How COVID-19 Impacted PM 2.5 and Air Quality in China’s Main Cities

Xuening Tang1, a, †, Bokai Yang2, b, † and Zhechen Wu3, c, †

1School of Environmental Science and Engineering, Shandong University, Qingdao, Shandong 266237, China;
2School of Petroleum Engineering, Southwest Petroleum University, Chengdu, Sichuan 610500, China;
3College of Art and Science, Boston University, Boston, Massachusetts, 02215, United States.

a201700210071@mail.sdu.edu.cn, b201731011608@stu.swpu.edu.cn,
czw31415@bu.edu

†These authors contributed equally.

Abstract. The air quality in modern cities is one of the topics that people are very concerned about, due to its impact on people’s health and production. There have been many studies on air quality improvement and transmission mechanisms, showing that proper measures can improve air quality efficiently. Under the unexpected COVID-19 time, lots of measures were taken by the government, and the question of whether those strict measures have somehow influenced the local air quality remains. This article mainly combines some relevant policies and behaviors during the outbreak of COVID-19 to explore whether this epidemic has an impact on emissions, and to observe whether the sub-index PM 2.5 representing air quality is changed. Based on assessing the cause of air pollution in each city and evaluating the policy implemented to prevent COVID-19 from spreading, the topmost effective policies that reduce air pollution are preventing residents’ transportation, reducing deliveries, and shutting down heavy industry factories.

1. Introduction

In recent years, China has advanced huge economic achievements that have resulted in increased anthropogenic activities, which led to air pollution. More than three-fourths of the total urban population in China suffer from the air quality that does not meet the national ambient air quality standards of China [1]. Due to China’s coal-dominated energy structure, most cities are heavily polluted by various hazardous air pollutants, including Sulfur Dioxide, Nitrogen Oxide, and particulate matter. The sources of air pollution on average can be attributed to several sectors: transportation fuels (15–25%), fossil fuel burning in power plants (30–50%), and industrial facilities (25–35%) that all contributes high concentration of NO2, which is also a significant source for PM2.5 [2].

Air pollution thereby became a societal issue that impacts both public health challenges and economic loss for the country. In 2010, a study estimated that over 3.2 million people in China could be attributed to PM2.5, which has increased from an estimated 2.9 million people back in 1990 [3]. Due to PM2.5, China has an estimated welfare loss of 248 billion US dollars in 2015 alone. The estimated pollution-health costs range from 3.9% to 5.4% to China’s historical gross domestic product (GDP) [3].
Noticing the severe threat from air pollution to public health, General Secretary of Chinese Communist Party Xi Jinping has addressed China’s air pollution as a significant threat to the country and has implemented multiple different strategies, including the elimination of ceramics, coal, and steel industries; and has proposed to develop green and low carbon industries. Thus, policy implementations have become a key tool to control air pollution. In 2008, in order to hold a clean Beijing Olympics, a series of pollution control measures were implemented from July 20, 2008, to September 17, 2008, limiting heavy manufacturing, reducing commercial combustion facilities in Beijing, and restricting car usage [4]. Studies have shown concentrations of particulate and gaseous pollutants decreased substantially between pre-Olympic to during-Olympic period (Rich et al). In 2013, the Chinese government issued the Air Pollution Prevention and Control Action Plan (APPCAP) where ten specific policy criteria are addressed, encouraging clean energy supplies and reducing cars that emit air pollutants [5]. In order to assess APPCAP’s effectiveness, a study on 74 cities showed a significant decrease in air pollution pollutants between 2013 to 2017, including a 33.3% decrease in PM$_{2.5}$ and a 27.8% decrease in PM$_{10}$ [6].

More extreme policy measures were implemented in 2020 for public health emergencies. 2019 Coronavirus disease (COVID-19) has become a severe global health threat, with almost every country in the world having people infected. The virus was first revealed in late December 2019 in the city of Wuhan of Hubei Province, where clusters of pneumonia cases of unknown virus brand were found. By January 30, 2020, the World Health Organization declared the coronavirus outbreak a public health emergency of international concern. In response to the outbreak, the Chinese government responded rapidly with a lockdown imposed on Wuhan on January 23 and quarantine all over the country, with most industries shutting off and transportation halted [7]. Most people were forced to stay at home and were only able to get out in a short time period. With China’s policies of locking down almost all nonessential businesses and activities, the air pollution emitted from transportation and industrial facilities might decrease significantly, and the air quality was better. Thus, the presented findings can help establish a connection between policies and air pollution and discuss potential applications of such policies’ impact on reducing air pollution. In the meantime, when calculating social welfare under the impact of COVID-19, the savings from the society suffering from less severe air pollution might also be considered.

This study will evaluate the impact of the policies on air pollution by using an environmental impact assessment method for four cities in different regions: Hangzhou, Wuhan, Xi’an, and Guangzhou, all of which have similar populations and GDP per capita but different economic structure. Then, the study will also present on how air pollution has changed before and after cities lockdown by using the PM$_{2.5}$ index, analyze economic structures and the potential reasoning of the decrease in PM$_{2.5}$, and finally provide results to evaluate policies that government might be able to implement to reduce PM$_{2.5}$ pollution efficiently in the future.

2. Data and Methodology

2.1 Air Quality Data
Air quality monitoring data for four Chinese cities were collected, and they were divided into three periods according to the COVID-19 timescale: November to December in 2019, January to March in 2020, and April to May in 2020. These are selected as the air quality data before, during, and after the outbreak of COVID-19 to compare the PM$_{2.5}$ concentrations to see whether there are any impacts of policies and activities in COVID-19. The average PM$_{2.5}$ values of each day in the seven months of the four cities were collected [8], and the average value was calculated to obtain the monthly average PM$_{2.5}$ value for comparison.

2.2 Policies Data
Policy data for different sectors were collected, including transportation, residents, industry, etc. Most of these policies originate from Internet collection and official websites of various departments in China.
The policies that related to the development of the epidemic mainly come from the National Health Commission [9], and they are also with regard to the overall coordinated deployment of sectoral actions within the country during the COVID-19, such as “Notice of the State Council on Strengthening Epidemic Prevention and Controlling Epidemics”. The data for transportation was obtained from the Ministry of Transport [10]. Such policies have standardized and restrained the traffic level in different periods of the epidemic from many aspects, ensuring the smooth passage of emergency materials transport vehicles [11], and the prevention and control of online car-hailing services [12]. The policy data for other measures and behaviors were obtained from the Internet and the National Bureau of Statistics. [13]

2.3 Assessment System
In order to better identify the impact of policies and behaviors on air quality during the COVID-19 period, an environmental impact assessment system was created. The previously mentioned policies can be divided into many different aspects of the impact, so we further accomplished a more detailed classification. Table 1 shows the corresponding activity data and different policies of different fields taken during the COVID-19. Through special behavior analysis in different fields, we can see whether it has an impact on the atmospheric environment and classify incidence to the atmosphere according to the magnitude of the impact.

| Measures | Activities |
|----------|------------|
| RTL      | Residents travel less |
| RCO      | The rise of cloud office |
| IUD      | Increased use of disinfection products |
| FPS      | Factory production cuts and shutdowns |
| RCC      | Reduced consumption of catering equipment |
| HAP      | Hoarding of agricultural and livestock products |
| DET      | The decrease in the express and takeaway delivery |
| PMI      | The production of masks has increased sharply |
| IWR      | Improvement of wildlife-related regulations |
| IAP      | Increased social awareness of environmental protection |
| ISM      | Increase in solid waste generated in medical and other industries |
| ECS      | Some environmental protection companies shut down |
| CPN      | Construction and production of medical facilities and equipment |
| IIS      | Increase investment in scientific research and promote industrial technology upgrade |

Based on the epidemic situation in three different periods, the Chinese government has taken a series of measures to contain the spread of COVID-19. As shown in Figure 1, we conducted several measures to evaluate their impacts on the atmosphere by different levels. Among them, RTL, DET, FPS measures have the most significant positive impacts on the atmosphere, mainly by reducing the direct or indirect emissions of harmful gases. However, the ISM and PMI measures have negative impacts on the atmosphere due to production and composting gases.
Figure 1. Identification and magnitude of the environmental impact of behavioral measures (Classification standard: Positive numbers represent positive effects; negative numbers represent negative effects. ”-10~-8/10~8” means “Seriously affect the atmosphere”; “-7~5/7~5” means “Affect the atmosphere”; “-4~3/4~3” means “Moderately affect the atmosphere,” and “-2~1/2~1” means “Slightly affect the atmosphere.”)

3. COVID-19 Outbreak Impact Analysis

3.1 Gap analysis on Policies and Measures

We investigated the policy differences in different time periods and collected some relevant data. For example, for the on-road transportation sector, we sorted the data about road freight volume and passenger flow in Table 2. These data showed the changes in China's transportation during this period, indirectly reflect the impact of relevant measures. At the first stage, pre-COVID-19, the road freight volume and passenger flow had a small increase compared with the same period of last year. However, during COVID-19, there was a significant decrease. Obviously, these measures have had an effective reduction in passenger activity. During the third stage of COVID-19, there has been a decrease in road freight volume and passenger flow compared with the same period of last year, whereas there was also a trend of steady growth in the following months, which indicated that measures to promote an effective resumption of work have made some progress in the remission of the epidemic.

According to relevant questionnaire statistics, during the outbreak of COVID-19, the number of Chinese adults who made regular daily trips dropped from 88.8% to 75.1%, showing a significant decrease [14]. In addition, according to the survey conducted by the China Cuisine Association, 93% of catering enterprises chose to close their stores during the epidemic. Of those, 73% closed all their restaurants [15]; 8% of the companies closed more than 80% of their stores. All the specific changes above on the human activity level revealed the effectiveness of these measures.

| Month, year | 11,2019 | 12,2019 | 01,2020 | 2,2020 | 3,2020 | 4,2020 | 5,2020 |
|-------------|---------|---------|---------|--------|--------|--------|--------|

Table 2. Passenger and cargo volume in China during COVID-19
3.2 Gap analysis in Air Quality Data

The monthly average PM$_{2.5}$ concentrations in three cities of Wuhan, Guangzhou, and Hangzhou are shown in Figure 2. It shows that the first period obviously had the highest average concentration at 149.54 (Wuhan), 122.14 (Hangzhou), and 123.59 (Guangzhou) $\mu$g/m$^3$, and then the air quality improved significantly from the second stage by dropping the average PM$_{2.5}$ concentration to 128.9, 94.8, and 83.13$\mu$g/m$^3$, respectively. Especially for Guangzhou, the decrease could reach to almost 35%. Although the data in Figure 2 of Xi’an was not the highest in the first stage, there has also been a significant downward trend from 213.5$\mu$g/m$^3$ in January to 92.1$\mu$g/m$^3$ in May. Therefore, the PM$_{2.5}$ of air quality in these cities has improved significantly during the outbreak of COVID-19. However, the specific average air quality value decline time, and the time each city began to adopt policy prevention and control are also very related.
b) Hangzhou

c) Guangzhou
Figure 2. Changes of average monthly PM$_{2.5}$ concentration (μg/m$^3$) in the whole three periods in four cities

However, in addition to the policy impact during the outbreak of COVID-19, there is also the impact of seasons on air quality. In winter, there are often many harmful gas emissions from household heating or coal-burning in north China, so this may also be the reason for the obvious improvement in spring air quality. But the heating time in most cities lasts from mid-March to April, and there is also a significant drop in March and April, which shows that the measures we mentioned are effective in improving air quality.

To eliminate this impact, we further investigated the air quality data for the same time as the second stage in 2019 for comparison, to confirm the policies and measures are truly making differences in air quality. In Figure 3, comparing the distribution of days monthly in different levels of PM$_{2.5}$ concentration, it is found that the numbers of heavily and moderately polluted days (>100μg/m$^3$) in four cities have been significantly reduced by 17.9% in Wuhan, 54.2% in Hangzhou, 42.1% in Guangzhou and 8.5% in Xi’an in 2020, and the numbers of days under good air quality have increased 85.7%, 70.3%, 18.4%, and 72.7%, respectively. These changes proved that the air quality was indeed better than the same period. It can also exclude some seasonal climate factors. Therefore, through these two sets of figures, it can be proved that the policy and behaviors influence pollution and air quality during the outbreak of COVID-19.
Month

a) Wuhan

Month

b) Hangzhou
Figure 3. PM$_{2.5}$ concentration distribution in four cities in February and March of 2019 and 2020

4. Conclusion
The study shows that PM$_{2.5}$ concentration in Wuhan, Hangzhou, Guangzhou, Xian cities decreased by 29.5%, 27.8%, 45.1%, and 56.9% maximally in three periods from the November of 2019 to the May
of 2020, and almost all the declines appeared from January to March in 2020 and slightly went back when it was April in 2020, which are potentially due to the impacts of the strict measures to control COVID-19 spread. It is further proved by the establishment of the evaluation system, which preliminary explained that some main behaviors and measures, like less residents’ traveling, decrease in the express and takeaway delivery, and shutdowns of factories during COVID-19, had huge impacts on the air quality by the significant decrease of polluted days in the second stage compared to the same period in 2019. The increase of good air quality days demonstrated the effectiveness of the evaluation system. Therefore, the improvement of these behaviors can improve urban air quality, and governments and policymakers can use these measures to implement emission reductions.

References
[1] Shao M, Tang X Y, Zhang Y H, Li W J, 2006. City clusters in China: air and surface water pollution. Frontiers in Ecology and the Environment, 4(7): 353–361. DOI: 10.1890/1540-9295(2006)004
[2] Rohde, Robert A., and Richard A. Muller. “Air Pollution in China: Mapping of Concentrations and Sources.” Plus One, vol. 10, no. 8, 2015, doi:10.1371/journal.pone.0135749.
[3] Zeng, Bohan, et al. “Interprovincial Trade, Economic Development and the Impact on Air Quality in China.” Resources, Conservation and Recycling, vol. 142, 2019, pp. 204–214., doi:10.1016/j.resconrec.2018.12.002.
[4] Rich DQ, Kipen HM, Huang Wei, et al. Association Between Changes in Air Pollution Levels During the Beijing Olympics and Biomarkers of Inflammation and Thrombosis in Healthy Young Adults. JAMA. 2012;307(19):doi:10.1001/jama.2012.3488.
[5] “The State Council of People’s Republic of China Announcing Ten Regulations of Air Pollution Prevention and Control Action Plan, 12 Sept. 2013, www.gov.cn/jrzg/2013-09/12/content_2486918.htm.
[6] Huang, Jing, et al. “Health Impact of China’s Air Pollution Prevention and Control Action Plan: an Analysis of National Air Quality Monitoring and Mortality Data.” The Lancet Planetary Health, vol. 2, no. 7, 2018, doi:10.1016/s2542-5196(18)30141-4.
[7] Zu, Zi Yue, et al. “Coronavirus Disease 2019 (COVID-19): A Perspective from China.” Radiological Society of North America, vol. 296, no. 2, 2021. RSNA, https://pubs.rsna.org/author/Xu%2C+Peng+Peng.
[8] Information on https://aqicn.org/map/china/cn/
[9] Information on http://www.nhc.gov.cn/wjw/index.shtml
[10] Information on http://www.mot.gov.cn/
[11] Information on http://www.stats.gov.cn/
[12] Information on http://xsgk.mot.gov.cn/2020/jigou/ysfws/202006/t20200623_3316062.html
[13] Information on http://xsgk.mot.gov.cn/2020/jigou/ysfws/202006/t20200623_3316072.html
[14] Nan, Jiang, et al. "Transportation Activity Patterns of Chinese Population during the COVID-19 Epidemic." Research of Environmental Sciences, vol. 33, no. 7, 2020, http://qikan.cqvip.com/Qikan/Article/Detail?id=7102351713.
[15] The China Culinary Association has released a report on the impact of COVID-19 on China's catering industry in 2020. China Food, 2020(4):80-87.