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A Systematic Literature Review of the Impact of COVID-19 Lockdowns on Air Quality in China

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ABSTRACT

This literature review systematically examines the effect of COVID-19 lockdowns on pollutant concentrations in China by synthesising the reported evidence. Following PRISMA guidelines, we used predefined eligibility criteria to search the databases of PubMed, Scopus, Web of Science and EBSCO Host for peer-reviewed published literature that investigated the nexus between COVID-19 and air quality in China. After screening the titles, abstracts and full texts of the retrieved results, two reviewers independently evaluated the relevant data. 35 of 508 studies met our criteria. The majority of the eligible studies reported data from central China (e.g., Wuhan and Hubei Province), and the most frequently measured air pollutant was nitrogen dioxide (NO$_2$; 51 values in 28 studies), followed by fine particulate matter (PM$_{2.5}$; 49 values in 26 studies). We found evidence of a substantial reduction in air pollution immediately after lockdown measures were implemented, with traffic-related NO$_2$ exhibiting the largest decrease. The reported reductions in air pollution varied by region and period. Specifically, urban, industrial and highly populated areas of China experienced greater improvements in air quality than rural, residential and less populated areas. Additionally, owing to meteorological factors, the effects differed between inland and coastal regions. However, despite the changes, the pollutant concentrations in many regions (e.g., Beijing, where PM$_{2.5}$ and PM$_{10}$ levels remained above 100 µg m^{-3}) still exceeded the World Health Organization (WHO)'s 24-hour mean guidelines (e.g., 25 µg m^{-3} and 50 µg m^{-3} for PM$_{2.5}$ and PM$_{10}$, respectively). Without the support of adaptive environmental strategies, the recent gains in air quality will be unsustainable.

Keywords: Air pollution, Air contamination, Atmospheric environment, Coronavirus, 2019-nCov

1 INTRODUCTION

The first novel coronavirus (COVID-19) outbreak was reported in Wuhan, China, in December 2019 (Filonchyk *et al.*, 2020; He *et al.*, 2020; Le *et al.*, 2020; Ghahremanloo *et al.*, 2021). Subsequently, COVID-19 has become a serious public health threat worldwide as it transmitted rapidly and caused millions of infections and deaths, especially among the elderly. Therefore, it has been declared as a global pandemic by the World Health Organization (WHO; Gautam, 2020). As of 23 March 2021, COVID-19 had affected 124 million people in 192 countries and territories with 2.7 million deaths around the world (Johns Hopkins University, 2021).

COVID-19 is an infectious disease that transmits from human to human through direct contact, droplet and aerosol transmission (Fernandez-Montero *et al.*, 2020; Wang and Du, 2020). To prevent the spread of this infectious disease, the Chinese government took a nationwide contingency plan (followed by other nations) to restrict human activities. More specifically, the Chinese government implemented widespread restricted road traffic and human activities in late January to early February 2020 (Chen *et al.*, 2020c). Similar measures have been taken by most of the countries of the world in the form of restricted transportation, and closing of business, economic, social, educational, cultural and recreational activities to control the transmission of the virus

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(Dantas *et al.*, 2020). During the lockdown, economic activities decreased dramatically, and people were isolated in their homes. Within a short period of time, environmental researchers noticed the positive side effect of the lack of human economic activity. Lockdown measures resulted in the improvement in air quality, as air pollutants such as particulate matter with a diameter of 10 µm or less (PM_{10}), particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), sulphur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) decreased significantly (Fan *et al.*, 2020a; Filonchyk *et al.*, 2020; Lian *et al.*, 2020; Nichol *et al.*, 2020; Pei *et al.*, 2020).

Air pollution is a significant environmental health threat to humans. According to the WHO (2016), ambient air pollution caused 4.2 million deaths worldwide and 81 deaths per 100,000 population in China in 2016 (WHO, 2016). Air pollution is a serious concern in China (Dong *et al.*, 2019). In 2016, the country contributed 33%, 24%, and 31% of the world's total emissions of SO_2, NO_2, and CO, respectively. Nationwide social lockdowns imposed by the national and provincial Chinese governments created an opportunity to evaluate changes in air quality. It is assumed that a decrease in human activities reduce pollutant levels in the atmosphere significantly.

The impact of lockdown on China's air quality, which has a significant effect on global air quality, cannot be ignored. This positive impact of lockdown in terms of improvement in air quality in China (ranked 11th based on the average $PM_{2.5}$ exposure) has not yet been identified adequately in the existing literature. In addition, there are significant heterogeneities in reported changes in the concentration of air pollutants in China during COVID-19 lockdowns. This calls for a comprehensive synthesis of the existing research. Several recent studies called for further research on this context (Chen *et al.*, 2020c; Ming *et al.*, 2020). There are several reasons for selecting China as the study setting. Firstly, with almost 1.4 billion people, China is the most populous country in the world (World Bank, 2017). Secondly, 48 Chinese cities featured among the 100 most polluted cities globally in 2019 (IQAir, 2020). Thirdly, China has an advanced nationwide air pollution monitoring system ensuring the availability of meticulous data (IQAir, 2020). Lastly, due to the COVID-19 outbreak, China imposed very strict lockdown measures in many cities and regions. Therefore, this study attempts to analyse evidence from scientific research articles on the extent of the improvement in China's air quality due to COVID-19-related lockdowns.

The objective is to provide a quantitative as well as a narrative synthesis of the recent evidence from the published literature that reported on changes in air quality in China during COVID-19 lockdowns. Given the differences in the impacts of partial or full lockdown on China's air quality at the national, provincial and regional level, the current study presented a systematic literature review based on a comprehensive analysis of 35 research articles published since February 2020.

This study considered two key issues: Did partial or full COVID-19-related lockdowns improve China's air quality significantly? And what is the level of improvement in air quality measured in terms of the reduction of $PM_{2.5}$, PM_{10}, SO_2, CO, ozone (O_3) and NO_2 and does it differ across China? The findings of this study may serve as reference for improvement in air quality due to lockdown measures and thus be helpful to policymakers for post-pandemic air quality management.

2 METHODS

2.1 Literature Search

The preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines were used to conduct this systematic literature review (McInnes *et al.*, 2018). The PRISMA approach provides strategies for a detailed database search using selected search terms and a set of predetermined inclusion and exclusion criteria (Shaffril *et al.*, 2018). The authors conducted a systematic review of the articles that focused on and reported changes in air quality during COVID-19 lockdown in Chinese cities and provinces. The online databases of EBSCO Host, PubMed, Web of Science, and Scopus were searched from inception to 10 September 2020. The following pollutants were considered as a measure of air quality: NO_2, $PM_{2.5}$, PM_{10}, SO_2, CO, O_3 and air quality index (AQI) (Xiong *et al.*, 2020).

2.2 Eligibility Criteria

This study included journal articles that estimated variations in air quality in China using the following criteria: 1) the peer-reviewed published article was original; 2) the study included at least one Chinese city or province; and 3) the study included quantitative measures or results of at least one of the air pollutants. Studies estimating only the outdoor air quality were included in the review, and the study did not apply any limitations regarding study design or time. Finally, studies that did not quantitatively estimate and report the change in air quality were also excluded from this study. Table 1 lists the predetermined exclusion and inclusion criteria used in this study.

2.3 Search Terms and Database

Table 2 includes the complete search strategy of this literature review. Search terms included “COVID-19”, “air pollution” and “China”. Search terms related to these specific keywords were also included. A research librarian assisted in developing the search strategy. Based on the predetermined search strategy and the inclusion and exclusion criteria, two reviewers autonomously conducted the database search. This study identified additional literature by scanning the references (backward search) of the selected articles. Detailed search terms for specific database have been listed in Appendix A. This study used EndNote (X9) software to organise and manage the references.

2.4 Study Selection and Data Extraction

Two authors independently evaluated studies identified from the database search to assess their eligibility for inclusion. They reviewed the title and abstract and screened full text of the article (if required). Full-text screening was conducted for articles that met the inclusion criteria (after an initial screening of the abstract). In case there were any differences of opinion, the two authors attempted to resolve the disagreement through discussion. If no agreement could be reached a third author was involved who resolved the conflict. Two authors also screened full-text versions of the included articles to provide independent judgment regarding their quality. Lastly, to locate potential additional studies, the reference lists of the included articles were also searched by the two authors independently.

The authors extracted the following data from the selected studies: author, year of publication, study design, study setting, time comparison, and key findings related to air pollutant measures. One author conducted the data extraction using the PRISMA guidelines (McInnes *et al.*, 2018) and others verified the extraction of data from the selected studies.

2.5 Assessment of Study Quality

To evaluate the quality of the included studies, this study used the Strengthening the Reporting of Observational Studies in Epidemiology (Cardona *et al.*, 2013) statement checklist (von Elm *et al.*, 2007). 15 tools from the STROBE checklist were used: background, objective, setting, participants, data source, study size, quantitative variables, statistical method, sensitivity analysis, descriptive

Table 1. Inclusion and exclusion criteria.

Criterion	Eligibility	Exclusion
Literature type	Peer-reviewed published journal articles.	Book, book series, chapter in book, conference proceeding, online report, short comments, correspondence, short points, reviews or letters, invited editorials, pre-prints without peer review, letter to the editor or editorials that summarised the results of the included articles.
Language	English (no studies were available in the official language of China).	Non-English language literature.
Country	China (mainland).	Any other country, state or region.
Other	Studies not focused on China; however, reported results from Chinese cities, provinces or regions. Studies exclusively focused on outdoor air quality.	Studies focused on COVID-19 outbreak and indoor air quality, meteorological parameters on the spread of COVID-19, air pollution and COVID-19 infection or deaths, preventing carbon emission retaliatory rebound post-COVID-19. Studies that reported aggregate (global) outcomes but the individual country-specific outcome was unavailable.

Table 2. Characteristics of the included studies.

Variables	No. of Studies (%)
Study design	
Quantitative	35 (100%)
Study year	
2020	35 (100%)
Source of data	
Satellite (TROPOspheric Monitoring Instrument)	12 (34%)
Ground-level station	23 (66%)
Time compared	
Pre- and post-lockdown 2020	8 (23%)
Post-lockdown 2020 with 2019	15 (43%)
Post-lockdown 2020 with mean of 2017–2019	7 (20%)
Post-lockdown 2020 with mean of 2015–2019	5 (14%)
Study setting	
Nationwide	9 (26%)
Cities, provinces or regions	26 (74%)
Type of analysis	
Descriptive analysis	28 (80%)
Regression analysis	7 (20%)
Criteria pollutants	
NO_2	28 (80%)
$PM_{2.5}$	26 (75%)
PM_{10}	17 (49%)
SO_2	17 (49%)
CO	18 (52%)
O_3	12 (34%)
AQI	7 (20%)

data adjusted and unadjusted results, limitations, interpretation of findings and funding sources of the study (Items 2, 3, 5–8, 10–14, 16, 18–20, 22) (Appendix B and Appendix C). Other items from the STROBE checklist were not relevant for assessing the quality of the papers.

Two authors independently evaluated the quality appraisal, which was further verified by another author. Each item was coded *Y = present*, *N = not present*, *P = partially present* or *N/A = not applicable*. Lastly, the positive judgement percentage was calculated to demonstrate the quality of the included studies.

2.6 Data Synthesis

There were considerable differences in the study setting, methods, measures of outcomes, time period comparison and significant results reported in the selected studies. Hence, this study conducted a narrative and qualitative synthesis of the key findings. The data are plotted in graphs to report the percentage change in air quality at different time periods, and box plots used to show median and interquartile ranges and correlation tests were conducted to understand the relationships between NO_2 and $PM_{2.5}$, PM_{10} and $PM_{2.5}$, and SO_2 and $PM_{2.5}$. The main objective was to categorise and report both qualitative summary and quantitative estimates demonstrating changes in air quality during COVID-19 lockdowns in China.

3 RESULTS

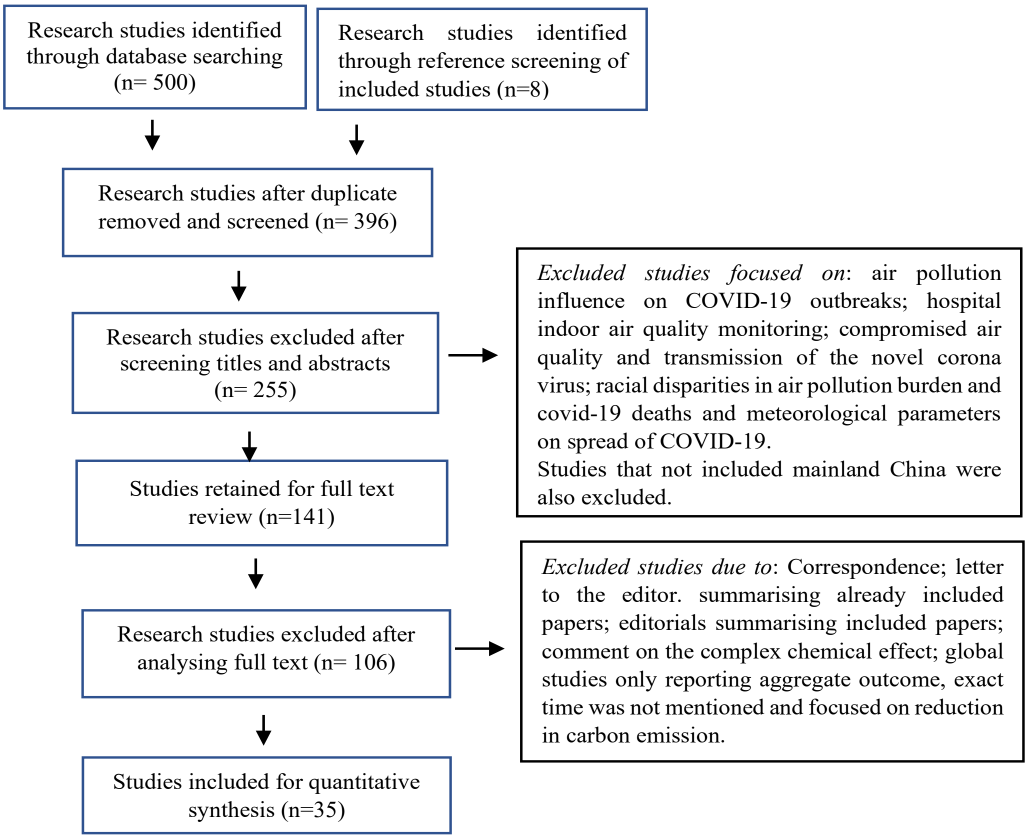
3.1 Identification and Characteristics of Studies

This study identified 500 studies through the literature search, and another eight studies were included through the backward search of the included studies. A total of 396 studies remained after duplicates (same articles from two different database searches) were removed. The authors reviewed the title and abstract of 396 articles, and screened full texts of 141 articles, amongst which 35 studies met the predetermined inclusion criteria (Fig. 1). Several articles were excluded, because their main focus was to examine the impact of air quality on COVID-19-related infections. Other key reasons for exclusion of articles are illustrated in Fig. 1. Nine of these reported aggregate data on China and the rest estimated air quality changes for various cities and provinces of China (Fig. 2). A majority of the studies (n=24) included Wuhan (located in Hubei Province) as the primary study location.

All the studies were published in the year 2020 and quantitative in their study design (Table 2). The included studies provided air quality data in China from satellite (n = 12) and ground-level (n = 23) stations. Further analysis revealed that studies conducting global analysis commonly used data from satellite and studies focusing on specific Chinese cities and provinces commonly used data from ground-level stations. A majority of the studies compared the lockdown period of 2020 in China with identical periods of 2019 (n = 15). Other studies compared pre- and post-lockdown periods of 2020 (n = 8), post-lockdown period of 2020 with a mean of identical periods of 2017–2019 (n = 7) or 2015–2019 (n = 5). 26 (74%) studies focused on measuring the change in air quality in specific cities, provinces and regions of China. Finally, we categorised the included studies based on types of pollutants measured. 28 (80%) provided 51 values for NO_2 and 26 (75%) recorded 49 values for $PM_{2.5}$.

3.2 Reduction in Air Pollution

Fig. 3 presents the dispersion of changes in the air quality measures of the included studies for all China, and the city of Wuhan and Hubei Province. The estimated median reduction for NO_2, $PM_{2.5}$, PM_{10}, SO_2, CO, and AQI during COVID-19 lockdown with data from all the included studies (irrespective of the time period compared) is 45.1%, 26.6%, 31.4%, 31.3%, 20.7% and 21.7%, respectively. All data box plots are comparatively short, which indicates fewer variations in the reported changes in air quality measures in China. All the means and medians are negative, which signifies improvement in air quality across China, irrespective of the time periods compared. The average reduction in all air quality measures (except for CO) were higher in Wuhan and Hubei



Research studies identified through database searching (n= 500)

Research studies identified through reference screening of included studies (n=8)

Research studies after duplicate removed and screened (n= 396)

Research studies excluded after screening titles and abstracts (n= 255)

Excluded studies focused on: air pollution influence on COVID-19 outbreaks; hospital indoor air quality monitoring; compromised air quality and transmission of the novel corona virus; racial disparities in air pollution burden and covid-19 deaths and meteorological parameters on spread of COVID-19.
Studies that not included mainland China were also excluded.

Studies retained for full text review (n=141)

Research studies excluded after analysing full text (n= 106)

Excluded studies due to: Correspondence; letter to the editor. summarising already included papers; editorials summarising included papers; comment on the complex chemical effect; global studies only reporting aggregate outcome, exact time was not mentioned and focused on reduction in carbon emission.

Studies included for quantitative synthesis (n=35)

Fig. 1. Framework of the systematic literature review process.

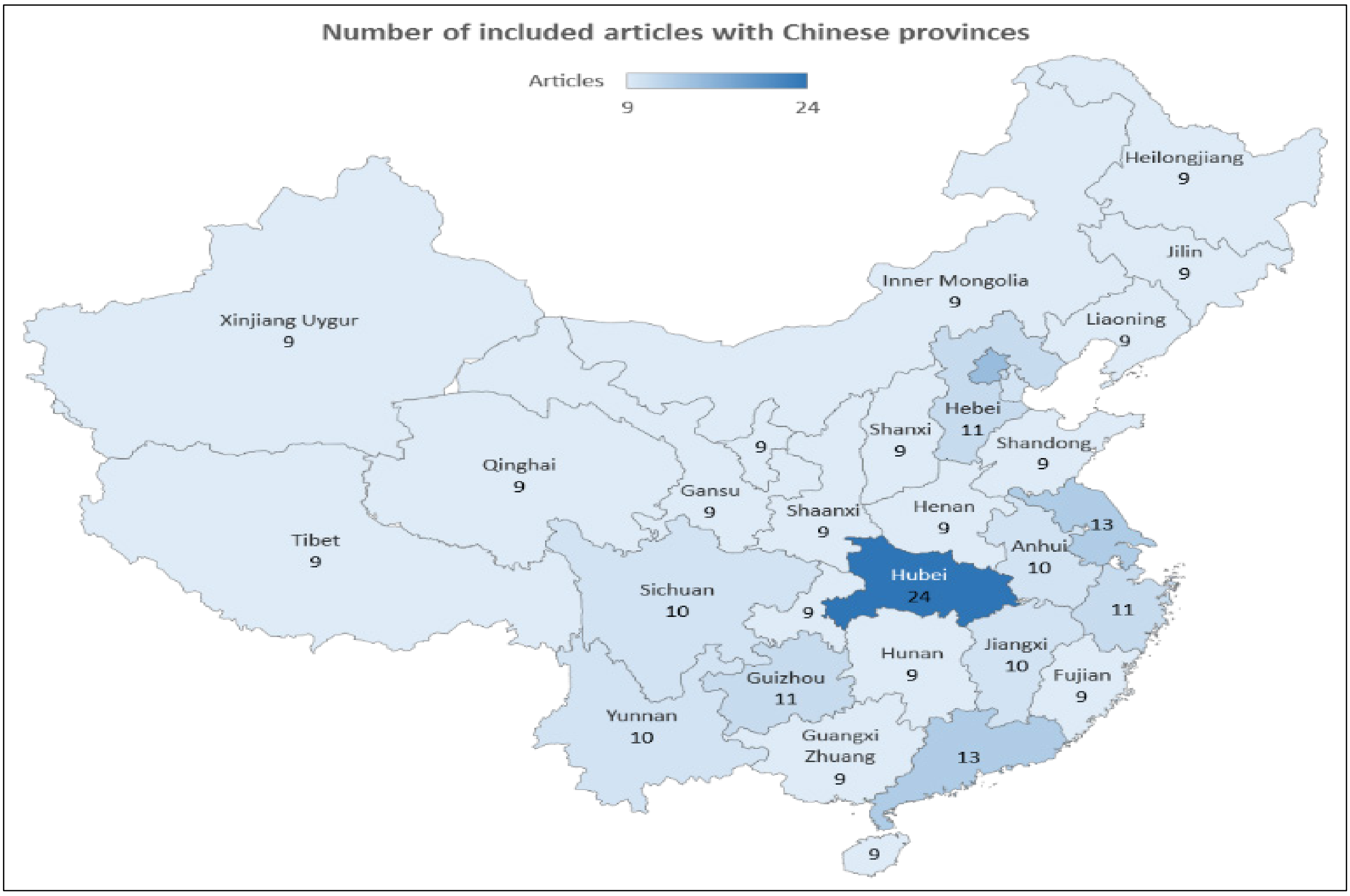


Fig. 2. Study setting of the included literature that met the inclusion criteria. Note: Several studies reported data on multiple regions.

Province (NO_2 = 56.7%, $PM_{2.5}$ = 31.4%, PM_{10} = 39.0%, SO_2 = 31.9%, CO = 16.5%, and AQI = 40.7%) than the average reduction in China overall. Noticeably, for Wuhan and Hubei Province, SO_2 showed the highest spread among the data followed by NO_2. The highest reported decrease in SO_2 was 105.6% (Zhang *et al.*, 2020a), and the lowest was 3.9% (Lian *et al.*, 2020).

Table 3 depicts the percentage change in NO_2, $PM_{2.5}$, PM_{10}, SO_2, CO, O_3, and AQI for Wuhan and other major regions and cities of China. These figures also present a comparison between different time periods.

Results from aggregate outcomes (China) indicated that average NO_2 and SO_2 60 days after lockdown were 80% and 50% lower, respectively, than 30 days before lockdown (Fan *et al.*, 2020a). Reduction in $PM_{2.5}$ was higher (37–39%) immediately after the lockdown (30 days following 23 January 2020); nonetheless, as the comparison time increased (60–90 days) the reported drop was 10.5% (Silver *et al.*, 2020) to 14.8% (Wang *et al.*, 2020b) when compared to identical dates of 2019.

In Wuhan, studies that compared post-lockdown period (23 January 2020 onwards) with pre-lockdown periods or identical times in 2019 or average of 2015–2019 (Table 3) reported a reduction in NO_2 (45–93%), $PM_{2.5}$ (30–44%) and PM_{10} (35–48.7%). One study compared January–March of 2020 with 2019 and found only a 25% fall in NO_2 because it included pre-lockdown period (before 23 January 2020).

For Beijing, the concentration of NO_2, $PM_{2.5}$, SO_2, and CO was 25.6–38.8%, 6.4–33.2%, 37.1–48.1% and 11–40% lower, respectively, in 2020 compared to the same months of 2019 (Table 3). In the Yangtze River Delta (YRD) region the reduction in NO_2 (27.2–45.1%) was similar to Beijing but the drop in SO_2 (7.6–20.4%) was significantly smaller in 2020 compared to the same time in 2019. One study reported the changes in air quality in urban and rural areas of Hangzhou (Wang *et al.*, 2020a). Post-lockdown, concentrations of NO_2 (58.4% vs. 48%), $PM_{2.5}$ (42.7% vs. 18.5%), and

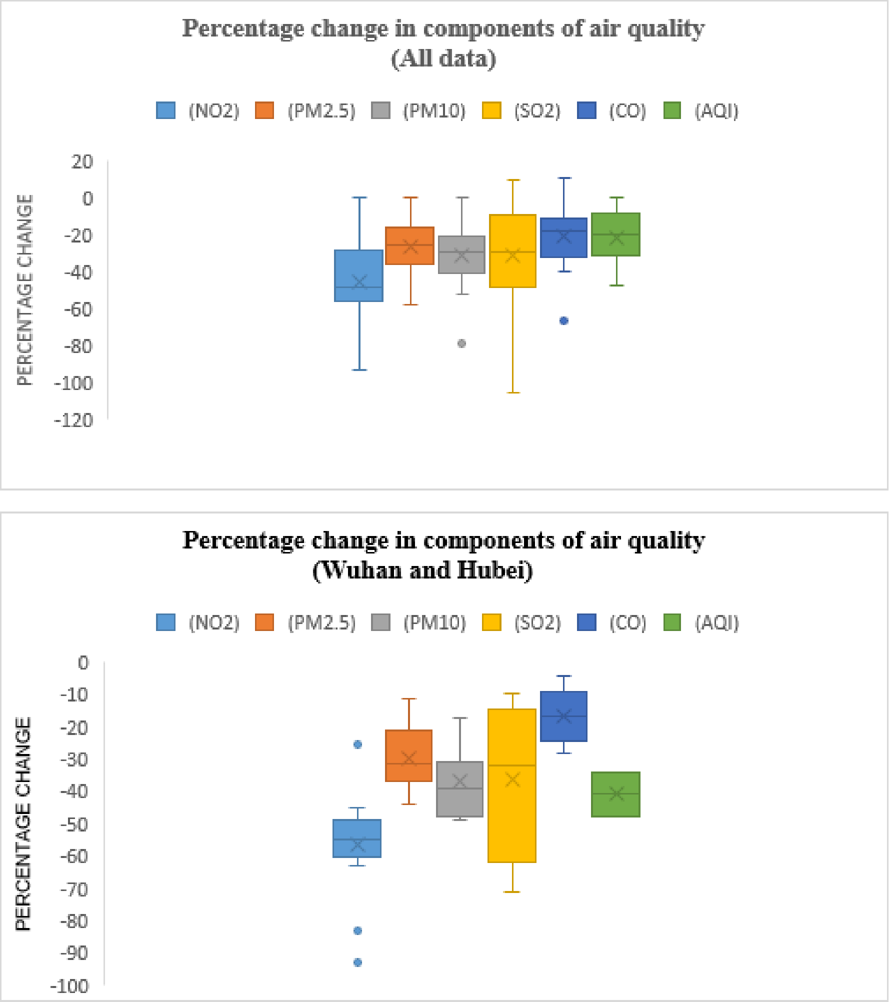


Fig. 3. Percentage change (median) in NO_2, $PM_{2.5}$, PM_{10}, SO_2, CO, and AQI during COVID-19 lockdown. Note: x indicates mean value, line in the middle is median value, top line of the box indicates upper quartile, bottom line of the box represents lower quartile and thus, the middle box represents the middle 50% of scores for the group. Lower whisker shows the bottom 25% (quartile group 1) and upper whisker demonstrates the top 25% (quartile group 4) values.

PM_{10} (47.9% vs. 39.6%) shrank considerably more in urban areas than rural (Table 3). Reduction in NO_2 was 31.1–32.3% in Guangdong, 48.6–49.2% in Hubei, 30.1–46% in Guangzhou and 43.7% in Shanghai. In contrast, the drop in $PM_{2.5}$ was 9.6–19.8%, 11.3–26.3%, 23–31% and 26.6–54.5% in Guangdong, Hubei, Guangzhou and Shanghai, respectively. The summary of the findings illustrates the percentage change in air quality in other key cities in China. All these studies reported significant reductions in NO_2 (20.2–70%), $PM_{2.5}$ (7.6–49.2%), PM_{10} (13.9–47.4%), SO_2 (18.9–105.6%) and CO (29.3–66.8%). In contrast, Zhang *et al.* (2020a) reported an 11% increase in CO in Luzhou, and Wan *et al.* (2020) and Shakoor *et al.* (2020) found that SO_2 concentration increased by 6.3% and 10.3% in Shenzhen, respectively.

The findings also indicated the rapidness of the change in air quality across China after the lockdown. For example, in the south-western region, NO_2 dropped by 49% within two weeks (Chen *et al.*, 2020d), by 63% within 12 days in Wuhan (Cole *et al.*, 2020) and by 31.1% in 10 days in Guangdong (Chen *et al.*, 2021) compared to the period before lockdown. Similarly, by the end of February 2020, NO_2 decreased by 64.3% in Jingmen, 65.2% in Enshi (Xu *et al.*, 2020a), and by 83% in Wuhan (Ghahremanloo *et al.*, 2021) compared to February 2019.

Eight out of 10 included articles reported an increase in O_3 during lockdown. The median increase was 11.4%, with the highest reported increases in south-western China (110%) and in Wuhan (116%) (Lian *et al.*, 2020) comparing periods before and after lockdown (23 January 2020)

Table 3. Quantitative summary of the key findings.

City/Province	Comparison	AOD	NO_2	$PM_{2.5}$	PM_{10}	SO_2	CO	O_3	AQI	First Author (year)
South-western										
Anqing	Feb 2020 with avg. of Feb 2017–2019		43.8	48.6	51.9	50.2	31.8	8.2		K. Xu (2020)
Chengdu	Feb 2020 with avg. of Feb 2017–2019		55.9	27.9	40.2	55.8	29.6	22.5		Zhang (2020)
Chongqing	Feb 2020 with avg. of Feb 2017–2019		63.6	18.4	27.8	78.8	37.1	3		J. Zhang (2020)
South-western	Before 24 Jan 2020 with 24 Jan–9 Feb 2020		49	58		74	12	230		Y. Chen (2020)
Southern										
Enshi	Feb 2020 with 2019		65.2	15.7	25.1	35.4	35.8	6.9		K. Xu (2020)
Foshan (Guangdong)	12 Jan–27 Mar 2020 with 2019		33	32.7	36.5	27.6	29.3	15.8	19.9	S. Wan (2020)
Shenzhen (Guangdong)	12 Jan–27 Mar 2020 with 2019		20.2	16.8	13.9	6.3	15.6		8.2	S. Wan (2020)
Guangdong	3 Feb 2020 (5 days before with 10 days after)		31.1	9.6	11.1	5.1	16.9			Z. Chen (2021)
Guangdong	Jan–April 2020 with 2019		32.38	19.82	26.41	10.32	25.69			A. Shakoor (2020)
Guangzhou	12 Jan–27 Mar 2020 with 2019		30.1	31	30.2	4.2	21.8	11.4	18.1	S. Wan (2020)
Guangzhou	23 Jan–20 Feb 2020 with 2019		46							Z. Pei (2020)
Luzhou (Sichuan)	Feb 2020 with avg. of Feb 2017–2019		70	7.6	23.5	105.6	11	5.6		J. Zhang (2020)
Northern										
Beijing	Jan–Mar 2020 with 2019		25.2							J. Nichol (2020)
Beijing	Jan–April 2020 with 2019		25.64	6.48	79.07	42.64	11.02			A. Shakoor (2020)
Beijing	Jan–Feb 2020 with avg. of 2015–2019		26.54	16.34		37.15	32.18	18.11		Z. Zhang (2020)
Beijing	Mar–Apr 2020 with avg. of 2015–2019		38.88	33.19		48.18	40.12	10.79		Z. Zhang (2020)
Beijing	23 Jan–20 Feb 2020 with 2019		28							Z. Pei (2020)
Beijing	Mar 2020 with 2019			50						A. Chauhan (2020)
Beijing-Tianjin-Hebei	Feb 2020 with 2019	31	54				8	17		M. Ghahremanloo (2021)
Beijing-Tianjin-Hebei (northern China)	23 Jan–4 Feb 2020 (10 days before and after Lockdown)		24.67	5.93	13.66	6.76	4.58		7.8	R. Bao (2020)
Eastern										
Hangzhou (rural)	24 Jan–15 Feb 2020 with 2019		48	18.5	39.6			15.7		L. Wang (2020)
Hangzhou (urban)	24 Jan–15 Feb 2020 with 2019		58.4	42.7	47.9	28.6	22.3	22.2		L. Wang (2020)
Hefei (Anhui)	Feb 2020 with avg. of Feb 2017–2019		50.2	49.2	47.4	41.7	38.6	3.3		K. Xu (2020)

Table 3. (*continued*).

City/Province	Comparison	AOD	NO_2	$PM_{2.5}$	PM_{10}	SO_2	CO	O_3	AQI	First Author (year)
Suzhou (Jiangsu)	Feb 2020 with avg. of Feb 2017–2019		64.4	41.6	47.3	65.5	38.2	0.06		K. Xu (2020)
Zhejiang	Jan–Apr 2020 with 2019		43.89	19.78	23.62	18.96	66.83			A. Shakoor (2020)
Others										
Central, eastern, and southern regions	20 Jan–8 Apr 2020 with 2019			16	20					Z. Fan (2020)
North central China	23 Jan–20 Feb 2020 with 2019		24							S. Griffith (2020)
Locked-down cities and Wuhan	1 Jan–1 Mar 2020 with 2019			24					22	G. He (2020)
Central										
Hubei	1 week after 23 Jan 2020		48.61	11.32						A. Agarwal (2020)
Hubei	Jan 2020 with 2019			20.17						A. Agarwal (2020)
Hubei	Feb 2020 with 2019			26.31						A. Agarwal (2020)
Hubei	Mar 2020 with 2019			9.97						A. Agarwal (2020)
Hubei	24 Jan 2020 (5 days before with 10 days after)			23	17.1		17			Chen Z. (2021)
Hubei	Jan–April 2020 with 2019		49.21	16.2	31	9.33	11.02			A. Shakorr (2020)
Wuhan	21 Jan 2020 (30 days before with 12 days after)		63		35	0	0			M. Cole (2020)
Wuhan	21 Jan–8 Apr 2020 with 2019			36	39					Z. Fan (2020)
Wuhan	Feb 2020 with 2019	62	83			71	4	50		M. Ghahremanloo (2021)
Wuhan	23 Jan–13 Feb 2020 with avg. 2015–2019		93	43.5						T. Le (2020)
Wuhan	24 Jan–23 Feb 2020 with 2019								47.5	X. Lian (2020)
Wuhan	4 Dec 2019–23 Jan 2020 with 24 Jan–23 Feb 2020		53.3	36.9	40.2	3.9	28	116.6	33.9	X. Lian (2020)
Wuhan	24 Dec 2019–23 Jan 2020 with 24 Jan–23 Feb 2020		53.2	29.9						C. Ma (2020)
Wuhan	Jan–Mar 2020 with 2019		45							J. Nichil (2020)
Wuhan	1–22 Jan 2020 with 23 Jan–29 Feb 2020		55	33			23	108		X. Shi (2020)
Wuhan	Feb 2020 with 2019		54.7	44	47.9	29.9	16.2	27.1		K. Xu (2020)
Wuhan	23 Jan–8 Apr 2020 with avg. of 2017–2019		57.2	36.3	48.7			37.7		P. Sicard (2020)
Wuhan	23 Jan–20 Feb 2020 with 2019		57							Z. Pei (2020)
Jingmen (Hubei)	Feb 2020 with 2019		64.3	30.5	48.4	34.9	31.9	8.9		K. Xu (2020)

Table 3. (*continued*).

City/Province	Comparison	AOD	NO_2	$PM_{2.5}$	PM_{10}	SO_2	CO	O_3	AQI	First Author (year)
Nationwide										
Nationwide	Jan 2020 with Mar 2020								30.95	Q. Liu (2020)
Nationwide	Jan–Feb 2020 with 2019		49	37		11				M. Marlier (2020)
Nationwide	Feb 2020 with avg. of 2010–2020		25							A. Metya (2020)
Nationwide	25 Dec 2019–24 Jan 2020 with 24 Jan–25 Feb 2020			39.97	25.58				30.49	W. Ming (2020)
Nationwide	23 Jan–31 Mar 2020 with avg. of 2015–2019		27	10.5	21.4		12.1			B. Silver (2020)
Nationwide	1–23 Jan 2020 with 24 Jan–9 Feb 2020		54	21	27	16			20	Y. Wang (2020)
Nationwide	Jan–Apr 2020 with 2019		25	14.8	20.5	21.4	6.2			Q. Wang (2020)
Nationwide	1 Jan–30 Apr 2020 with 2019		16	14	15	12	12	9		Q. Chen (2020)
Nationwide	30 days before to 60 days after 25 Jan 2020		80			50				C. Fan (2020)
South-eastern										
Shanghai	Jan–April 2020 with 2019		43.78	26.6	29.14	31.19	18.21			A. Shakoor (2020)
Shanghai	Mar 2020 with 2019			54.54						A. Chauhan (2020)
Yangtze River Delta region										
YRD region	26 Feb–31 Mar 2020 with 2019		27.2	33.2		7.6				L. Li (2020)
YRD region	24 Jan–25 Feb 2020 with 2019		45.1	31.8		20.4				L. Li (2020)
YRD region	Jan–Mar 2020 with 2019		30				20			M. Filonchkyk (2020)

Note: avg. = average value; with = compared with.

(Table 3). Two studies matched O_3 concentration in Wuhan between February 2020 with February 2019 and recorded 50% (Ghahremanloo *et al.*, 2021) and 27.1% (Xu *et al.*, 2020a) increases. Zhang *et al.* (2020b) also showed 10.7% and 18.1% drops in O_3 concentration in Beijing during March and April 2020 when compared with the average of March and April over the period 2015–2019. The presence of ultraviolet radiations from sunlight or a lack of sunshine in Beijing during the period was the likely cause of this reduction (Zhang *et al.*, 2020b).

In Table 4, the correlation between various measures of air pollutants was analysed. As expected, these pollutants demonstrated a positive relationship when measured against the reported data from the included studies. 10 studies reported changes in AQI, and the percentage changes in AQIs were significantly correlated with the changes in $PM_{2.5}$, NO_2, CO and PM_{10}. As expected, changes in the level of $PM_{2.5}$ in the air is highly correlated with PM_{10} and NO_2 with SO_2.

Table 5 summarises the findings of eight included studies that reported data comparing changes in the air quality for a single geographical area based on different levels of lockdowns or different time periods. Chen *et al.* (2020d) concluded that air quality improved significantly during Level I (24 January–15 March) compared to Level II (16 March–1 April). Identical findings were reported by Li *et al.* (2020), who found that reductions in concentration of $PM_{2.5}$ were 10% lower in Level II than in Level I. Compared with 2019, the reductions of NO_2 were 45.1% in Level I and 27.2% in Level II. He *et al.* (2020) showed that AQI in locked-down cities (19.8) reduced at a higher rate compared to cities that did not have formal lockdowns (6.3). Metya *et al.* (2020) concluded that China experienced larger reductions in NO_2 in February (33%) than in March (15%).

Table 4. Correlation analysis.

	NO_2	$PM_{2.5}$	PM_{10}	SO_2	CO	AQI
NO_2	1.00					
$PM_{2.5}$	0.41	1.00				
PM_{10}	0.33	0.50	1.00			
SO_2	0.62	0.18	0.34	1.00		
CO	0.09	0.34	0.21	−0.09	1.00	
AQI	0.83	0.87	0.78	0.25	0.80	1.00

Table 5. Effect of lockdown on air quality at different times and lockdown levels (summary of the key findings).

First Author (year)	Study Setting and Method	Time	Lockdown Stage	Conclusion
Y. Chen (2020d)	South-western China; QT	17 January–April 1	Level I and II response to major public health emergencies (RMPHE)	During the strictest control measures from the Level I RMPHE to 9 February 2020, $PM_{2.5}$, PM_{10}, NO_2, SO_2, and BC decreased to 58%, 52%, 49%, 74%, and 61% respectively; the concentrations were then restored to 72%, 74%, 80%, 90%, and 82% between 10 February and 15 March (when the Level II RMPHE was announced). After the Level II RMPHE, SO_2, NO_2, and PM_{10} rose to 220%, and 105% compared with before the Level I RMPHE.
G. He (2020)	Nationwide; QT	1 January–1 March	With or without formal lockdowns	Within weeks, the AQI in the locked-down cities was brought down by 19.84 points ($PM_{2.5}$ down by 14.07 µg m^{-3}) relative to the control group. In addition, air quality in cities without formal lockdowns also improved because of the enforcement of other types of counter-virus measures. The AQI in those cities was brought down by 6.34 points ($PM_{2.5}$ down by 7.05 µg m^{-3}) lockdown effects are larger in colder, richer and more industrialised cities.
L. Li (2020)	YRD region (Shanghai, Hangzhou, Nanjing and Hefei); QT	Pre-lockdown (1–23 January), Level I response (roughly 24 January–25 February), Level II response (roughly 26 February–31 March) and Level III response (31 March onwards)	Pre-lockdown, Level I response, Level II response, Level III response	Concentrations of $PM_{2.5}$, NO_2 and SO_2 decreased by 31.8%, 45.1% and 20.4% during the Level I period; and 33.2%, 27.2% and 7.6% during the Level II period compared with 2019. Reductions in $PM_{2.5}$ concentration in Level II is approximately 10% lower than Level I.
Q. Liu (2020b)	Nationwide; QT		Monthly average in January, February, and March	The study also discovered a significant decreasing trend in the daily average AQI for mainland China from January to March 2020, with cleaner air in most provinces during February (60) and March (54), compared to January (82) 2020. This is due to shutdown policies in China around 7–10 February 2020.

Table 5. (*continued*).

First Author (year)	Study Setting and Method	Time	Lockdown Stage	Conclusion
A. Metya (2020)	North-central China; QT	January–April 2020	January, February, March, April	Compared to 2019, a 6.5% and 5.1% reduction in CO is observed over north-central China in February and March 2020, respectively. Compared to 2019, China experienced a maximum reduction in NO_2 in February (33) 2020, than reduction in March (15).
S. Wan (2020)	Foshan; QT	January, February, March	Highest AQI days in January, February and March	AQI were 83, 85, and 72 in mid-January, February and March, respectively. $PM_{2.5}$ were 42, 43, and 34 in mid-January, February and March, respectively. SO_2 (ppb) were 3.5, 2.45, and 2.10 in mid-January, February and March, respectively. CO (ppm) were 0.88, 0.56, and 0.64 in mid-January, February and March, respectively.
L. Wang (2020a)	10 urban sites in Hangzhou; QT	January–February	Before city lockdown, 1–23 January; during city lockdown, 24 January–15 February; and during resumption, 16–28 February	For the urban area, before the lockdown period, January 1–23, 2020/2019 decreases amounted to 24.8% for $PM_{2.5}$, 19.8% for PM_{10}, 29.2% for SO_2, 14.1% for CO and 13.7% for NO_2. By comparison, the decreases were much higher during the lockdown period, 24 January–15 February: 42.7% for $PM_{2.5}$, 47.9% for PM_{10}, 22.3% for CO and 58.4% for NO_2, except for SO_2 (28.6%). After 15 February, these trends began to reverse due to the resumption of work and production activities and both $PM_{2.5}$ and PM_{10} levels rose to higher values after resumption.
K. Xu (2020a)	Wuhan, Jingmen, and Enshi; QT	January–March	January, February, March	The average air quality index (Xiong et al., 2020) for Wuhan, Jingmen, and Enshi in January, February, and March 2020 were 32.2%, 27.7%, and 14.9% lower than the levels in 2017–2019, respectively. The average $PM_{2.5}$ for Wuhan, Jingmen, and Enshi in January, February, and March 2020 were 36.2%, 30.1% and 15.8% lower than the levels in 2017–2019, respectively.

Note: QT = quantitative study design; AOD = aerosol optical depth.

Furthermore, Wang *et al.* (2020a) indicated that after 15 February (during resumption of work and production activities) both $PM_{2.5}$ and PM_{10} increased in Hangzhou compared to the lockdown periods of 24 January–15 February. The findings from all of these studies demonstrate the immediate impact of COVID-19-related lockdowns on air quality in different parts of China. However, as restrictions were eased in subsequent months the rapid pace of improvement in air quality also receded. On the other hand, Liu *et al.* (2020b) and Wan *et al.* (2020) identified lower levels of AQI nationwide and in Foshan, respectively, in March (54 and 34, respectively) compared to January (82 and 83, respectively).

3.3 Key Findings in the Included Literature

The included studies made several important arguments regarding the fluctuations of criteria pollutants in China during COVID-19 lockdown. These studies unanimously concluded that lack of traffic movement due to travel restrictions played an important role in reducing air pollution in China (Agarwal *et al.*, 2020; Bao and Zhang, 2020; Cole *et al.*, 2020; Fan *et al.*, 2020a; Le *et al.*, 2020). Others found curbing industrial production, household consumption, and engineering construction (along with traffic movement) also contributed to improvement in air quality (Fan *et al.*, 2020b; Le *et al.*, 2020; Liu *et al.*, 2020b; Ming *et al.*, 2020; Wan *et al.*, 2020; Zhang *et al.*, 2020a; Zhang *et al.*, 2020b).

Restriction on traffic mobility and industrial activity had a variable impact on different criteria pollutants across China. According to Fan *et al.* (2020b), lower traffic movement caused more reduction in $PM_{2.5}$ in east China and PM_{10} in central China. In contrast, reduced industrial activities contributed to a higher drop in $PM_{2.5}$ and PM_{10} in south-western and north-eastern China, respectively. The literature also suggested that urban and densely populated areas had experienced larger reductions in air pollution compared to rural areas (Fan *et al.*, 2020a; Filonchyk *et al.*, 2020; Wang *et al.*, 2020a). In addition, Chen *et al.* (2020c) found that improvements in air quality was more prominent in north-eastern and inland provinces than in south-eastern coastal and western provinces. Similarly, Pei *et al.* (2020) concluded that concentration of $PM_{2.5}$ decreased more in Wuhan (inland) compared to Guangzhou and Beijing and Wang *et al.* (2020a) found a sharp decrease in the NO_2 concentration in urban than in rural areas of Hangzhou. In another study, Liu *et al.* (2020b) showed higher levels of improvement in air quality in commercial areas compared to residential areas.

Several studies argued the importance of accounting for weather conditions when observing pollution levels (Bao and Zhang, 2020; Chen *et al.*, 2020c; Cole *et al.*, 2020; Fan *et al.*, 2020a; He *et al.*, 2020; Pei *et al.*, 2020; Xu *et al.*, 2020b; Zhang *et al.*, 2020b). For example, Cole *et al.* (2020) used a two-stage random forests machine learning approach and Bao and Zhang (2020) used a least-square dummy variable method to control for the confounding effects of meteorological conditions from pollution patterns. Noticeably, some included studies did not control for this key factor while measuring air quality. However, all the studies that took weather condition into consideration overwhelmingly concluded that COVID-19 lockdown significantly reduced air pollution in China (Bao and Zhang, 2020; Chen *et al.*, 2020c; Fan *et al.*, 2020a; He *et al.*, 2020; Pei *et al.*, 2020; Xu *et al.*, 2020b; Zhang *et al.*, 2020b).

There was an important distinction between the sources of data among the included studies. One group of studies collected data from satellite sources (Metya *et al.*, 2020; Nichol *et al.*, 2020; Shi and Brasseur, 2020; Sicard *et al.*, 2020; Silver *et al.*, 2020; Wang and Su, 2020; Wang *et al.*, 2020a; Zhang *et al.*, 2020b) and others from ground monitoring stations (Agarwal *et al.*, 2020; Chauhan and Singh, 2020; Chen *et al.*, 2020c; Cole *et al.*, 2020). Marlier *et al.* (2020) concluded that satellite-based results were in general similar to air quality data from ground monitoring stations.

Lastly, numerous studies have concluded that the reduction in air pollution during COVID-19 whilst welcome is unsustainable for China (Bao and Zhang, 2020; Lian *et al.*, 2020; Liu *et al.*, 2020b; Nichol *et al.*, 2020; Shi and Brasseur, 2020). Furthermore, Nichol *et al.* (2020) and Sicard *et al.* (2020) commented that despite the improvements, air quality in some regions in China during lockdown were still below the WHO and EU recommended standards.

4 DISCUSSION

The outbreak of COVID-19 pandemic has caused more than a million fatalities globally, which has prompted governments around the world (including China) to take unprecedented actions such as lockdowns of affected cities and regions. Restricting human mobility has assisted in lowering COVID-19 infection, morbidity and mortality. Although lockdown disrupted people’s lives and their livelihoods, one of the silver linings was the improvement in air quality globally. In particular, countries such as China, with some of the most polluted cities in the world, experienced significant improvements in air quality immediately following the lockdown. In addition, areas with stringent lockdown responses (Level I or formal lockdowns) experienced greater impact on air quality in China, compared to areas that had partial lockdowns. Through this novel systematic review, we attempted to provide a quantitative and narrative synthesis of the recent studies that examined the influence of COVID-19 lockdown on improvement in outdoor air quality in China.

The included studies demonstrated that the measures of air pollutants improved significantly during COVID-9 lockdown. Pollutants such as $PM_{2.5}$, PM_{10}, NO_2, SO_2 and CO dropped, whilst on the contrary, the O_3 level increased. The increase in O_3 concentration is due to NO_2 emissions, and formaldehyde (HCHO) concentrations remaining steady due to the volatile organic compound (VOC) limitations during lockdown (Chen *et al.*, 2020d; Kanniah *et al.*, 2020; Pei *et al.*, 2020; Sicard *et al.*, 2020; Wan *et al.*, 2020; Wang *et al.*, 2020a; Wang *et al.*, 2020c; Xu *et al.*, 2020b). The overall reduction in all air pollutants was attributable to the limited movement of people (Agarwal *et al.*, 2020; Bao and Zhang, 2020; Chauhan and Singh, 2020; Chen *et al.*, 2020d; Cole *et al.*, 2020). 50% of air pollutant PM (Li *et al.*, 2017), 80% of CO and 40% of NO_2 (Wang *et al.*, 2008; Xue *et al.*, 2010) in major urban cities of China originate from vehicular exhaustion. Previously, Wang *et al.* (2017) also found that fossil fuel consumption and transport were the primary elements of air pollution in urban areas of China. Hence, the dramatic reduction in road traffic (e.g., 77% and 39% fewer trucks and cars in the Beijing-Tianjin-Hebei region, respectively) played a major role in improving the air quality in China. Temporary suspension of other human activities such as industrial production (Bao and Zhang, 2020; Cole *et al.*, 2020; Fan *et al.*, 2020b) and construction (Li *et al.*, 2020; Lian *et al.*, 2020) were also responsible for the reduction in air pollution.

The findings further demonstrated that urban, industrial and densely populated areas of China experienced major improvements in air quality compared to rural, residential and less populated areas (Chen *et al.*, 2020c; Filonchyk *et al.*, 2020; Wang *et al.*, 2020a). One probable explanation is that metropolitan and industrialised regions with many inhabitants are most likely to have initial poorer air quality (Chen *et al.*, 2020a; Griffith *et al.*, 2020; He *et al.*, 2020; Ghahremanloo *et al.*, 2021). Hence, lockdown measures had a greater effect. Noticeably, as traffic density is high in urban areas, it is highly correlated with NO_2 concentration than in rural and less populated areas (Wang *et al.*, 2020a). Since lockdown commenced, the flow of traffic reduced more in urban areas; it contributed to a greater improvement in air quality. Further analysis of the data also indicated that regions that were subject to stricter lockdown (e.g., Hubei Province) had more significant benefits. For example, Wuhan was under lockdown for 76 days, and its improvement in air quality was much higher than other regions (e.g., Beijing and Shanghai). Moreover, inland cities such as Wuhan had a greater reduction in air pollution compared to coastal cities, such as Guangdong. Due to meteorological factors such as high precipitation and wind flow, air pollution in coastal cities is comparatively low compared to inland cities (Chen *et al.*, 2020c; Wan *et al.*, 2020; Chen *et al.*, 2021). Agarwal *et al.* (2020) show identical findings for coastal and inland states of India.

Three studies compared the variances in the improvement in air quality based on lockdown levels in China (Chen *et al.*, 2020d; He *et al.*, 2020; Li *et al.*, 2020). All of the studies concluded that during the strictest control measures, all components of air quality ($PM_{2.5}$, PM_{10}, NO_2, SO_2, CO) improved significantly compared to areas that had lower levels of restrictions or periods when restrictions were lifted. Others concluded that the reduction in CO, NO_2, $PM_{2.5}$, SO_2 were highest immediately after the lockdowns (February 2020) compared with other months (March or April 2020) (Liu *et al.*, 2020a; Metya *et al.*, 2020; Wan *et al.*, 2020; Wang *et al.*, 2020a). This is understandable as stricter lockdowns were associated with extremely low levels of traffic movements, industrial production and other human and economic activities.

It is well documented that weather conditions (e.g., temperature, rain and snowfall, daily maximum and minimum wind speed) play a pivotal role in the concentration of air pollutants (Demuzere *et al.*, 2009; Grange and Carslaw, 2019; Fan *et al.*, 2020a). Several of the included studies accounted for and recorded meteorological factors when indicating the percentage change in concentrations of air pollutants, and the evidence could be regarded as more reliable and complete. Nonetheless, the current study found sufficient evidence of improvement in air quality in China during COVID-19 lockdown irrespective of the changes in weather conditions.

It is important to mention that the level of air pollutants' concentration in China was largely dependent on the time period compared. For example, Sicard *et al.* (2020) reported that in Wuhan, NO_2 reduced by 57.2%, $PM_{2.5}$ by 36.3%, PM_{10} by 48.7% and O_3 increased by 37.7% between 23 January to 8 April in 2020 compared to the same period of the average of 2017–

2019. In contrast, Xu *et al.* (2020a) concluded that NO_2 reduced by 54.7%, $PM_{2.5}$ by 44%, PM_{10} by 47.9% and O_3 increased by 27.1% in February 2020 compared to February 2019. Therefore, policymakers and researchers interpreting the changes in air quality data need to pay consideration to this to avoid any misrepresentation of the actual impact of COVID-19 lockdown on air quality. Irrespective of this variability, the findings indicate a strong relationship between human economic activity and air quality. A significant improvement in the air quality immediately after the lockdown is an indication that with appropriate policies, efficient use of technology, and by reducing avoidable traffic movement, it is possible to reverse air pollution.

Several key policy implications could be drawn from the findings of our study. First, all the included studies concluded that reducing human activities (road traffic, industrial production, large scale construction etc.) can significantly improve air quality in a short period of time. However, these activities are essential for continuing economic growth. Hence, one area the Chinese government should focus on (to control air pollution) is reducing the consumption of fossil fuel through private vehicle restrictions (Chen *et al.*, 2021; Liu *et al.*, 2020b). The government should invest in improving public transport networks and encourage the use of vehicles with low carbon emission through tax incentives (Wu *et al.*, 2017). Second, during this pandemic, many workers used internet-based virtual technology to conduct meetings and worked from home, which reduced traffic emissions (Han *et al.*, 2020). Further studies are required on how to use digital technology to curb avoidable road traffic movements without compromising human economic activities. A long-term structural change in economic activities could be initiated (e.g., promote working from home and holding teleconferences) that emits less carbon. Third, China has already implemented many environmental policies that were effective in reducing pollution (Chen *et al.*, 2020b; Ming *et al.*, 2020; Venter *et al.*, 2020). Since 2013 one of the key policies was to establish an air quality monitoring system across the country. This has ensured quality and real-time data on the concentrations of air pollutants throughout China. Accurate information is the key to making successful environmental policies. Other developing countries battling with air pollution could learn from the experience of China to generate accurate air quality information which will assist in developing policies related to air quality management. Fourth, for a large and geographically diverse country like China, it is important to be flexible in implementing environmental policies in different regions. Due to the level of industrialisation, population density and variation in meteorological factors, the concentration of air pollutants differs across China. The policy that is fit for a coastal region might not be appropriate or effective in an inland region. Lastly, future studies should use long-term data from specific regions to understand the exact long-run impact of COVID-19 lockdown in different regions in China. It is important to understand whether length or measures (strict to liberal) of lockdown or weather conditions (e.g., temperature, rainfall) played an important role in reducing air pollution during the lockdown. This will assist in implementing an effective air quality management plan in the future.

Some limitations of this systematic literature review are as follows. First, due to significant differences in the study design, statistical estimation and categories of treatment measured in the selected studies, it was not feasible to conduct a meta-analysis. Second, this study excluded all grey literature, report or non-English language articles. One downside of including published articles only is that studies with null findings has a limited probability of being accepted. Therefore, similar to past systematic reviews, this study could not avoid the likelihood of publication bias. Third, this study did not conduct any forward searching; hence, it difficult to judge whether all potential studies have been included in the review despite all the systematic effort. Lastly, the final search was conducted on the 20 September 2020. Any publication after that that was not included in this study.

5 CONCLUSIONS

This qualitative systematic review provides a narrative synthesis of the reported changes in air quality across China due to COVID-19-related lockdowns. Owing to the restrictions imposed on human activities, air pollution, led by traffic-related NO_2, decreased significantly within a short period. However, the improvement in air quality varied by location: urban, industrial and densely populated areas experienced the largest gains, but inland regions also showed higher reductions in pollution than costal ones. Additionally, the percentage of decrease in the air pollution depended strongly on the periods chosen for comparison.

Compared to less stringent measures, full lockdowns produced considerably greater effects on the environment. Furthermore, meteorological factors, such as rainfall and temperature, strongly influenced the concentrations of pollutants in an area, although several of the eligible studies failed to address the role of weather conditions in their measurement results. The air pollutant data appeared to be consistent between the satellites and the ground-level monitoring stations, but the lack of identical studies precluded us from statistically verifying this agreement. Lastly, the lockdown-driven improvements in air quality will be insufficient as well as unsustainable unless strict, region-specific environmental policies are implemented.

Despite the limitations of the eligible studies, our review elucidates the relationship between economic activity and air pollution. Future research should continue investigating this link by focusing on specific activities and areas as well as incorporating meteorological factors (e.g., sunlight or rainfall) into estimates of pollutant concentrations. Finally, additional qualitative and quantitative studies should be conducted to assess the role of ground-level monitoring stations, which may enable other severely polluted regions to replicate China’s progress in air quality management.

ADDITIONAL INFORMATION

The authors of this study declare the following:

Ethics Approval and Consent to Participate

Not applicable as the study is a systematic literature review.

Consent for Publication

Not applicable.

Availability of Data and Materials

Not applicable.

Competing Interests or Conflict Of Interest

The authors of this study declare that they have no competing interest. The authors have no affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers’ bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Authorship Contribution Statement

RHR: worked on conceptualisation, developing methodology, and writing—original draft. SAK: conducted formal analysis. JG: writing—review and editing.

SUPPLEMENTARY MATERIAL

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