value to provide sufficient information on the overall water quality. For policy-makers, they can use WQIs to understand water quality and its trends for different purposes, allocate funds, enforce standards, and inform the public. At present, there are multiple WQIs using different parameters and equations depending on the water quality management goals across the world (Abbasi and Abbasi, 2012a). For example, Wu et al. (2018) used temperature, pH, conductivity, turbidity, DO, TN, NH_3-N, nitrite (NO_2-N), nitrate (NO_3-N), calcium (Ca), magnesium (Mg), total chlorine (Cl), and SO_4^{2-}. Brown et al. (1970) used DO, FC, pH, BOD_5, NO_3-N, TP, temperature, turbidity, and total suspended solids (TSS).

This study’s WQI calculation was mainly based on that from Wu et al. (2018) and used equation (1). In consideration of the availability of monitoring data and the

C_i and P_i values from the literature (Abbasi and Abbasi, 2012b; Debels et al., 2005; Koçer and Sevgili, 2014; Zhao et al., 2013), we used eleven water quality parameters: T, pH, DO, TN, NH_3-N, TP, COD_{Cr}, COD_{Mn}, BOD_5, ANS, and FC. According to the WQI values, water quality is classified into five grades, including excellent (91-100), good (71-90), moderate (51-70), low (26-50), and bad (0-25).

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \tag{1}$$

Where n is the total number of parameters used in the study, Ci is the normalized value of parameter i (see Table S2), and Pi is the weight of parameter i. Pi's minimum value was 1, and the maximum weight assigned to parameters that affect water quality was 4.

2.4. Water quality changes during 2000-2019 and the COVID-19 lockdown

We used data from the thirteen long-term monitoring sites to quantify water quality trends from 2000 to 2019. The monitoring data are annual mean concentrations/values of pH, DO, conductivity, and pollutants. There are one background, one inflow, three interior, and two outflow sites in the Min Basin. In the Tuo Basin, there are two inflow, two interior, and two outflow sites. Water at the background site is minimally affected by anthropogenic pollutant discharges, as its upstream is sparsely-populated rural, mountainous areas. The inflow and outflow sites are close to the locations where water flows into and out of the Chengdu territory, respectively. The interior sites are in Chengdu’s interior areas. To quantify inter-annual variations, we used the Mann-Kendall test (Kendall, 1975; Mann, 1945) for the entire 2000-2019 period and generated the time-series of five-year mean values of pH, DO, conductivity, and pollutant concentrations. The five-year periods are 2000-2004, 2005-2009, 2010-2014, and 2015-2019.

We used the hourly measurements at the seven on-line sites to analyze the impacts of the COVID-19 lockdown from 24th January to 17th February in 2020. The time-series of daily concentrations/values of pH, DO, conductivity, and pollutant concentrations cover three periods: before, during, and after the 25-day COVID-19 lockdown (day -23 to 0, day 0 to 25, and day 25 to 60, respectively). We also used the time-series of 2019 to understand the Spring Festival Holiday impacts in the non-COVID-19 year. Day 0 in 2020 is 24th January and the first day of lockdown and Spring Festival Eve. Day 0 in 2019 is 4th February and the Spring Festival Eve.

3. Results

3.1. Water quality in 2019

3.1.1. Annual mean concentrations and water quality grades

In 2019, water from nearly 2/3 of monitoring sites (61/93) violated the national III standards (Figure 2) and was thus deemed unsuitable for recreational activities with direct human contact (MEE, 2002). The seven major pollutants were TN, FC, TP, NH_3-N, COD_{Cr}, BOD_5, and COD_{Mn}, as the maximum concentrations of each of them exceeded the national III standards for both basins (Table 1). TN and FC were the most critical pollutants (Figure S4). The annual mean concentration of TN exceeded the national III standard at 60% of all monitoring sites (50% and 85% of Min and Tuo Basin sites, respectively; Figure S4). Basin-wide annual mean concentrations of TN also exceeded the national III standard for both the Min and Tuo Basins (1.79 and 2.71 mg L^{-1}, respectively; Table 1). The national III standard for FC was exceeded at 35% of all sites (30% and 55% of Min and Tuo Basin sites;

Figure S4) and for the basin-wide annual mean concentrations in both basins (33,972 and 33,352 per L in the Min and Tuo Basins, respectively; Table 1). In 2019, the annual mean concentrations of all the other pollutants (ANS, As, Cd, Cyanides, Cr(VI), Cu, fluoride, Hg, Pb, OC, Se, SO_4^{2-}, VP, and Zn) at each site achieved the national III standards (Table S3). The pH ranges were 7.37-8.41 and 7.10-8.19 in the Min and Tuo Basins, respectively (standard is 6-9). DO concentrations at all sites achieved the national III standard of ≥5 mg L^{-1} (5.3-10.9 and 5.1-9.7 mg L^{-1} in the Min and Tuo Basins, respectively).

Water quality at the 93 sites in 2019 achieved better ratings using the WQI method than using the CNWQS method, and water quality was better in the Min Basin than in the Tuo Basin (Figures 2 and S5). No sites had water at either excellent or good grades using the CNWQS method, while water was classified into excellent or good at ~70% of sites using the WQI method (Figure 2a). More sites had water at the moderate or worse grades using the CNWQS (91%) than using the WQI methods (31%). Based on the CNWQS method, water quality was moderately polluted or worse at more sites in the Min Basin than in the Tuo Basin (49% vs. 77%). Based on the WQI method, water quality was at the moderate or worse grades at more sites in the Min Basin than in the Tuo Basin (30% vs. 40%).

3.1.2. Spatial variations

Water quality in the Min Basin presented a deterioration trend from the upstream to downstream in 2019 (Figure 3). For example, the annual DO concentration was 9.5 mg L^{-1} at the background site (DJY) and then decreased to 6.10-8.0 mg L^{-1} downstream of the central urban area. Also, the annual mean concentrations of TN, NH_3-N, TP, and COD_{Mn} increased from 1.08, 0.09, 0.06, and

1.18 mg L^{-1} at DJY to 2.01-7.59, 0.51-1.50, 0.10-0.2, and 2.1-4.0 mg L^{-1} downstream of the central urban area, respectively. FC was less than 2,000 per L^{-1} at DJY but increased to more than 10,000 per L^{-1} downstream of the central urban area. The COD_{Cr} and BOD_5 concentrations achieved the national I standards (4-15 and 0.7-3.0 mg L^{-1}, respectively) at most sites (66/67 sites). The sites with higher COD_{Cr}, BOD_5, and FC concentration ranges were in the central urban and/or downstream regions. These spatial patterns suggest that the pollution of Min Basin is mainly from Chengdu's pollutant discharges.

In the Tuo Basin, water quality in 2019 already violated the national III standards at the two inflow sites (201H and QJDQ), through where water flowed into Chengdu (Figure 4). For example, the annual concentrations of TN and FC were 3.27 mg L^{-1} and 148,833 per L at 201H and 3.03 mg L^{-1} and 158,133 per L at QJDQ, respectively, and these values all exceeded the corresponding national III standards. From the 201H and QJDQ to their downstream regions, there were no clear improving or worsening trends of water quality. Thus, water in the Tuo Basin was polluted by not just local pollutant discharges but also inter-city transport of pollutants.

3.2. Long-term changes during 2000-2019

3.2.1. Min Basin

Water quality was generally insignificantly improved from 2000 to 2019 at Min Basin's six non-background long-term sites, including EJS, HLX, JP, LNH, YA, and YDZ ($p>0.05$; Figure 4). This is because TN, TP, and FC violated the national III standard in 2019 at least one of the five interior/outflow sites (five, one, and four sites, respectively), and the three pollutants' concentrations were stable from 2000 to

2019 at all the interior/outflow sites, except for FC at one site. In addition, the concentrations of TN, BOD_5, and ANS at the inflow site (JP) increased significantly, although they all achieved the national III standards in 2019.

There were some achievements in water quality improvement (Figure 4). DO concentrations and pH significantly improved at two and four sites, respectively ($p<0.05$). At the background site, the concentrations of nine pollutants (NH_3-N, COD_{Cr}, FC, ANS, As, Hg, OC, Se, and SO_4^{2-}) increased significantly. At the inflow site, the pollution of Cd, Pb, and VP reduced significantly. At the five interior/outflow sites, the pollution of NH_3-N, TP, BOD_5, COD_{Mn}, COD_{Cr}, and FC significantly reduced from 2000 to 2019 at two, one, five, three, two, and one, respectively. At the interior/outflow sites, the pollution of ANS, As, Cu, F^-, Hg, OC, Se, SO_4^{2-}, VP, and Zn reduced significantly at five, four, one, three, four, five, two, five, three, and two sites, respectively.

Five-year mean concentrations of DO and the major pollutants (TN, NH_3-N, TP, COD_{Cr}, COD_{Mn}, BOD_5, and FC) also suggested some water quality improvement (Figure S6). DO concentrations at the five interior/outflow sites improved from 2000-2004 to 2015-2019. From 2000 to 2019, all the major pollutants' concentrations experienced a continuous decreasing trend or raised first and then decreased at all the interior/outflow sites, except for TN at two sites.

3.2.2. Tuo Basin

Water quality generally deteriorated at the Tuo Basin's six long-term sites, including 201H, GNDQ, QJDQ, SHM, SYDQ, and WFLY (Figure 4). First, the annual concentrations of TN and FC in 2019 exceeded the national III standards at all the sites. From 2000 to 2019, the TN and FC pollution presented a significant rising trend at four and two sites and a stable pattern at two and four sites, respectively. Second, the pollution of ANS, As, Cd, Cyanides, Cr(VI), Cu, F^{-}, Hg, Pb, OC, Se, SO_4^{2-}, VP, and Zn significantly increased at up to three sites from 2000 to 2019, although the concentrations in 2019 all achieved the national III standards. Despite the environmental quality deterioration, there was some water quality improvement: the pollution of NH_3-N, BOD_5, and COD_{Mn} significantly reduced at one, three, and five sites, respectively. DO and pH significantly improved at one and two sites, respectively.

Five-year mean concentrations of water pollutants during 2000-2019 also suggested the insufficient water pollution control and the inter-city transport of major pollutants for the Tuo Basin (Figure S7). At the interior/outflow sites, the pollution of TN, TP, and FC increased in the most recent five and ten-year periods (2014-2019 and 2010-2019, respectively), while the pollution of NH_3-N, COD_{Cr}, COD_{Mn}, and BOD_5 decreased or were stable. In 2014-2019, the TN and TP concentrations at the inflow sites were in the same ranges measured at the interior/outflow sites (approximately 3-4 mg L^{-1} and 0.2-0.3 mg L^{-1}, respectively). Also, the FC concentrations at the inflow sites (~75,000 and 100,000 per L) were close to or higher than that at the interior /outflow sites (~2,000-100,000 per L) in 2014-2019.

3.3. Changes during the COVID-19 lockdown

In the Min Basin, water quality responses to the COVID-19 lockdown and Spring Festival Holiday were different between the background and non-background sites (Figure 5). At the background site (DJY), the water quality parameters (pH, conductivity, DO, TN, NH_3-N, COD_{Mn}, and TP) were insensitive to both the 25-day lockdown of 2020 and the 7-day holiday in both 2019 and 2020. In contrast, at the three non-background sites (EJS, HLX, and YDZ), the seven parameters were sensitive to the lockdown and the holiday, except for COD_{Mn} at one outflow site. The changes in the seven parameters at the non-background sites started a few days before the lockdown and the holiday. This was likely because each year many people began their vacations before the holiday. In 2019, daily concentrations of TN, NH_3-N, COD_{Mn}, and TP at the non-background sites started to increase around the end of the holiday. However, the four pollutants' concentrations did not increase significantly after the end of the holiday and lockdown in 2020 at the non-background sites, except for TN at EJS. In general, water quality at the non-background sites improved due to the COVID-19 lockdown and the holiday, while water quality did not significantly change at the background site.

In the Tuo Basin, daily concentrations of TN, NH_3-N, COD_{Mn}, and TP were insensitive to the lockdown and holiday in 2020 at two or all of the three on-line monitoring sites, including 201H, HY, and SYDQ (Figure S8). Slightly reduced concentrations of TN, NH_3-N, and COD_{Mn}, likely due to the holiday and lockdown, occurred at only one site each. Concentrations of TN at the inflow site even increased for about six days during the holiday and lockdown.

4. Discussion

4.1. Enhanced water governance and its achievements

Water governance in Chengdu followed that of the national laws, regulations, and policies, the first of which were issued in the 1980s and early 1990s, such as the Water Pollution Control Law, Ground Water Pollution Control Law (GB3838-83), Water Pollution Control Law (GB8978-88), Water Quality Standards for Irrigation

(GB5084- 93), and Water Pollution Standards for Recreation (GB12941-91; Xu et al., 2019). Before 1995, water pollution control focused on industries, but the supervision was very weak; in addition, domestic sewage treatment and water management at a basin scale did not receive much attention. The first pollution control plan at a basin scale was issued for the Huai River in 1996, followed by other river's plans during the 9th Five-Year Plan Period (1996-2000). The 11th Five-Year Plan (2006-2010) for the first time clarified the responsibilities of provincial governments, proposed the conservation on drinking water, and suggested the inter-provincial cooperation to control inter-jurisdictional water pollutant transport. The 12th Five-Year Plan (2011-2015) set the targets to not just control total pollutant discharges but also water quality grades for major river basins. The 12th Plan also proposed pollution control tasks from six aspects, including drinking water safety, industrial pollution control, urban domestic pollution control, environmental comprehensive improvement, ecological restoration, and hazardous prevention. The tasks were eventually composed of 6007 engineering projects and received an investment of RMB 346 billion Yuan. The most comprehensive and ambitious policy, the Water Pollution Prevention Action Plan, was issued in 2015 during the 13th plan (SCC, 2015). This plan requires by 2030 over 75% of national monitoring sites in the seven major basins (Songhua, Liaohe, Haihe, Yellow, Huaihe, Yangtze, and Pearl River Basins) should have water quality at the III level or better. In 2016, the River and Lake Chief System started to be implemented across China in order to strengthen the enforcements and accountability concerning key water policy measures at the provincial, municipal, county, township, and village levels. The Chiefs are senior officials and each of them is responsible for a particular stretch or section of rivers/lakes (Koçer and Sevgili, 2014).

Owing to the tremendous efforts, the ratio of the national water monitoring sites having water quality at the I to III grades increased from 27.4% to 74.9% from 1995 to 2019, while the ratio of sites having water quality worse than the V grade reduced from 36.5% to 3.4% (MEE, 2020; Xu et al., 2019). However, it should be noted that most of these national monitoring sites are in larger rivers. The changes in smaller rivers, which are closer to pollutant sources and have lower water environmental capacity, needs to further investigate.

In 2016, the Chengdu Municipality Government released a plan to localize the national Water Pollution Prevention Action Plan (CMG, 2016). The local plan included but were not limited to: (1) control pollution discharges from industries, urban domestic activities, and agricultural sources, (2) adjust industrial structures, (3) improve geographical locations of pollutant sources, (4) recycle resources, (5) reduce water use quantity, (6) facilitate the development and application of relevant technologies, (7) improve economic measures, (8) modify regulations, (9) strengthen governmental and public supervision, (10) secure drinking water source, (11) protect wetlands, (12) clarify the responsibilities and management goals of each governmental and public institutions, (13) built a mechanism for better inter-institutional cooperation, and (14) enhance the transparency of environmental information. This plan and many others resulted in some water quality improvement for Chengdu’s Min and Tuo Basins from 2000 to 2019 (Figures 4, S6, and S7).

4.2. Further needs to improve water quality

In 2019, water at 61 of the 93 sites still violated the national III standards (Figure 2). This ratio was far from the national goal by 2030 over 75% of national monitoring sites should have water quality at the III level or better (SCC, 2015), although most of the monitoring sites in Chengdu are not at the national level. Chengdu’s top two pollutants were TN and FC, followed by TP, NH_3-N, COD_{Cr}, BOD_5, and COD_{Mn} (Table 1; Figure S4). From 2000 to 2019, water quality at the five non-background sites in the Min Basin did not significantly improve. This was because the annual concentrations of TN, TP, and FC, which violated the national III standard at least one of the five interior/outflow sites in 2019, were stable from 2000 to 2019 at all the non-background sites, except for FC at one site. Water quality at the Tuo Basin's long-term sites generally degraded because the annual concentrations of TN and FC at the basin's long-term sites presented a stable or deterioration pattern from 2000 to 2019 (Figure 4). It is clear that there is a need to further control water pollution.

Water pollution in the Min Basin was mainly from Chengdu's pollutant discharge, while the pollution in the Tuo Basin was from both local and inter-city transport of pollutants. In the Min Basin, water quality achieved the national I level at the background site (DJY) in 2019. Concentrations of the major pollutants generally increased from the upstream to downstream in 2019, while DO generally deteriorated from the upstream to downstream (Figures 3). In the Tuo Basin, the annual concentrations of TN, TP, and FC in 2019 and 2015-2019 already violated the national III standards at the inflow sites (Figures 3). Therefore, controlling Chengdu's pollutant discharges alone is likely to sufficiently improve water quality in the Min Basin. However, improving water quality in the Tuo Basin requires inter-jurisdiction cooperation.

4.3. Potential chance of COVID-19 lockdown for quantifying major pollution sources

Water quality may not immediately improve after reducing anthropogenic pollutant discharge (Stålnacke et al., 2004). These buffered responses suggest that various natural and anthropogenic factors mediate anthropogenic impacts on water quality, including climate, geology, hydrology, groundwater/surface-water interaction, pollutant discharges from point and non-point sources, land use, water use, sedimentation, biological processes, atmospheric deposition of pollutants, stream channelization, sediments, and others (Stålnacke et al., 2004).

During the COVID-19 lockdown, water quality largely improved at the Min Basin’s non-background on-line sites (Figure 5). In contrast, water quality at the Min Basin's background site was insensitive due to low anthropogenic impacts there. Water quality at the Tuo Basin’s on-line monitoring sites did not significantly improve (Figure S8). These results may reflect varying water pollution sources and pollution levels for the two basins. Pollution in the Min Basin was mainly from Chengdu's pollutant discharges, and controlling local pollutant discharges can likely significantly improve the basin's water quality. However, controlling the inter-city transport of pollutants is essential for mitigating pollution in the Tuo Basin. Further investigations of what pollutant sources were shut down and led to the improved water quality in the two basins during the lockdown can help develop incremental pollutant discharge reduction targets. In contrast, an investigation of what pollutant sources still operated during the COVID-19 lockdown may help to understand why there was no significant reduction in water pollution and what sources should be largely controlled in the future.

4.4. Suggestions for future water governance

Based on this study's results, we provide three suggestions for future water governance in Chengdu, and these suggestions might also be helpful for other river basins with rapid economic growth and/or intensive agricultural activities.

(1) Governments need to update and better enforce water legislation and regulations, which serve as the foundation of water governance (ADB, 2018; WBG et al., 2018). The latest Chinese National Water Law was revised in 2002. This law and the national and local relevant regulations should be updated to reflect the latest water protection goals (e.g., total water use, water use efficiency, and total water pollution discharges) and challenges (e.g., inter-jurisdictional water pollution and management, responsibility clarification, water quality assessment, data and information sharing, and governmental-public-private-academic cooperation's). Chengdu's Tuo Basin is clearly affected by inter-city transport of water pollutants and thus requires relevant local and inter-jurisdictional regulations.

(2) Data collection, evaluation, and sharing need to be improved for scientific research and decision making. The establishment of a national and regional platforms on water quality monitoring and evaluation and pollutant discharge inventories will be helpful for a more efficient pollution control (WBG et al., 2018). TN, TP, and FC were among the major pollutants in Chengdu (Figure S3 and Table 1). TN and TP are usually from chemical fertilizers, while FC is usually associated with poultry and livestock farms (Madhav et al., 2020). However, at present, Chengdu and adjacent jurisdictions have no detailed inventories of these pollutants, including when, where, and how much these pollutants are released. Furthermore, water quality assessment methods need to be modified based on a well understanding of the water use types and water pollution mitigation goals for different areas of Chengdu. In this study, water quality was worse assessed by using

the CNWQS method than using the WQI method (Figure 2), and this result might be confusing for policy makers and the public to make decisions. It is much needed to develop a water quality assessment method that can provide the policy makers with appropriate information.

(3) Ecological engineering measures should be considered more in avoiding, controlling, and trapping water pollutants. The TN, TP, and FC pollution in Chengdu should be largely associated with non-point sources, which are widespread and usually hard to control. At the same time, ecological engineering was not widely applied in Chengdu’s previous water control infrastructural constructions. For example, 17 km of natural river channels were cleaned in the Fu & Nan River Restoration Project, but the pavement of river banks and bottoms greatly reduce the resilience to floods and the natural biological capability to reduce water pollutant concentrations (Zhang and Cao, 2004). We suggest to use cover crops, nutrient management plans, artificial or modified wetlands, and residue and tillage management to reduce pollutant release from non-point agricultural sources, as the Mississippi River Basin Healthy Watersheds Initiative (MRBI) successfully implemented these methods in 12 states of the America (USDA, 2020).

5. Conclusion

Despite some water pollution mitigation achievements, water quality did not significantly improve in Chengdu from 2000 to 2019. In 2019, 66% of the 93 monitoring sites still violated the national III standards for recreation with direct human contact. This ratio was far from the national goal by 2030 over 75% of national monitoring sites should have water quality at the III level or better. The top two pollutants were TN and FC, followed by TP, NH_3-N, COD_{Cr}, BOD_5, and

COD_{Mn}. As water quality level classification results are affected by the equations and parameters used, no sites had water at either excellent or good grades using the CNWQS method, while water was classified into excellent or good at ~70% of sites using the WQI method. The different results between the CNWQS and WQI methods may confuse policymakers and the public. Thus, there is a need to develop water quality assessment method according to the local water management goals.

Water quality in Chengdu's Min Basin can be greatly improved through controlling the city's pollutant release alone. For the Tuo Bain, inter-city transport of water pollutants and local pollutant discharges should be both reduced. An investigation of the causes leading to the improved water quality in the Min Basin but no significant changes in the Tuo Basin during the COVID-19 lockdown in 2020 can help identify major pollution control targets. In the future, the water governance needs to be improved through (1) updating legislation, regulations, and technologies, (2) improving the data collection, evaluation and sharing among jurisdictions, and (3) promoting ecological engineering application.

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References

Abbasi, T., Abbasi, S.A., 2012a. Chapter 1 - Why Water-Quality Indices, in: Abbasi, T., Abbasi, S.A. (Eds.), Water Quality Indices. Elsevier, Amsterdam, 9-24.

Abbasi, T., Abbasi, S.A., 2012b. Chapter 2 - Approaches to WQI Formulation, in: Abbasi, T., Abbasi, S.A. (Eds.), Water Quality Indices. Elsevier, Amsterdam, 9-24.

ADB, 2018. Asia Development Bank. Managing water resources for sustainable socioeconomic development. https://www.adb.org/sites/default/files/institutional-document/473576/country-water-assessment-prc.pdf.

Arif, M., Kumar, R., Parveen, S.J., 2020. Reduction in water pollution in Yamuna river due to lockdown under COVID-19 pandemic. doi: 10.26434/chemrxiv.12440525.

Brown, R.M., McClelland, N.I., Deininger, R.A., Tozer, R.G., 1970. A water quality index - do we dare? Water Sewage Works 117, 339-343.

CBS, 2010 and 2019. Chengdu Bureau of Statistics. Statistical Yearbook of Chengdu. http://www.cdstats.chengdu.gov.cn/htm/list_menu_020109.html.

Chen, Y., Zhang, S., Huang, D., Li, B.-L., Liu, J., Liu, W., Ma, J., Wang, F., Wang, Y., Wu, S.J., 2017. The development of China’s Yangtze River Economic Belt: How to make it in a green way. Scientific Bulletin 62(9), 648-651.

CMG, 2016. Chengdu Municipality Government. Action Plan of Water Pollution Control for the Chengdu Municipality. http://gk.chengdu.gov.cn/uploadfiles/070902170304/2016031614064494.docx.

Debels, P., Figueroa, R., Urrutia, R., Barra, R., Niell, X., 2005. Evaluation of water quality in the Chillán River (Central Chile) using physicochemical parameters and a modified water quality index. Environmental Monitoring and Assessment 110(1), 301-322.

Kendall, M.G., 1975. Rank correlation methods, (Griffin, London, UK).

Koçer, M.A.T., Sevgili, H., 2014. Parameters selection for water quality index in the assessment of the environmental impacts of land-based trout farms. Ecological Indicators 36, 672-681.

Lijuan, C., Manyin, Z., Weigang, X., 2018. Yangtze River Basin (China), in: Finlayson, C.M., Milton, G.R., Prentice, R.C., Davidson, N.C. (Eds.), The Wetland Book: II: Distribution, Description, and Conservation. Springer Netherlands, Dordrecht, 1551-1563.

Luo, Q., Luo, L., Zhou, Q., Song, Y., 2019. Does China's Yangtze River Economic Belt policy impact on local ecosystem services? Science of the Total Environment 676, 231-241.

Madhav, S., Ahamad, A., Singh, A.K., Kushawaha, J., Chauhan, J.S., Sharma, S., Singh, P., 2020. Water Pollutants: Sources and Impact on the Environment and Human Health, in: Pooja, D., Kumar, P., Singh, P., Patil, S. (Eds.), Sensors in Water Pollutants Monitoring: Role of Material. Springer Singapore, Singapore, 43-62.

Mann, H.B., 1945. Non-parametric tests against trend. Econometrica 13, 245-259.

MEE, 2002. Ministry of Ecology and Envrionment of the People’s Republic of China. Environmental quality standards for surface water.

http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/shjbh/shjzlbz/200206/W020061027509896672057.pdf.

MEE, 2011. Methods to evaluate surface water quality. http://www.mee.gov.cn/gkml/hbb/bgt/201104/W020110401583735386081.pdf.

MEE, 2020. The implementation progress of the Water Pollution Prevention Action Plan. http://www.mee.gov.cn/ywgz/ssthjbh/swrgl/202005/t20200515_779400.shtml.

Saadat, S., Rawtani, D., Hussain, C.M., 2020. Environmental perspective of COVID-19. Science of the Total Environment 138870.

SCC, 2015. State Council of China. Water Pollution Prevention Action Plan. http://www.gov.cn/zhengce/content/2015-04/16/content_9613.htm.

SCC, 2020. Yangtze River Protection Law. https://www.mee.gov.cn/ywgz/fgbz/fl/202012/t20201227_814985.shtml.

She, Y., Liu, Y., Jiang, L., Yuan, H., 2019. Is China's River Chief Policy effective? Evidence from a quasi-natural experiment in the Yangtze River Economic Belt, China. Journal of Cleaner Production 220, 919-930.

Stålnacke, P., Vandsemb, S., Vassiljev, A., Grimvall, A., Jolankai, G., 2004. Changes in nutrient levels in some Eastern European rivers in response to large-scale changes in agriculture. Water Science Technology 49(3), 29-36.

Sun, C., Chen, L., Tian, Y., 2018. Study on the urban state carrying capacity for unbalanced sustainable development regions: Evidence from the Yangtze River Economic Belt. Ecological Indicators 89, 150-158.

USDA, 2020. United States Department of Agriculture, Mississippi River Basin Healthy Watersheds Initiative, https://www.nrcs.usda.gov/wps/portal/nrcs/detail/wi/programs/?cid=nrcs142p2_020764.

Wang, Q., Su, M., 2020. A preliminary assessment of the impact of COVID-19 on environment–A case study of China. Science of the Total Environment, 138915.

WBG, GWSP, DRC, 2018. World Bank Group (WBG), Global Water Security & Sanitation Partnership (GWSP), Development Research Center of the State Council (DRC). A new era of water governance in China. https://www.worldbank.org/en/news/infographic/2018/12/27/a-new-era-of-water-governance-in-china.

Wu, Z., Wang, X., Chen, Y., Cai, Y., Deng, J., 2018. Assessing river water quality using water quality index in Lake Taihu Basin, China. Science of the Total Environment 612, 914-922.

WWF, 2012. World Wildlife Fund (WWF). Chengdu river cleanups. https://wwf.panda.org/wwf_news/?204394/Chengdu-river-cleanups.

Xia, C., Liu, H.W., 2001. Project of Chengdu Fu-Nan River Conservancy and Sustained Development of the City. World Science-Technology Research and Development 23(5), 64-66.

Xu, M., Zhang, T., Wang, D., Zhao, Y., Xie, Y.C., Ma, Y.K., 2019. Review and prospect of water pollution prevention and control of China in the forty years of reform and opening-up. Chinese Journal of Environmental Management 3, 65-71.

Xue, Z.C., You, J.J., Yang, Z.H., 2018. The Chengdu carrying capacity of water resources status evaluation based on the variable sets. IOP Conference Series: Earth and Environmental Science 199, 022048.

Zhang, Y.X., Cao, H.L., 2004. With the comprehensive improvement project of Funanhe River in Chengdu as an example. Planners(6), 52-55.

Zhao, P., Tang, X., Tang, J., Wang, C., 2013. Assessing water quality of Three Gorges Reservoir, China, over a five-year period from 2006 to 2011. Water Resources Management 27(13), 4545-4558.

Figures

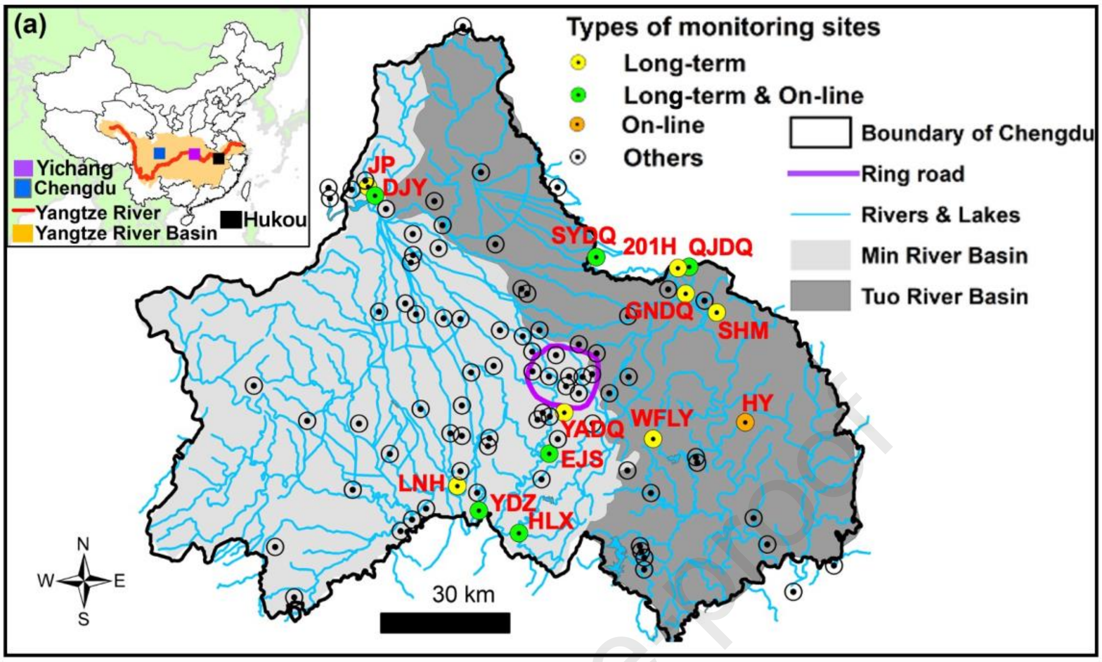


Fig. 1. (a) Location of Chengdu in China and (b) locations of water monitoring sites in Chengdu. Monthly monitoring data are available at the long-term monitoring sites from 2000 to the present. Hourly monitoring data are available at the on-line sites. The central urban area of Chengdu is within the marked ring road.

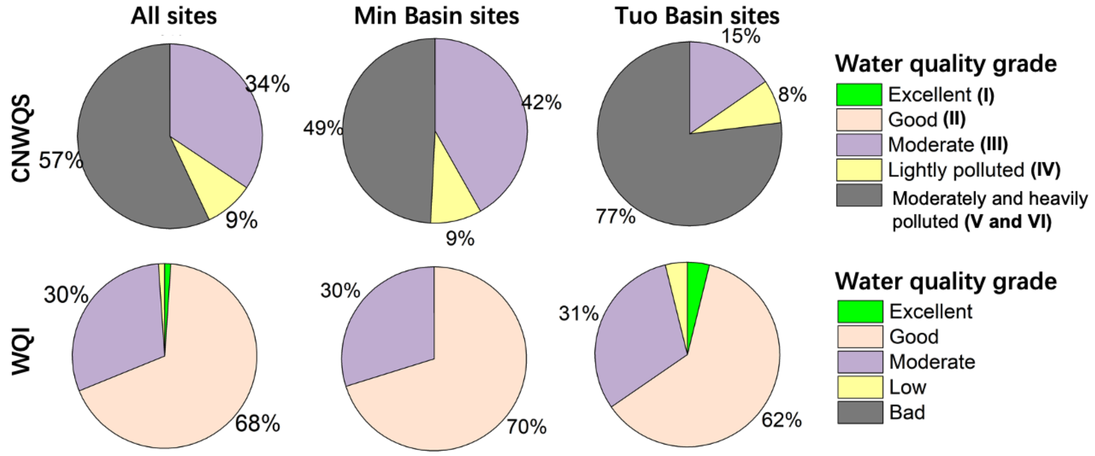


Fig. 2. Water quality levels of all 93 monitoring sites, 67 sites of the Min Basin, and 26 sites of the Tuo Basin in 2019 based on the CNWQS and WQI methods.

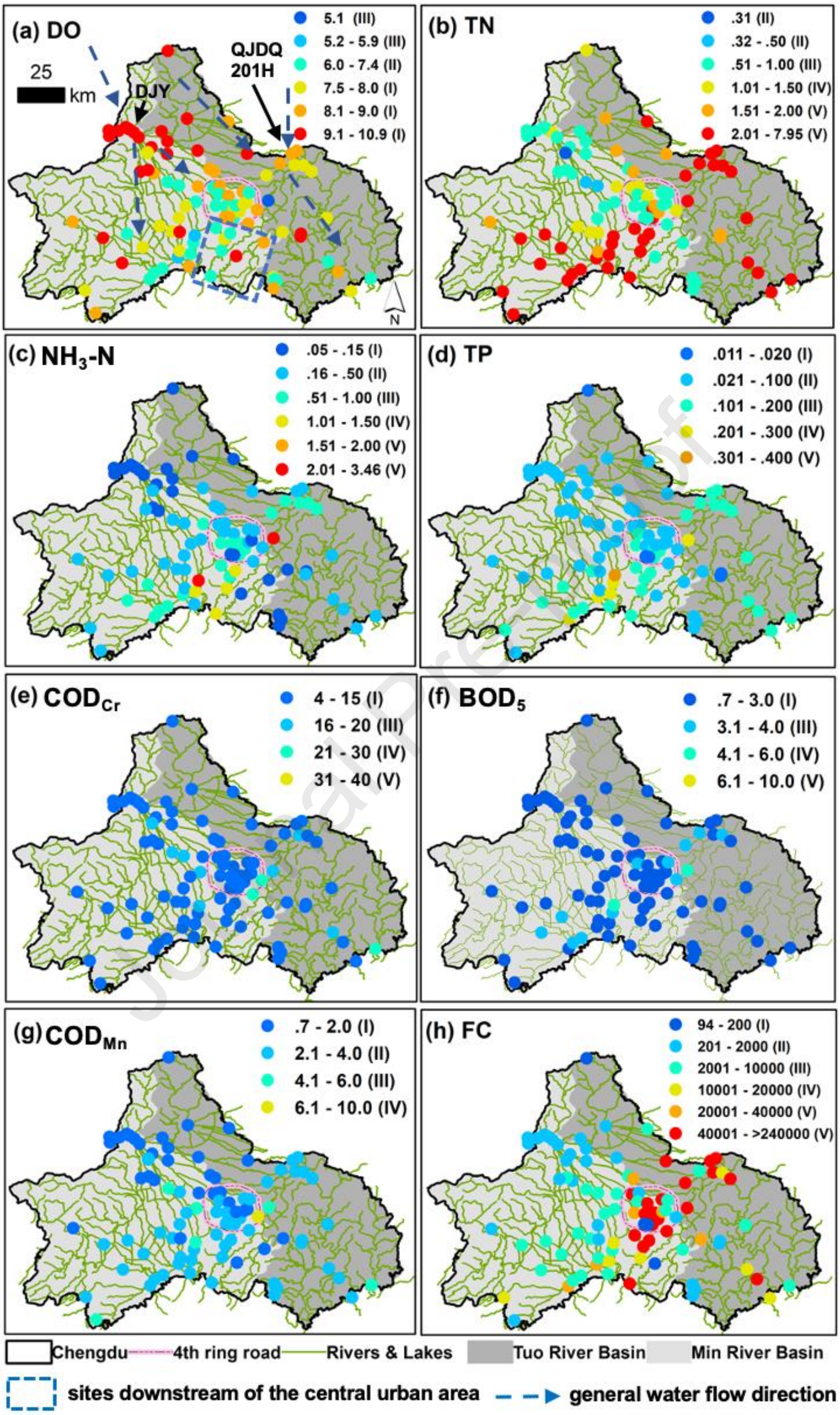
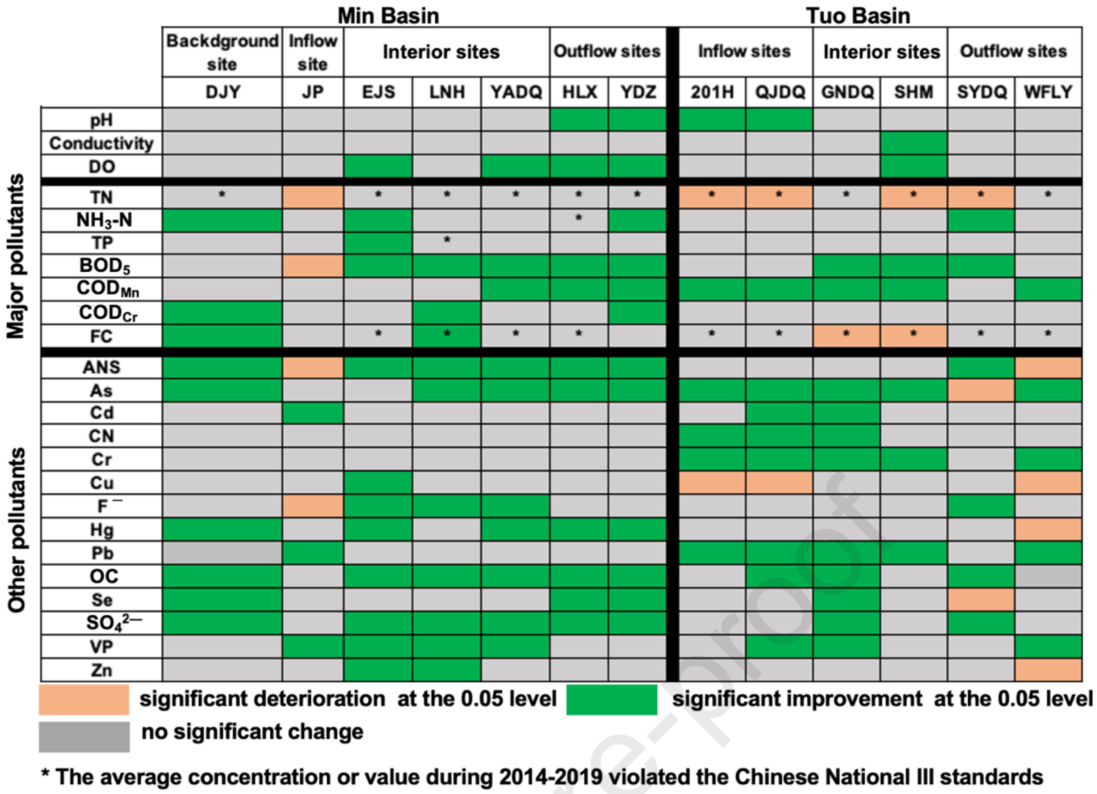


Fig. 3. Spatial variations of annual mean concentrations of DO and the major water pollutants in Chengdu, 2019. The units are mg L^{-1} for all the pollutants except for FC. The unit of FC is number per liter. The pollutant concentration ranges are the based on the Chinese I, II, III, IV, V, and VI standards.



		Min Basin							Tuo Basin					
		Backdground site	Inflow site	Interior sites			Outflow sites		Inflow sites		Interior sites		Outflow sites	
		DJY	JP	EJS	LNH	YADQ	HLX	YDZ	201H	QJDQ	GNDQ	SHM	SYDQ	WFLY
	pH	⬜	⬜	⬜	⬜	⬜	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
	Conductivity	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜
	DO	⬜	⬜	🟩	⬜	🟩	🟩	🟩	⬜	⬜	⬜	🟩	⬜	⬜
Major pollutants	TN	⬜ *	🟧	⬜ *	⬜ *	⬜ *	⬜ *	⬜ *	🟧 *	🟧 *	⬜ *	🟧 *	🟧 *	⬜ *
	NH_3-N	🟩	⬜	🟩	⬜	⬜	⬜ *	🟩	⬜	⬜	⬜	⬜	🟩	⬜
	TP	⬜	⬜	🟩	⬜ *	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
	BOD_5	⬜	🟧	🟩	🟩	🟩	🟩	🟩	⬜	⬜	🟩	🟩	🟩	⬜
	COD_{Mn}	⬜	⬜	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩
	COD_{Cr}	🟩	⬜	⬜	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜
	FC	🟩	⬜	⬜ *	🟩 *	⬜ *	⬜ *	⬜	⬜ *	⬜ *	🟧 *	🟧 *	⬜ *	⬜ *
Other pollutants	ANS	🟩	🟧	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	🟩	🟧
	As	🟩	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩
	Cd	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	🟩	🟩	⬜	⬜	⬜
	CN	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	🟩	🟩	⬜	⬜	⬜
	Cr	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	🟩	🟩	🟩	⬜	🟩
	Cu	⬜	⬜	🟩	⬜	⬜	⬜	⬜	🟧	🟧	⬜	⬜	⬜	🟧
	F^{-}	⬜	🟧	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜
	Hg	🟩	⬜	🟩	⬜	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	🟧
	Pb	▨	🟩	⬜	⬜	⬜	⬜	⬜	🟩	🟩	🟩	🟩	⬜	🟩
	OC	🟩	⬜	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	⬜	🟩	▨
	Se	🟩	⬜	⬜	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	🟧	⬜
	SO_4^{2-}	🟩	⬜	🟩	🟩	🟩	🟩	🟩	⬜	⬜	🟩	⬜	🟩	⬜
	VP	⬜	🟩	🟩	🟩	🟩	⬜	⬜	⬜	🟩	🟩	⬜	⬜	🟩
	Zn	⬜	⬜	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧

🟧 significant deterioration at the 0.05 level 🟩 significant improvement at the 0.05 level

▨ no significant change

* The average concentration or value during 2014-2019 violated the Chinese National III standards

Fig. 4. Trends of annual mean concentrations/values of pH, DO, conductivity, and pollutants at thirteen long-term monitoring sites of Chengdu from 2000 to 2019 based on the Mann-Kendall test.

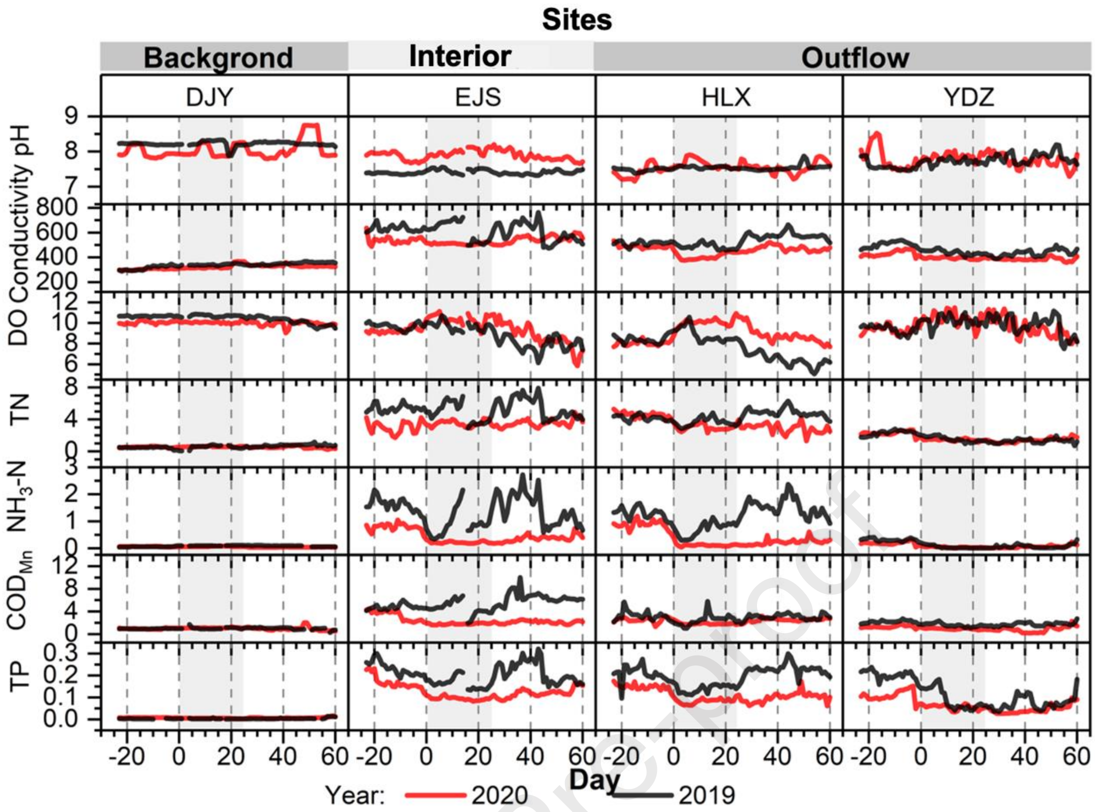


Fig. 5. Daily mean concentrations of DO, TN, NH_3-N, TP, and COD_{Mn} at four on-line monitoring sites of Min Basin in Chengdu before, during, and after the 25-day COVID-19 lockdown in 2020 (day -23 to 0, day 0 to 25, and day 25 to 60, respectively). Day 0 in 2019 and 2020 were the Spring Festival Eve, and Day 0 in 2020 was also the first day of local COVID-19 lockdown. The unit of conductivity is mS m^{-1}. The units of DO, TN, NH_3-N, TP, and COD_{Mn} are mg L^{-1}.

Tables

Table 1. The statistics of annual mean values of pH, DO, and the seven major pollutants* measured at each site in 2019.

Indices	Units	Mean	Median	Min	Max	S.D.	National III standards
Min Basin (Number of sites=67)							
pH	-	7.82	7.8	7.37	8.41	0.25	6~9
BOD$_5$	mg L^{-1}	2.12	2	0.7	4.1	0.72	4
COD$_{Cr}$	mg L^{-1}	11.5	11.7	3.8	21	3.2	20
COD$_{Mn}$	mg L^{-1}	2.4	2.3	1.2	6.6	1	6
DO	mg L^{-1}	8	7.9	5.3	10.9	1.1	5
FC	number L^{-1}	33972	4682	94	240000	65277	10000
NH$_3$-N	mg L^{-1}	0.46	0.29	0.08	3.46	0.53	1
TN	mg L^{-1}	1.79	1.04	0.31	6.72	1.48	1
TP	mg L^{-1}	0.09	0.08	0.02	0.31	0.07	0.1
Tuo Basin (Number of sites=26)							
pH	-	7.76	7.8	7.1	8.19	0.35	6~9
BOD$_5$	mg L^{-1}	1.94	1.88	0.8	4.81	0.9	4
COD$_{Cr}$	mg L^{-1}	12	12.2	4.1	24.5	4.7	20
COD$_{Mn}$	mg L^{-1}	2.5	2.5	0.7	4.9	1.1	6
DO	mg L^{-1}	8.2	8	5.1	9.7	1	5
FC	number L^{-1}	33352	3747	178	158133	48618	10000
NH$_3$-N	mg L^{-1}	0.37	0.21	0.05	2.02	0.42	1
TN	mg L^{-1}	2.71	2.92	0.7	7.95	1.73	1
TP	mg L^{-1}	0.1	0.06	0.01	0.28	0.07	0.1

*Annual mean concentration of the seven pollutants violated the national III standards at least one site in 2019. Table S3 presents the data of all measured pollutants. S.D., standard deviation. The boxes in grey show the data exceeded the national III standards.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: