Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Health and related economic benefits associated with reduction in air pollution during COVID-19 outbreak in 367 cities in China

Tingting Ye\textsuperscript{a,b,1}, Suying Guo\textsuperscript{c,1}, Yang Xie\textsuperscript{d,e}, Zhaoyue Chen\textsuperscript{f}, Michael J. Abramson\textsuperscript{a}, Jane Heyworth\textsuperscript{g}, Simon Hales\textsuperscript{h}, Alistair Woodward\textsuperscript{i}, Michelle Bell\textsuperscript{j}, Yuming Guo\textsuperscript{a,b,h,j}, Shanshan Li\textsuperscript{a,i,j}

\textsuperscript{a} Climate, Air Quality Research Unit, School of Public Health and Preventive Medicine, Monash University, Level 2, 553 St Kilda Road, Melbourne, VIC 3004, Australia
\textsuperscript{b} School of Public Health and Management, Binhau Medical University, Yantai, Shandong 264003, China
\textsuperscript{c} National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention (Chinese Center for Tropical Diseases Research); NHC Key Laboratory of Parasite and Vector Biology (National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention), Shanghai 200025, China
\textsuperscript{d} School of Economics and Management, Beihang University, Beijing 100191, China
\textsuperscript{e} Beijing Advanced Innovation Center for Big Data-based Precision Medicine, Beihang University, Beijing 100191, China
\textsuperscript{f} Barcelona Institute for Global Health (ISGlobal), Barcelona 08003, Spain
\textsuperscript{g} School of Population and Global Health, The University of Western Australia, Crawley, WA 6009, Australia
\textsuperscript{h} Department of Public Health, University of Otago, Wellington, Otago 9016, New Zealand
\textsuperscript{i} School of Population Health, University of Auckland, Auckland 1010, New Zealand
\textsuperscript{j} School of the Environment, Yale University, New Haven, CT 06520, USA

** Corresponding author at: Climate, Air Quality Research Unit, School of Public Health and Preventive Medicine, Monash University, Level 2, 553 St Kilda Road, Melbourne, VIC 3004, Australia.
** Corresponding author.

E-mail addresses: yuming.guo@monash.edu (Y. Guo), shanshan.li@monash.edu (S. Li).

\textsuperscript{1} Tingting Ye and Suying Guo contributed to this work equally and should be regarded as co-first authors

https://doi.org/10.1016/j.ecoenv.2021.112481
Received 2 February 2021; Received in revised form 24 June 2021; Accepted 28 June 2021
Available online 30 June 2021
0147-6513/© 2021 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

COVID-19, the disease caused by the SARS-CoV-2 virus (Huang et al., 2020a), was declared to be a pandemic by the World Health Organization (WHO) on March 11, 2020, and had caused more than 178 million confirmed cases and 3 million deaths worldwide by June 21, 2021 (https://covid19.who.int/). Measures that have been commonly applied to control COVID-19 including quarantine (Nussbaumer-Streit et al., 2020), stay at home orders and ban on large gatherings (Aquino et al., 2020; Mazumder et al., 2020; Xiao et al., 2020). In addition to the effects on transmission of the virus, these actions have cut air pollution due to restrictions on travel and production activities (Chen et al., 2020; Wang et al., 2020). Evidence from environmental monitoring sites and satellite data has been presented in previous studies of improved air quality.
during the outbreak in China (Chen et al., 2020; Zheng et al., 2020), India (Gautam, 2020), Brazil (Nakada and Urban, 2020), the United States (Son et al., 2020), and Spain (Tobias et al., 2020).

Short-term exposure to air pollutants, including particulate matter with aerodynamic diameters of $\leq 2.5 \mu m$ (PM$_{2.5}$) (Chen et al., 2017) and 10 $\mu m$ (PM$_{10}$), carbon monoxide (CO) (Liu et al., 2018), ozone ($O_3$) (Yin et al., 2017), nitrogen dioxide (NO$_2$) (Chen et al., 2018), and sulfur dioxide (SO$_2$) (Wang et al., 2018), increases risks of mortality and morbidity. However, little has been published to date on the economic gains from health improvements due to reduced emissions during the COVID-19 outbreak in China. Furthermore, quantifying avoided air pollution-related health costs, using tools such as the value of statistical life (VSL) may illuminate the cost and severity of air pollution impacts for policy makers and researchers (Bai et al., 2018).

China implemented a severe, nation-wide lockdown to control transmission of SARS-CoV-2 between January 23, 2020 and April 8, 2020. Understanding the health and economic changes, due to the improvement of air quality during the lockdown period, would be helpful to guide future public health policy and environmental protection strategies. Chen et al. (2020) have reported decreased deaths associated with reductions in NO$_2$ and in PM$_{2.5}$ concentrations during the COVID-19 outbreak in China. This study provides useful insights, but was derived from a simple difference-in-difference approach without fully accounting for factors such as long-term trends and the influence of weather conditions on air pollution. In this study, we aimed to comprehensively estimate the changes in mortality and related costs based on the VSL that may be attributed to the reductions in air pollution during the COVID-19 outbreak in 367 cities in China.

2. Material and methods

2.1. Study setting

We performed an analysis of national air quality monitoring data and mortality data from 367 cities located in 31 provinces (including municipalities and autonomous regions) in mainland China (Fig. A1).

2.2. Air pollution exposure

Data for hourly concentrations of PM$_{2.5},$ PM$_{10},$ CO, NO$_2,$ SO$_2,$ and O$_3$ concentrations in each city from January 1, 2015 to March 31, 2020 were downloaded from China’s National Urban Air Quality Real-time Publishing Platform (http://106.37.208.233:20035/). The 24-hour average concentrations of PM$_{2.5},$ PM$_{10},$ CO, NO$_2,$ and SO$_2,$ and 8-hour maximum O$_3$ concentrations were then calculated if less than a third of hourly data were missing on that day for a given pollutant. Otherwise, the concentrations were estimated using the mean values of the daily average concentrations on the day before and after that day.

2.3. Population and mortality data

Data on the annual average population and annual all-cause mortality rate from 2015 to 2019 were collected from the China Statistical Yearbook and Statistical Report of each city. Due to the lack of recent data, daily deaths in February and March 2020 were estimated by the count of deaths on day $i$ in city $j$, representing the health burden (HB$_{ij}$) attributed to a specific air pollutant, was calculated as:

$$ HB_{ij} = \left( e^{\beta \Delta \mu} - 1 \right) \times N_j $$

where, ER is the estimated risk indicating the percentage increase of mortality with $\Delta \mu$ increment in concentration of a specific air pollutant. $\beta$ is the log relative risk per unit (1 mg/m$^3$ for CO and 10 g/m$^3$ for other pollutants) change in concentration of air pollutant. $\Delta \mu$ is the excess daily concentration over the threshold (We assumed the threshold was zero as several studies have indicated the lack of a safe threshold level for air pollution and health (Brook et al., 2010; Schwartz and Zanobetti, 2000; Ye et al., 2019; Zhang et al., 2017).). $N_j$ is the count of deaths on day $i$ in city $j$. Due to the lack of daily death counts at city level, $N_j$ was calculated by multiplying the baseline overall mortality rate and size of the exposed population in each year in each city, then divided by 365 days.

The ER was extracted from previous studies which estimated exposure-response relationships between short-term exposure to air pollutants and mortality (Table 1) (Chen et al., 2011, 2017, 2018, 2019; Tao et al., 2011; Wang et al., 2018; Yin et al., 2017). Because of the lack of a national study on association between the CO concentration and all-cause mortality, we utilized a pooled coefficient drawn from work in seven Chinese cities (Anshan (Chen et al., 2011), Taiyuan (Chen et al., 2011), Shanghai (Chen et al., 2011), Guangzhou (Tao et al., 2011), Foshan (Tao et al., 2011), Zhongshan (Tao et al., 2011), and Zhuhai (Tao et al., 2011)).

The health benefit due to air pollution reduction in February and March in 2020 was defined as the difference in health burden ($\Delta$HB$_{ij}$).

$$ \Delta HB_{ij} = HB_{BAU2020} - HB_{observed2020} $$ (2)
Table 1
Percentage increase of all-cause mortality associated per specified unit increment of the air pollutant and its 95% confidence interval (CI).

| Air pollutant       | Increase unit | Percentage increase (%) | 95% CI (%) |
|---------------------|---------------|-------------------------|------------|
| PM$_{2.5}$          | 10 μg/m$^3$   | 0.22                    | 0.15, 0.28 |
| PM$_{10}$           | 10 μg/m$^3$   | 0.23                    | 0.13, 0.33 |
| Carbon monoxide     | 1 mg/m$^3$    | 1.76                    | 0.11, 3.42 |
| Nitrogen dioxide    | 10 μg/m$^3$   | 0.90                    | 0.70, 1.10 |
| Ozone               | 10 μg/m$^3$   | 0.24                    | 0.13, 0.35 |
| Sulfur dioxide      | 10 μg/m$^3$   | 0.59                    | 0.42, 0.77 |

Where $HB_{BAU2020}$ and $HB_{observed2020}$ were daily mortality calculated by model [1] with business-as-usual (BAU) and observed concentrations of air pollutants on day $i$ in city $j$, respectively. This was summed by days to get city-specific health benefits during the lockdown period in 2020.

2.6. Estimating economic impact of avoided mortalities

We estimated the economic impact of the avoided mortalities as calculated in Section 2.5. The non-market VSL lost was monetized to capture the impact of the change of air pollution due to the COVID-19 outbreak, based on the method applied by West et al. (2013). Details of this method have been described elsewhere (Kim et al., 2020; Tian et al., 2018, 2019, Xie et al., 2016, 2018, 2019, 2020). Although the value of life was reported to range from 8.2 to 31.1 million USD in a previous study (Matus et al., 2012), we adopted here a much lower value of life was reported to range from 8.2 to 31.1 million USD in a previous study (Matus et al., 2012), we adopted here a much lower

3. Results

There were considerable reductions in PM$_{10}$, PM$_{2.5}$, CO, and SO$_2$ concentrations over 2015–2019, but reductions in NO$_2$ were only found during 2017–2019 (Fig. 1), which occurred in a non-linear pattern. The average (± SD) PM$_{10}$ concentration in February and March reduced from 106.09 ± 47.22 μg/m$^3$ in 2015–64.44 ± 45.92 μg/m$^3$ in 2020, PM$_{2.5}$ from 59.39 ± 20.66 μg/m$^3$ to 37.37 ± 16.42 μg/m$^3$, CO from 1.25 ± 0.50 mg/m$^3$ to 0.75 ± 0.21 mg/m$^3$, and SO$_2$ from 32.10 ± 22.35 μg/m$^3$ to 10.28 ± 5.31 μg/m$^3$.

Table A2 includes more details of descriptive statistics (the mean, median, maximum, minimum, and quartiles of the observed concentrations of the six air pollutants in 367 Chinese cities during February and March from 2015 to 2020).

As shown in Fig. 2 and Table A3, significant reductions were found in the observed concentrations of PM$_{2.5}$, CO, NO$_2$, O$_3$, and SO$_2$ in 2020, compared with the estimated business-as-usual concentrations in 2020 and the average concentrations during 2015–2019. As this figure shows, long-term trends indicate declines in air pollution (see differences in the red and blue lines), but a larger decline for 2020 (green line).

Compared to the business-as-usual scenario, health benefits from air pollution improvement during the quarantine period were substantial (Table 2). At a national level across all cities, NO$_2$ led to the greatest reduction on deaths, followed by PM$_{10}$, CO, PM$_{2.5}$, SO$_2$, and O$_3$ as shown in Table 2. At a city level (Fig. 3), Beijing (136 deaths), Chongqing (116), Chengdu (69), Shanghai (77), and Suzhou (74, in Jiangsu Province) experienced most of the NO$_2$-related avoided deaths. Overall, cities in east, north, and central provinces such as Jiangsu, Hebei, and Zhejiang accounted for most of the health benefits.

Estimated economic benefits from reductions in PM$_{2.5}$, PM$_{10}$, CO, NO$_2$, O$_3$, and SO$_2$ at a city level were shown in Fig. 4, which amounts to a total of 1.22, 2.60, 1.36, 4.05, 0.20, and 0.95 billion USD at a national level across all cities. The non-market VSL lost was monetized to get city-specific health benefits during the lockdown period in 2020.

4. Discussion

This study estimated the changes in mortality and associated VSL caused by the changes of six air pollutants during the early stages of the COVID-19 outbreak in 367 cities in China, comparing observed levels with those expected under a business-as-usual scenario.
The concentrations of PM$_{2.5}$, PM$_{10}$, CO, NO$_2$, and SO$_2$ in February and March 2020 were substantially lower than the average concentration in the same months during 2015–2019. One possible reason for the overall decline in pollution across time, as demonstrated by business-as-usual estimates lower than the 2015–2019 levels, could be the effective air pollution control policy, issued by the State Council of China in 2013, known as the Air Pollution Prevention and Control Action Plan (APP-CAP). Previous studies reported the APPCAP has been effective in decreasing ambient concentrations of PM$_{2.5}$, PM$_{10}$, SO$_2$, and CO in the past few years (Huang et al., 2018; Maji et al., 2020). It should be also noted that the observed O$_3$ concentration tended to increase from 2015 to 2018. Another study also reported an increasing trend of O$_3$ 3 $\mu$g/m$^3$/year in North and Southwest China from 2013 to 2017 (Liu et al., 2020), while there was a decrease in NOx emissions in the same period (Li et al., 2019). Changes in volatile organic compounds (Alghamdi et al., 2014; Song et al., 2020) and solar radiation reaching...
the surface (Chang et al., 2019; Huang et al., 2020b) may have played a part in these trends. Note that we compared air pollutant levels in the months immediately preceding the outbreak and found a sudden decrease after the lockdown which was unlikely due to changes in APPCAP.

We conclude the key reason for air pollution levels being lower in February and March 2020 compared to business-as-usual estimates is likely to be the restriction during the COVID-19 outbreak, which impacted transportation and other economic sectors, cutting emissions of air pollutants as well as pollutant precursors. The observed ambient concentrations of all the six air pollutants in February and March, 2020 were markedly lower than the predicted values (business-as-usual

Fig. 3. The reduced health burden (death count) due to the decrease in concentrations of air pollutants in 367 cities during COVID-19, compared to the business-as-usual scenario.

Fig. 4. Value of statistical life (unit: billion USD) saved due to avoided mortalities from decrease in air pollutants for February and March 2020 in 31 provinces during COVID-19, comparing to the business-as-usual scenario.
especially the improvement in NO\textsubscript{2} and PM\textsubscript{10}. Another study (Chen et al., 2020) estimated that a total of 8911 (95%CI: 6950–10866) NO\textsubscript{2}-related (89% higher than our estimates) and 3214 (95%CI: 2340–4087) PM\textsubscript{2.5}-related (159% higher than our estimates) deaths were avoided for 367 cities by the improved air quality during the study period. In that study, the impact of seasonality conditions on air pollution were adjusted using a different approach (difference-in-difference). They directly calculated the avoided deaths on the basis of the average pollution concentration of the past four years and the mortality data from 2018, only. Our models have adjusted for weather and long-term trend and suggested that pollutant concentrations would have been less than the 2016–2019 average in the absence of the quarantine policy for COVID-19. In this context, Chen et al. may have overestimated the health benefits.

Considerable economic benefits, as estimated by VSL, were estimated from the reduced mortality burden attributed to the decrease in six air pollutants during the epidemic outbreak, with improved NO\textsubscript{2} concentrations contributing the most. To our knowledge, this is one of the first studies assessing the health economic impacts due to the change of air quality in China and other countries during the epidemic. We cannot model the independent effects of six air pollutants because of their co-linearity and lack of epidemiological does-response functions that account for the full suite of pollutants; thus some mortalities may be double counted. Third, air pollution is associated with other adverse health outcomes besides mortality, such as morbidity of many kinds and lower labor productivity (Xie et al., 2019). Costs of the full range of health outcomes should also be included, in order to gain a full picture of economic gains associated with lower air pollution. The avoided deaths that we counted in this study do not represent the full suite of health benefits from better air quality.

5. Conclusions

In conclusion, with a large data set covering 367 Chinese cities, significant reduction in observed concentrations of PM\textsubscript{2.5}, PM\textsubscript{10}, CO, NO\textsubscript{2}, O\textsubscript{3}, and SO\textsubscript{2} due to the lockdown were found during February and March, 2020, comparing with an estimated business-as-usual scenario of air pollution concentrations. As a result, a total of 1587 CO-related, 4711 NO\textsubscript{2}-related, 215 O\textsubscript{3}-related, 2777 PM\textsubscript{2.5}-related, 1239 PM\textsubscript{10}-related, and 1088 SO\textsubscript{2}-related deaths were estimated to be avoided. Benefits of 1.22 billion USD from PM\textsubscript{2.5}, 2.60 from PM\textsubscript{10}, 1.36 from CO, 4.05 from NO\textsubscript{2}, 0.20 from O\textsubscript{3}, and 0.95 from SO\textsubscript{2} are estimated from these avoided mortalities. Cities in the eastern, northern, and central provinces accounted for higher health and economic benefits. While the pandemic lockdown is clearly not an appropriate path to long-term air quality control, these findings suggest that substantial health and economic benefits associated with reduction in air pollution could be achieved, if strict air pollution control measures are carried out.

CRediT authorship contribution statement

Tingting Ye: Formal analysis, Writing - original draft Suying Guo: Formal analysis, Writing - original draft Yang Xie: Formal analysis Zhaoyue Chen: Formal analysis Michael Abramson: Writing - review & editing Jane Heyworth: Writing - review & editing Simon Hales: Writing - review & editing Alistair Woodward: Writing - review & editing Michelle Bell: Writing - review & editing Yuming Guo: Conceptualization, Supervision, Writing - review & editing Shanshan Li: Conceptualization, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: MJA holds investigator initiated grants from Pfizer and Boehringer-Ingelheim for unrelated research. He has undertaken an unrelated consultancy for and received assistance with conference attendance.
from Sanofi. He has also received a speaker’s fee from GSK. There are no potential conflicts of interests for other authors.

Acknowledgements

This work was supported by the Australian National Health and Medical Research Council (#APP1109193 to SL and #APP1107107 to YG) and the China Scholarship Council (#201906320051 to TY).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ecoenv.2021.112481.

References

Alghamdi, M.A., Khoder, M., Abdelmaksoud, A.S., Harrison, R.M., Husseini, T., Li, Y., Zhou, D., Xie, Y., Zhang, Q., Yang, X., Zhan, Y., Wei, L., Yin, M., Wang, S., Cao, J., 2020. Air pollution and COVID-19 mortality: a nationwide time-series analysis in 272 cities in China. Lancet Planet. Health 2, e12-e18.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

Review

from Sanofi. He has also received a speaker’s fee from GSK. There are no potential conflicts of interests for other authors.

Acknowledgements

This work was supported by the Australian National Health and Medical Research Council (#APP1109193 to SL and #APP1107107 to YG) and the China Scholarship Council (#201906320051 to TY).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

References

Alghamdi, M.A., Khoder, M., Abdelmaksoud, A.S., Harrison, R.M., Husseini, T., Li, Y., Zhou, D., Xie, Y., Zhang, Q., Yang, X., Zhan, Y., Wei, L., Yin, M., Wang, S., Cao, J., 2020. Air pollution and COVID-19 mortality: a nationwide time-series analysis in 272 cities in China. Lancet Planet. Health 2, e12-e18.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

Review

from Sanofi. He has also received a speaker’s fee from GSK. There are no potential conflicts of interests for other authors.

Acknowledgements

This work was supported by the Australian National Health and Medical Research Council (#APP1109193 to SL and #APP1107107 to YG) and the China Scholarship Council (#201906320051 to TY).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

References

Alghamdi, M.A., Khoder, M., Abdelmaksoud, A.S., Harrison, R.M., Husseini, T., Li, Y., Zhou, D., Xie, Y., Zhang, Q., Yang, X., Zhan, Y., Wei, L., Yin, M., Wang, S., Cao, J., 2020. Air pollution and COVID-19 mortality: a nationwide time-series analysis in 272 cities in China. Lancet Planet. Health 2, e12-e18.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

References

Alghamdi, M.A., Khoder, M., Abdelmaksoud, A.S., Harrison, R.M., Husseini, T., Li, Y., Zhou, D., Xie, Y., Zhang, Q., Yang, X., Zhan, Y., Wei, L., Yin, M., Wang, S., Cao, J., 2020. Air pollution and COVID-19 mortality: a nationwide time-series analysis in 272 cities in China. Lancet Planet. Health 2, e12-e18.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

Review

from Sanofi. He has also received a speaker’s fee from GSK. There are no potential conflicts of interests for other authors.

Acknowledgements

This work was supported by the Australian National Health and Medical Research Council (#APP1109193 to SL and #APP1107107 to YG) and the China Scholarship Council (#201906320051 to TY).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

References

Alghamdi, M.A., Khoder, M., Abdelmaksoud, A.S., Harrison, R.M., Husseini, T., Li, Y., Zhou, D., Xie, Y., Zhang, Q., Yang, X., Zhan, Y., Wei, L., Yin, M., Wang, S., Cao, J., 2020. Air pollution and COVID-19 mortality: a nationwide time-series analysis in 272 cities in China. Lancet Planet. Health 2, e12-e18.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

Review

from Sanofi. He has also received a speaker’s fee from GSK. There are no potential conflicts of interests for other authors.

Acknowledgements

This work was supported by the Australian National Health and Medical Research Council (#APP1109193 to SL and #APP1107107 to YG) and the China Scholarship Council (#201906320051 to TY).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.ecoenv.2021.112481.

References

Alghamdi, M.A., Khoder, M., Abdelmaksoud, A.S., Harrison, R.M., Husseini, T., Li, Y., Zhou, D., Xie, Y., Zhang, Q., Yang, X., Zhan, Y., Wei, L., Yin, M., Wang, S., Cao, J., 2020. Air pollution and COVID-19 mortality: a nationwide time-series analysis in 272 cities in China. Lancet Planet. Health 2, e12-e18.
Xie, Y., Wu, Y., Xie, M., Li, B., Zhang, H., Ma, T., Zhang, Y., 2020. Health and economic benefit of China’s greenhouse gas mitigation by 2050. Environmental Research Letters. 15 (10), 104042. https://doi.org/10.1088/1748-9326/aba97b.

Ye, R., Cai, L., Peng, X., Yu, K., Cheng, F., Zhu, Y., Jia, C., 2019. Effect and threshold of PM2.5 on population mortality in a highly polluted area: a study on applicability of standards. Environ. Sci. Pollut. Res. 26, 18876–18885.

Yin, P., Chen, R., Wang, L., Meng, X., Liu, C., Niu, Y., Lin, Z., Liu, Y., Liu, J., Qi, J., You, J., Zhou, M., Kan, H., 2017. Ambient ozone pollution and daily mortality: a nationwide study in 272 Chinese cities. Environ. Health Perspect. 125, 117006.

Zhang, Y., Peng, M., Yu, C., Zhang, L., 2017. Burden of mortality and years of life lost due to ambient PM 10 pollution in Wuhan, China. Environ. Pollut. 230, 1073–1080.

Zheng, H., Kong, S., Chen, N., Yan, Y., Liu, D., Zhu, B., Xu, K., Cao, W., Ding, Q., Lan, B., Zhang, Z., Zheng, M., Fan, Z., Cheng, Y., Zheng, S., Yao, L., Bai, Y., Zhao, T., Qi, S., 2020. Significant changes in the chemical compositions and sources of PM2.5 in Wuhan since the city lockdown as COVID-19. Sci. Total Environ. 739, 140000.