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Major pollutant changes affected by Covid-19 lockdown in Shanghai

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Abstract: China repond quickly to exposure of Covid-19. This paper aims to evaluate the impact of lockdown on 5 major airborne pollutant in Shanghai. Chongming, Xuhui and Jinshan areas of Shanghai were studied and compared. Overall, the Covid-19 lockdown has changed pollutant concentration in both long and short terms. All the five concentrations except for O₃ increased. SO₂ had significant correlations with all other pollutants. Ozone on eath surface are mainly from green plants and can be reduced by both NO₂ and some organic matters. PM_{2.5} nd PM₁₀ are more external than local procuded. NO₂, SO₂ and PM matters sharply reduced in Jinshan and Xuhui during dued to the limited usage of fossil fuel. All these activies could both meet humen's neccesary needs and keep a better air quality. Proper and systematic measures should be taken to in keeping better air quality and economic growth in the whole world.

Key Words : Shanghai; different functional area; major airborne pollutants; Covid-19; effective policy

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More than 273.17 million people worldwide have been diagnosed with COVID-19, resulting in more than 3.56 million deaths on 1st June^[1]. This has a serious impact on the world economy and health^[2]. The first infection of Covid-19 was detected in Wuhan in December 2019^[3] and China responded fast to stop its spread^[4] by starting the first-level response in January 2020^[3]. The responses included traffic restrictions and factory closure^[5-7]. The reported peak cases was on 12th Feb^[8], then the cases gradually decrease to single digits^[8].

The Covid-19 also greatly impact air quality due to the lockdown^[9,10]. The major air pollutants are NO₂, SO₂, O₃, PM_{2.5} and PM₁₀ in Shanghai^[11]. During them, NO₂ produces photochemical smog and is oxidized by O₃ or O₂ to produce NO₃. This causes photochemical smog and acid rain^[12-14]. Both traffic and heavy industry produce SO₂^[14-16], short-term exposure of which can increase death rate^[18]. Surface O₃ usually forms in agricultural and forestry areas around large cities^[13,14,16,19,21]. Its concentration varies with season and meteorology^[13,21,22,24]. High concentration damages human health and agriculture production^[7,13,22-24] because O₃ oxidizes nitrogen and VOCs^[13,16,17,21,26,27]. Both PM_{2.5} and PM₁₀ are harmful to human health as some toxic gases and pathogenic microorganisms such as bacteria and virus can attached to them^[12,15,17-20,22-28]. Besides, PM_{2.5} directly cause human death. It has caused more than 2.1 million people's death because of its acidity penetrating the lower airways which links to the respiratory and cardiovascular disease^[12,22,27-30]. Short term exposure of these pollutants will increase the risk of Covid-19 infection^[12,18]. Daily average concentrations of the five pollutants were collected from

1st January to 9th February, 2020^[10]. Data of the same pollutant belonging to different functional areas were compared to make a comprehensive study. Besides, the corresponding average data from years 2018 and 2019 were used as a baseline to make a comparison.

Results

Major pollutants in different areas of Shanghai during Covid-19 in year 2020.

Although concentrations of different pollutants had different maximum and minimum values at different parts in Shanghai, their changing trends were generally the same (Fig. 1). Four of the five pollutants had decreasing concentrations while O₃ had increasing concentrations, which showed maximum value at Chongming with large part of green plants, followed by Xuhui with high population density and Jinshan with heavy industry. This was in line with the oxidation effect of O₃ to VOCs and NO_x^[10,21,26]. So, very significant negative correlations ($p < 0.001$) were shown between NO₂ and O₃ (Fig. 2). NO₂ decreased immediately after the lockdown as this mainly produced by cars with maximum values in Xuhui, where has the most population density and cars. Correlations between PM and O₃ were also negative because some VOCs and NO_x attached to PM^[21,26,27]. Due to Spring Festival celebrating by family barbecues, little peaks appeared after about seven days during the late time of the Chinese Spring Festival (Fig. 1). The celebration increased NO_x and VOCs, which increased the concentration of O₃^[5,21,26,27]. The significant ($p < 0.05$) positive correlation between PM_{2.5} and O₃ before lockdown shows that increase of PM_{2.5} attaching with NO_x and VOCs also increased the concentration of O₃.

Comparison of major pollutants in different functional areas. In Chongming (Fig. 1), the concentration of both NO₂ and SO₂ decreased by 51%, which was less than half of their original level during the block period. Comparatively, the concentration of PM_{2.5} only decreased 20% of concentration before the blockade. The average concentration of O₃ almost kept smoothly with values of 79.4 and 79.1 µg/m³, respectively, before and after the lockdown period. In Xuhui, the concentration of NO₂ and SO₂ decreased by 24% and 28%, respectively; and of PM₁₀ and PM_{2.5} decreased by 28% and 14%, respectively. However, concentration of O₃ increased 9% of that in the blockade period. Comparatively, the concentration of PM_{2.5} only decreased 20% of concentration before the blockade. In Jinshan, NO₂, SO₂ and PM₁₀ relatively decreased by 29%, 37% and 39% compared with those before the lockdown period. This is in accordance with that this area has the most factories. Like Xuhui, concentration of O₃ also increased.

No significant effects on both PM_{2.5} and O₃ were shown by the blockade in all the three parts of Shanghai (Fig. 1). Whereas, very significant effects ($p < 0.001$) on NO₂ and SO₂ were shown. Weak ($p < 0.05$), significant ($p < 0.01$) and very significant ($p < 0.001$) effects were respectively shown on PM₁₀ in Chongming, Xuhui and Jinshan parts. This is in line with the control of the two main resources of PM₁₀, i.e., fossil combustions and vehicle traffics. Significant decrease of both NO₂ and SO₂ and other reductants reduced the decrease of O₃ in both Xuhui and Jinshan. However, the results of PM_{2.5} was interesting that although the concentration was also obviously decreased, no significant changes were found before and during the lockdown period in different

functional parts of Shanghai. This indicates that local combustion of fossil fuels may not be the main source of PM_{2.5}^[22,26]. Generally, all the pollutants had very significant ($p < 0.001$) changes before and during the lockdown period. Only O₃ increased more than 20% than that before the lockdown. Comparatively, concentration of SO₂ decreased to 27%, and those of NO₂, PM_{2.5} and PM₁₀, respectively, decreased to 36%, 72% and 34%. This effect could last if proper policies were carried out as shown by the gradually decreasing AIQ before, during and after the lockdown periods, with their respective values of 85.7, 62.8 and 53.5. Most pollutants were clearly separated before and during the lockdown period (Fig. 1 in Supplementary materials); the same pollutants may have different sources in different functional areas (Fig. 2 in Supplementary materials).

Comparison of major pollutants in the same days from different years. All pollutants varied dramatically in 2020 compared with the same period in 2018 and 2019, especially during the Covid-19 lockdown period (Fig.3). The average decreasing rate of SO₂, NO₂, PM₁₀, PM_{2.5} and O₃ were 46%, 10%, 32%, 34% and 3%, respectively, before the lockdown period. Whereas, the corresponding data were 46%, 54%, 38%, 34% and -16.2%, respectively, during the lockdown period. So, the lockdown policy indeed altered the pollutant concentrations. Reducing heavy industry and motor vehicles are effective ways to control most pollutants.

Discussion

Exposure to air pollution may play important role in COVID-19 incidence and deaths^[1,4,13,23,24]. Especially NO₂ and PM_{2.5}, released from tailpipe^[32], is able to

increase the risk of lung infections^[12,15,30,31]. During the 5 major pollutants in Shanghai, NO₂ and SO₂ are environmental indicators directly related to local economic activities^[10]. More sustainable industry should be established for desulphurisation and to maintain SO₂ at a low concentration^[10,14]. NO₂ concentration was serious to pollution level in Shanghai^[6]. When GDP in Shanghai reached 38,155.32 billion yuan in 2019 (China Statistics Bureau, 2019), NO₂ became the only major pollutant that failed to meet the nation standard (GB3095-2012). Besides its role in causing lung disease, NO₂ might be an important trigger of mental disorders^[33,34] and associated with morbidity and mortality of COVID-19^[35]. Lockdown in 2020 sharply decreased concentration of NO₂ by about 45% compared with the relative value before that period. The whole data were about 28% and 46%, respectively, lower than the relative decreasing rates in Delhi and Mumbai^[5]; and about 20% lower in Almaty while^[35,36]. The globe decreasing rate were about 9% and 10% respectively, in March and April 2020^[5]. This was much higher than the decreasing rate during the lockdown period in Shanghai, but almost the same with that before the lockdown, i.e., from 1st to 23rd January 2020 (Fig.2). Consequently, Shanghai performed well in controlling SO₂ compared with other cities in the world. Comparatively, the decreasing rate of SO₂ varied little before and during the lockdown periods in this study, but about 10% higher than those released by traffic in 2020^[5]. Comparatively, the decreasing rate were 27% and 9% higher than those in Delhi and Mumbai. Consequently, SO₂ were mainly from heavy industry and traffic, both of which use fossil as fuel. SO₂ was the most decreased major pollutant in year

2020 compared with those from 2018 and 2019. This is different from those of Lima, Madrid, Moscow, Rome, Sao Paulo and Wuhan, where SO₂ concentration remained unchanged during lockdown, because power plants and traffic were still operational^[36,37].

Driven by particular meteorological conditions, PM are primary pollutant during winter in Shanghai (Shanghai Municipal Bureau of Ecology and Environment, 2020). The wind which contains pollutants came across the Yangzi Delta from November onwards seasonally^[5]. The concentration of PM_{2.5} and PM₁₀ result in more dust pollution^[38,39]. The average concentrations of these two matters were dropped by 66% and 65% during past 5 years with proper control of gas emissions from factories in Shanghai and nearby (Shanghai Municipal Bureau of Ecology and Environment, 2020). The decrease of PM_{2.5} during the lockdown period was more than 4 times of the average all over China (72%:17%)^[40]. The decrease were about 10% lower than the values caused by traffic in the same periods in Shanghai (20~40% : 24–47%)^[5], but still more than 10% higher than the corresponding values in Delhi and Mumbai of Indian^[5]. So, like SO₂, emission of PM_{2.5} is also well controlled in Shanghai compared with other international cities. There were almost no difference between the concentrations from year of 2018-2019 and 2020 in Shanghai with decreasing rate of 34%. This is comparable with those in northern China (29 ± 22%)^[41] and further validates that large amount of PM_{2.5} in Shanghai is from the northern region^[5,22,26,32].

Ozone is another major pollutant in Shanghai (Shanghai Municipal Bureau of Ecology and Environment, 2020). It also varies with season and meteorology^[5,13,16].

The peak of its concentration occurred in summer due to higher temperature and more sunshine^[5]. Although concentration of O₃ has been recognised by municipal government in Shanghai in 2016, the complexity in O₃ forming made it hard to regulate its emission^[5,42]. In 2016, concentration of O₃ accounted for 57.8% of primary pollutants in summer and was not improved in following years^[10]. However, O₃ increased much in 2020 with an opposite changing trend of NO₂ because of the complex oxidation effect of O₃ to NO_x^[5,26,41,42]. The average increasing rate (7%) of O₃ in our study were in accordance with that at the non-road side sites^[5]. As our data were all from non-road side sites, O₃ increased before the lockdown period except for that in Chongming with large parts of green plants. This validated the decrease of NO₂ ($p < 0.001$) and VOCs could increase O₃^[41] and also indicates a balance has reached in Chongming. Concentration (16%) during the lockdown period were comparable with those at the roadside sites (17%) in Shanghai^[5]; and increased more than 2.5 times than those in northern China^[41,43]. All the five major pollutants and the AIQ varied much more than the averages all over China^[44].

Major pollutants in different functional areas during Covid-19. To our knowledge, most work only analyzed the effect of lockdown on some of the airborne pollutant. There are almost no studies to trace pollutant changes in long time series and comparing data between pre-lockdown and post-lockdown^[2,9,35,45]. They relate empirical evidences to their observed major pollutants and get results of temporary reductions of these pollutions during the lockdown period^[2,9,35]. Although most part of the world still suffers from Covid-19 and its varieties with more than 27 million

confirmed cases on 4th June 2021^[1], few comprehensive analysis are carried out from pre- to post lockdown's impact on pollutions^[4,5]. As the first reported Covid-19 cases were in China, which really does well in contralling the virus, it offered an excellent oppotunity to study the air-quality before, during and after the lockdown^[6,46].

Concentrations of these pollutants were significantly correlated with wether conditions^[46,47]. The average temperature was about 8 to 9° C with relatively high pressure in Shanghai in January. This aggravated air pollution (Meteorological Administration Official Website). Furthermore, sand from Mongolia desert was carried to Shanghai in winter. This increased the pollution of PM₁₀ in the air^[10]. If the sand dust superposed the impact of local high pressure, it would spread further from north to south Yangzi Delta area including Shanghai to increase the concentration of PM_{2.5} there^[5,25,47,48]. Rainfall and wind speed also matter^[5,48]. The average precipitation is 116.06 mmand 69.25mm in in January and February, respectively^[7]. This indicates there was enough rain over the lockdown period. Rain also absorbs the pollutant and lower down the pollutant concentration^[16,22,29]. The average wind speed was 3.75m/s, a low speed for the spread of airborne pollutants in Shanghai^[10]. So, although there were enough rainfall, the low wind speed and high pressure still increased airborne pollutants.

Availability of lockdown policy respond to diffusion of Covid-19. As we know, Covid-19 brings bad effects on not only human health^[18,20,29,49], but also socio-economic^[18,29]. The lockdown policy indirectly offered chances to study and comparison environmental changes in China before, during and after the lockdown

time^[1]. Policies like lockdowning cities and shutting down factories could reduce the emission of air pollutants from transport and production^[3,16,18,23]. Xuhui, Chongming and Jinshan with various natural landscapes and anthropologic facilities are different functional areas in Shanghai. Compared pollutant changes in the three areas can well discuss how the pollutant concentration was affected by lockdown itself and other determinants^[3,16,23,29]. As mentioned earlier, the lockdown included both the restriction on nonessential travel and the interruption of manufacturing activities^[3,26,47]. Given that the relatively shorter lockdown in Shanghai during the Spring Festival, i.e., 24th Jan to 9th Feb did not involve much industrial production, Table 1 only shows the traffic control in Shanghai as background applicable to all 3 sites. The results is in accordance with the ones in Fig. 1, i.e, only 2 or 3 little peaks were found for SO₂, NO₂ and PM₁₀, the main resource of which are fuel combustion^[9,25,38]. The general decrease during this period is in accordance with the “holiday effect”^[50]. The little pollutant concentration peaks were mainly from cooking and traffic. Whereas, low concentrations were found to both O₃ and PM_{2.5}. As mentioned above (Fig. 2 and Fig. 3), O₃ reduced because of increase of NO₂ and organic reduction produced by human activities^[42,50]. The decreasing rate before lockdown (3%) was almost the same with the value during the lockdown period in northern China^[41]. Whereas the source of PM_{2.5} is external and has less correlation with the local human activities in Shanghai^[25]. Only SO₂ has significant correlations with all other pollutants, that is because it is mainly from fuel combustion, and can attach to PM_{2.5} and PM₁₀^[22].

The global air quality had a dramatic promotion throughout the pandemic of COVID-19^[44,46] because the lockdown supplied a relatively non-industrial period^[36,40,41,44-47,50]. Isolation is an effective way to block the spread of COVID-19^[36,40,41,44-47,50]. However, this means that people have to be blocked at home or somewhere else. They are unable to go out for work, and plants have to stop or reduce their production. This results in lack of living material in some place and could increase human's mental problems such as anxiety and depression^[20,49], which would increase the instability of society^[20]. The progress of social economy is largely dependent on development of some heavy industries, which discharge greenhouse gas and accelerate global warming^[2].

Implication on Environment Policies taken by China. The lockdown period in China during the COVID-19 just rightly provided an effective model that could be pushed throughout the whole world. Concentration of NO₂ in oceans was 3 to 4 times lower than those in total land without the Antarctic^[41], where has a huge ozone hole and with low NO₂ concentration^[51]. The data of Shanghai highlights efforts of keeping pollutant concentration low for years when its growth trajectory takes sustainability into account^[17,22]. Although the improvement of air quality is good within the lockdown period, it is unlikely to be maintained for long if the economy is still supposed to grow at a high speed. Necessary policies should be made to maintain or even improve the post-lockdown air quality^[45]. Wiser policies rather than forced reducing industry and transport should be taken into consideration^[23]. Green energy sources such as wind, solar and photovoltaic power generation are good alternatives

to traditional fossil consumptions, which is high in pollution. Besides, China respond to the concept and task of "carbon neutralization" and "carbon peak" at the first time in order to better safeguard the world's environment and stabilize the climate. Besides, people in China quickly and positively respond to the Blue Carbon Initiative. The plan's aim is to ensure economic growth on the basis of recover good natural environment. It is a good way to control carbon releasing to the atmosphere as ocean is a big sink to the greenhouse gases, such CO, CO₂ and CH₄^[52-54].

Methods

Data collection. The daily data of the pollutants (NO₂, SO₂, O₃, PM_{2.5} and PM₁₀) were provided by Shanghai Municipal Bureau of Ecology and Environment (<https://sthj.sh.gov.cn/>), and average values were used for each day. Three parts (Fig. 4), i.e., Chongming, Xuhui and Jingshan stations were chosen as different functional parts for data analysis. Chongming represents the area covered by large amounts of vegetation. Its total area is 50.94 km² and population of 678,000 with density of about 1 person km⁻² by the end of 2018. Xuhui is the Central Business District (CBD) area for Shanghai. Its total area is 1413 km² and had 818,100 permanent residents^[10] with density of about 13,310 person km⁻² by the end of 2018. Xuhui is the typical area to study how concentrations of the major air pollutants vary in populated urban environment. There are 176 companies registered in Jinshan industrial zone and most of them are chemical companies. In addition, 59 of those firms exhale pollutants^[10]. Its total area is 50.94 km² and the registered population were 522,300 with density of about 10,253 person km⁻² by the end of 2020. We collected a enviromental data set

containing 613 values belonging to year of 2018-2020 from all the three stations.

Data Processing. 1. Two comparisons were done: First, comparison before lockdown period (1st Jan-23rd Jan) and during lockdown period (24th Jan - 9th Feb) in year of 2020. Second, comparison data from the same dates but of different years (**average data of 2018-2019 and data of 2020**).

2. One-way ANOVA, Nonmetric Multidimensional scaling (NMDS) analysis and cluster analysis were used to process the data. SPSS (SPSS Inc., Chicago, USA) was used to do one-way ANOVA; whereas R were used to do cluster analysis (version 3.4.1).

3. The calculation of the Air Quality Sub-Index (AQI) for Air Pollutant (IAQIP) measures the total quality of air are as followed:

$$AQI = \max (I_1, I_2, \dots, I_n) ; IAQIP = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} (C_p - C_{low}) + I_{low}$$

C_p : the concentration of pollutant p ; C_{low} : the concentration breakpoint that is $\leq C_p$

C_{high} : the concentration breakpoint that is $\geq C_p$; I_{low} : the index breakpoint corresponding to C_{low} ; I_{high} : the index breakpoint corresponding to C_{high} .

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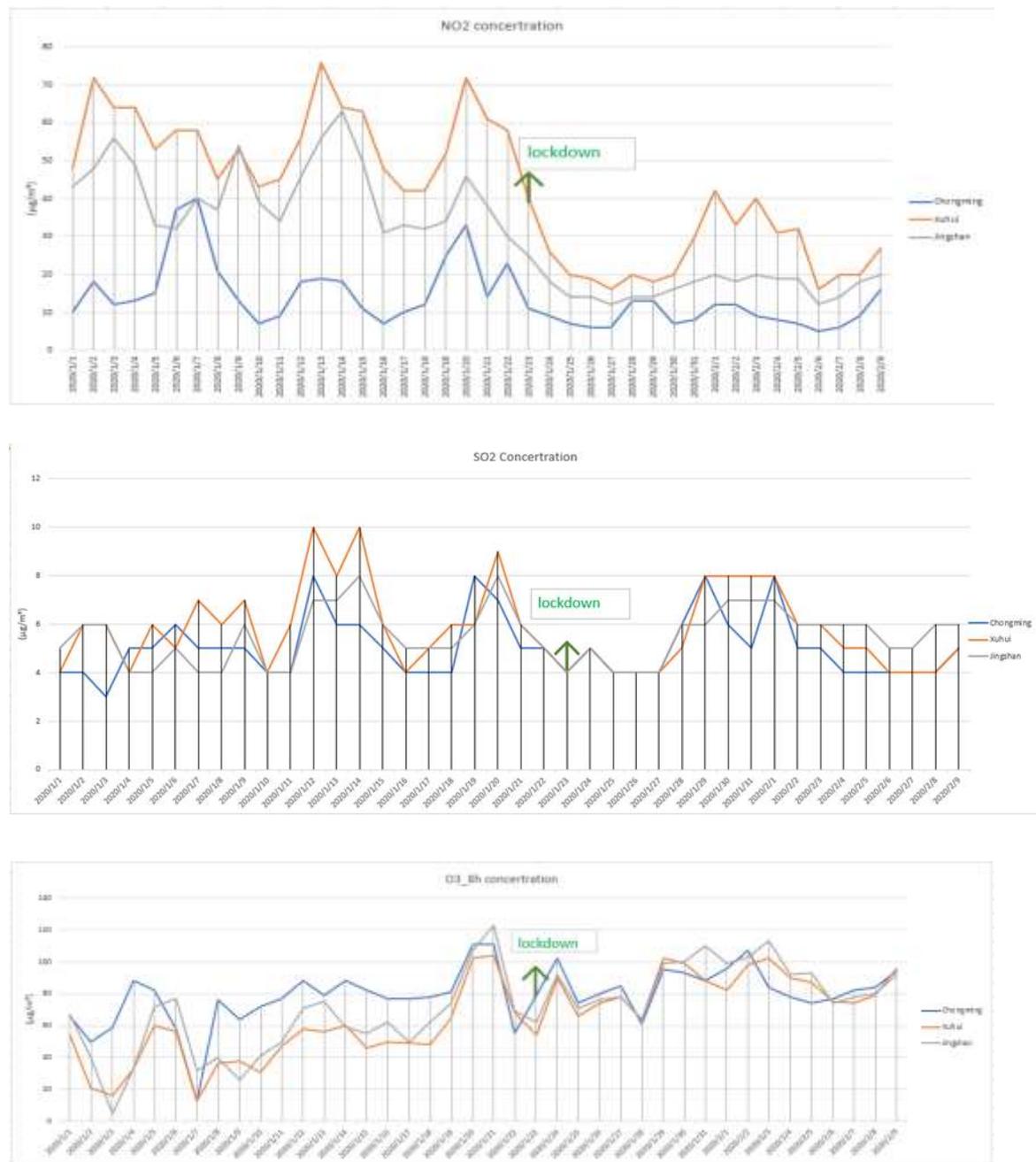
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Figure legends & Figures

Fig. 1 Changes of major pollutants from 1st Jan to 9th Feb with lockdown beginning date of 23rd Jan at different parts of Shanghai



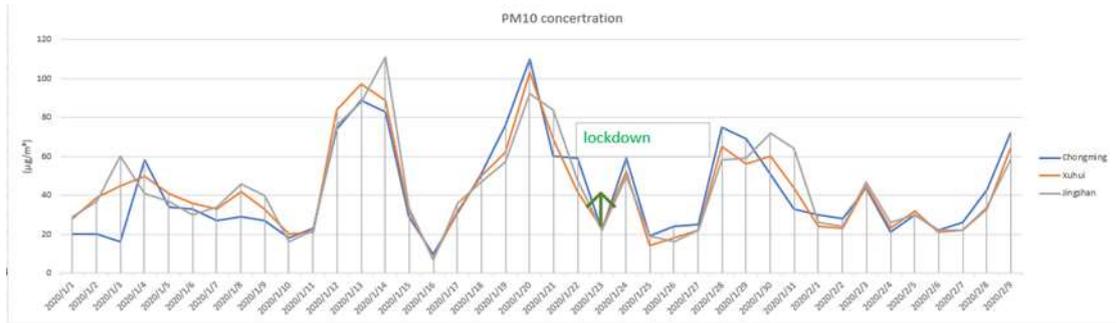


Fig. 2 One-way ANOVA analysis for different parts and total of Shanghai before and during the Covid-19: during (B) and before (F) lockdown peirod

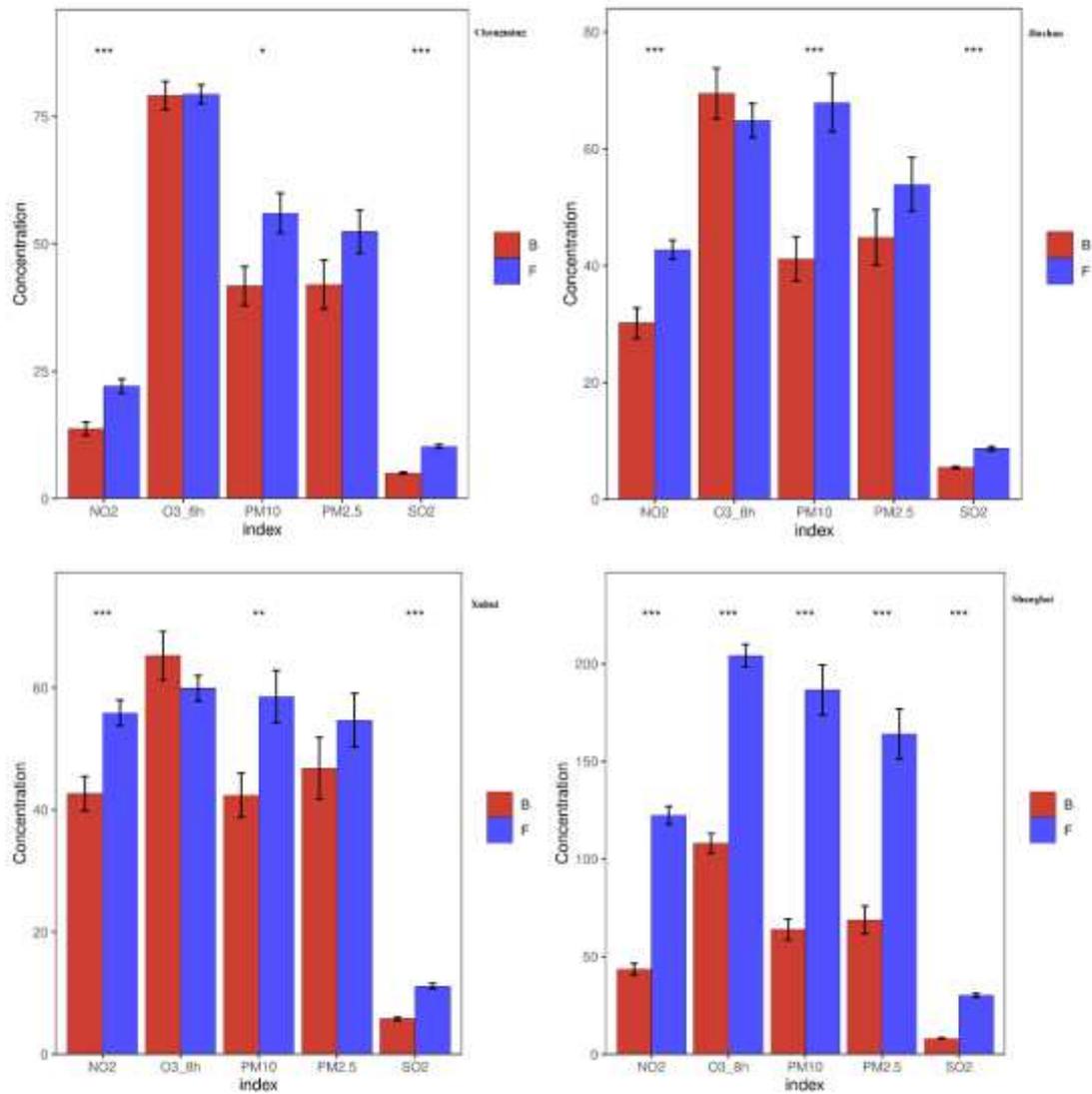
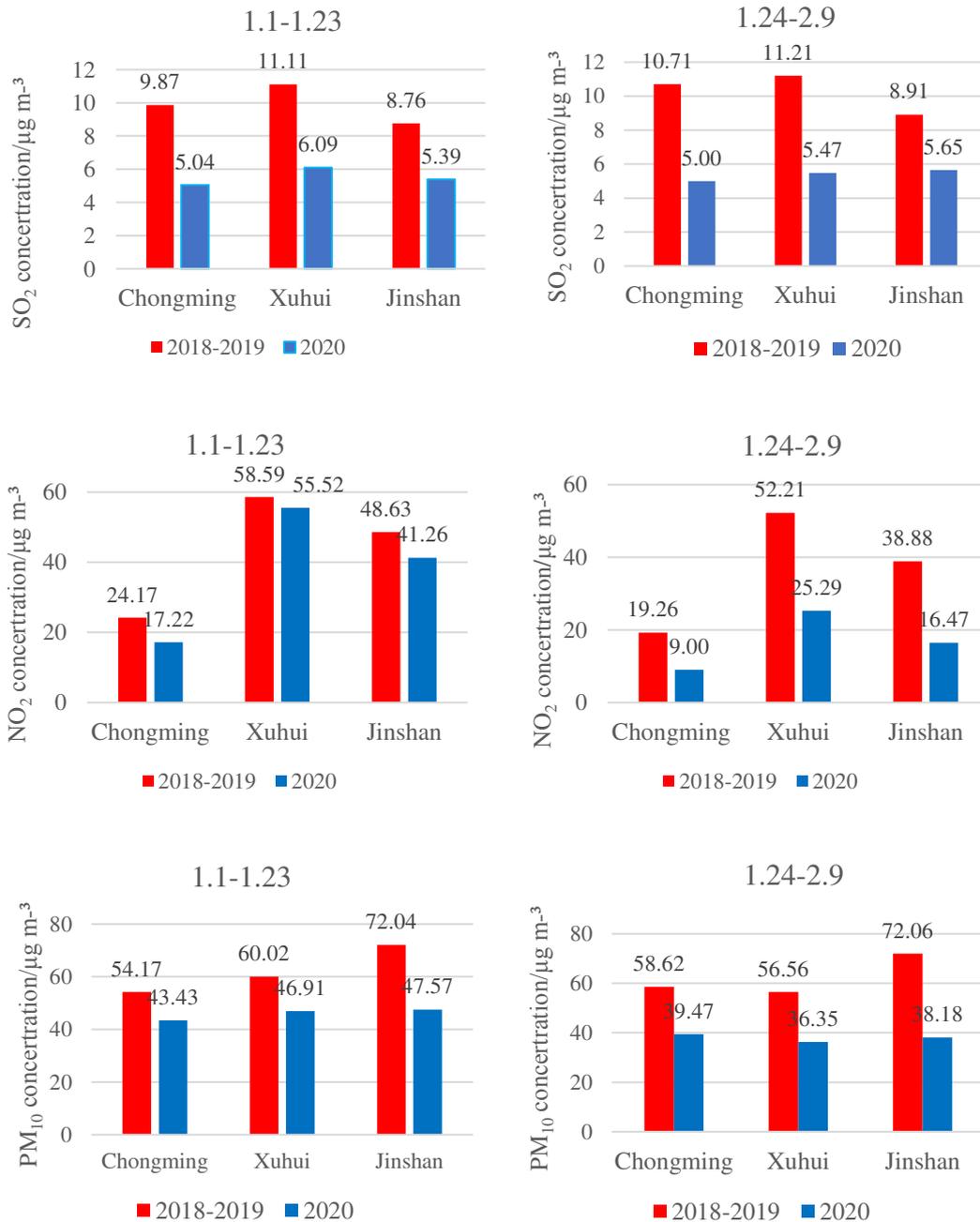


Fig 3. Average concentrations of different pollutants in different years of Shanghai before and during the Covid-19 period



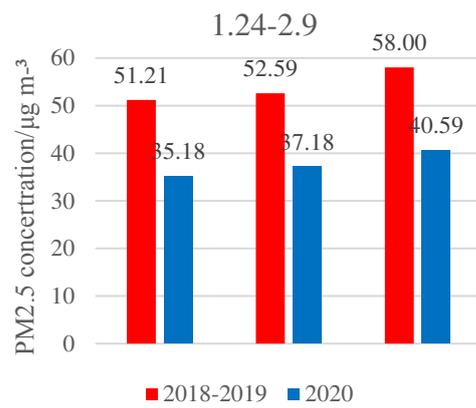
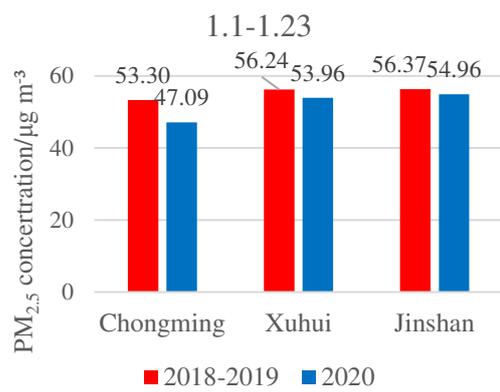


Fig. 4 Sampling areas in Shanghai, China



Table 1 Traffic control in January and February of 2020 in Shanghai from Shanghai

Bureau of Statistics

	January	February	
Total amount of cargo transported (10,000 tons)	10173.28	8583.22	-8.48%
Highway	3560	2200	-23.61%
Airport	30.22	19.16	-22.40%
Railway	1050.49	68.25	-87.80%
Harbour	6.3	0.01	-99.68%

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