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.
COVID-2019 lockdown in Beijing: A rare opportunity to analyze the contribution rate of road traffic to air pollutants

Yalu Xin\textsuperscript{a,b}, Shuangquan Shao\textsuperscript{c}, Zhichao Wang\textsuperscript{a,b,c}, Zhaowei Xu\textsuperscript{a,b}, Hao Li\textsuperscript{a,b}

\textsuperscript{a} China Academy of Building Research, Beijing, 100013, China
\textsuperscript{b} State Key Laboratory of Building Safety and Built Environments, Beijing, 100013, China
\textsuperscript{c} School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China

1. Introduction

Since 2009 the World Health Organization (WHO) has declared six international public health emergencies. These emergencies are: the swine influenza virus (H1N1) in 2009; the resurgence of the poliovirus in May 2014; the spread of the Ebola virus in West Africa in August 2014; the Zika virus outbreak in 24 countries and regions in 2016; another Ebola virus outbreak in the Democratic Republic of the Congo in 2019; the COVID-19 outbreak in 2019. As of 16:00 on November 5, 2020 (Beijing time), 48438926 people have been infected with COVID-2019, and 1231014 people have died (Baidu Real Time Big Data Report of COVID-2019 see https://voice.baidu.com/act/newpneumonia/newpneumonia/). COVID-19 has become the most serious public health incident since the establishment of the WHO. To curb the spread of COVID-19, the government imposed an unprecedented lockdown on Wuhan from January 23, 2020 (Chong et al., 2020; Wu, Gamber, & Sun, 2020). Since then, similar lockdowns have been introduced in many cities, which have included limits on nonessential movement in and out of cities, suspension of all transport, and closure of industries, thus reducing personal contact and effectively suppressing the spread of COVID-19 (Chinazzi et al., 2020; Kraemer et al., 2020; Tian et al., 2020).

Another effect of the lockdown has been, to a certain extent, the improvement in air quality (Bao & Zhang, 2020; Wyche et al., 2021). Ou et al. (2020) found that the lockdown severely affected gasoline demand in the United States. This leads to a reduction in pollutant emissions. In China, lockdown produced a 25% drop in CO\textsubscript{2} (Carbon Brief, 2020, see https://www.carbonbrief.org), a 63% drop in NO\textsubscript{2}, and a 35% drop in PM2.5 (Cole, Elliott, & Liu, 2020). Laurent et al. (2020) found that throughout Western Europe the concentration of NO\textsubscript{2} decreased by 30%–50% during the lockdown, and the concentration of fine particulate matter dropped by 5%–15%. Kumar et al. (2020) observed substantial reductions in PM2.5 concentrations during lockdown, from 19 to 43 % (Chennai), 41–53 % (Delhi), 26–54 % (Hyderabad), 24–36 % (Kolkata), and 10 %–39 % (Mumbai). Similarly, Latif, Dominick, Hawari, Mohtar, and Othman (2021) found that in Klang Valley there were significant reductions in the concentrations of PM10, PM2.5, NO\textsubscript{2} and CO during the lockdown.

As China’s capital, its political and cultural center and a hub for international communication, Beijing has a permanent population of...
more than 20 million. A large number of local emissions and geographical conditions (as shown in Fig. 1) result in serious air pollution in Beijing. In order to control the air pollution problem, Beijing has adopted a series of measures, including the use of electricity for heating in rural areas instead of coal (Xu et al., 2020), and the replacement of coal-fired with gas-fired thermal power plants. This has improved Beijing’s air quality, but there are still certain gaps with the air quality guidelines specified by the WHO. For example, the average PM2.5 concentration in Beijing in 2017 was 58 μg/m³, which was 35 % lower than 89.5 μg/m³ in 2013, but this concentration level is still much higher than the 10 μg/m³ air quality guideline specified by the WHO. Further measures are needed to reduce the concentration of pollutants in the atmosphere.

In cities, particulate matter with an aerodynamic diameter lower than 2.5 μm (PM2.5), nitrogen dioxide (NO₂) and tropospheric ozone (O₃) are among the most threatening air pollutants in terms of harmful effects on human health associated with respiratory and cardiovascular diseases and mortality (Cohen et al., 2017; Nuvolone, Petri, & Voller, 2018; Pascal et al., 2013; Stafoggia, Samoli, Alessandrini, Cadum, & Linares, 2013; Weinmayr, Romeo, De Sarro, Welland, & Forastiere, 2010). Road traffic is considered an important source of PM2.5 and NO₂ (Shekarrizfard et al., 2017; Tang, McNabola, & Mistreart, 2020; Wang et al., 2020a), and it has an important impact on the concentration of O₃. Zhang, Zhang et al. (2020) found that secondary aerosols, solid fuel combustion, dust and marine aerosols are the principal pollution sources of PM2.5, accounting for about 46.1 %, 22.4 % and 13.0 % respectively, and vehicle emissions could be the main anthropogenic source of secondary aerosols in Beijing. Hua et al. (2020) found that heating is the main source of PM2.5 and vehicles are the main source of NO₂ in Beijing. Because of the lockdown, road traffic in Beijing has dropped sharply, which provides us with a rare opportunity to study the impact of road traffic on atmospheric pollutants through experiments. This will provide a natural, experimental basis for Beijing to formulate reasonable road traffic policies and ultimately realize the sustainable development of the city.

This paper creatively puts forward the concept of the MPCR and estimates the Maximum Possible Contribution Rate (MPCR) of road traffic to PM2.5 and NO₂ by analyzing the daily air pollution data and road traffic data in Beijing from January 24 to March 31, 2020 and the same period in 2019. The results show that the PM2.5 concentration during the lockdown dropped by 5.6 % compared with the same period last year, and the NO₂ concentration dropped by 29.2 %. This, combined with the road traffic data obtained on Baidu, finally infers that the MPCR of road traffic to PM2.5 and NO₂ are 11.9 % and 62.3 %, respectively. In addition, we found that the O₃ concentration did not increase significantly during the lockdown. The reason for this phenomenon may be due to more rainfall and snowfall during the lockdown and the decrease in the concentration of CO, a precursor of O₃.

2. Related works

The concentration of pollutants in the atmosphere is affected by many factors. Different cities have different types and scales of pollution sources, climatic conditions, topographical conditions, etc. Whether it is to predict the concentration of pollutants in the future (Chang, Chang, Kang, Wang, & Huang, 2020; Doreswamy, Harishkumar, Yogesh, & Ibrahim, 2020), figure out the contribution rate of pollution sources to pollutants or for other research purposes, it is often necessary to conduct specific research on this city (Table 1). It is impossible to copy the research results of other cities.

There are many studies on Beijing’s air pollution, which are related to the domestic and international influence of Beijing. Many of these studies use a simulation method (Ji, Wang, & Zhuang, 2019; Xu, Zhang, Chen, & Li, 2018). In addition, when important events such as APEC are held in Beijing, studies are also carried out to take advantage of the on-site monitoring method to conduct analysis (Fontes, Li, Barros, & Zhao, 2018; Xu, Liu, Liu, Dore, & Tang, 2019). At such times, the government will often take some measures to limit the number of vehicles.
The lockdown has imposed greater restrictions on road traffic. Many articles have used the impact of the lockdown to study the air pollution in some cities (Aiymgul et al., 2020; Maria, Alessandro et al., 2020; Patel, Talbot, & Salmond, 2020; Ramachandran, Rupakheti, & Lawrence, 2020; Saadat, Rawtani, & Hussain, 2020; Wang & Li, 2020). At present, there is no research to analyze the contribution rate of Beijing’s pollution sources through the lockdown.

We found that those studies using experimental methods usually only draw qualitative conclusions on the contribution rate of a certain pollution source. Quantitative conclusions are often drawn by using simulation methods. This is related to the fact that the influencing factors related to air pollution are too complicated and uncontrollable in real life. Usually, we only need to know the approximate value of a certain pollution source’s contribution rate to guide the formulation and implementation of policies, and it is not necessary to accurately calculate the contribution rate. Therefore, this paper creatively puts forward the concept of the MPCR. When a major change occurs in a pollution source, and other influencing factors have a positive impact on a pollutant, the change in the concentration of this pollutant can be regarded as having been completely caused by this pollution source. The MPCR of this pollution source to the pollutant can be obtained. Although this method cannot obtain an accurate contribution rate, it greatly simplifies the calculation process. The MPCR can prevent us from overestimating the impact of a certain pollution source, and has a strong reference value for the formulation and implementation of emission reduction policies. At the same time, as long as the conditions for the use of this method can be met, other cities in the world can also use this method to calculate the MPCR of a certain pollution source to pollutants, so as to guide the city to formulate a reasonable emission reduction policy.

3. Methodology

Before studying the MPCR of road traffic on PM2.5 and NO₂ in the atmosphere, it is necessary to first determine the weather conditions in Beijing in 2020 and the concentration of pollutants from other sources of PM2.5 and NO₂ (industry and households) compared to the same period in the previous year. If these effects are positive, we can calculate the MPCR of road traffic on PM2.5 and NO₂ through the changes in road traffic and the changes in PM2.5 and NO₂ concentrations during the lockdown. The flowchart of the research methodology is shown in Fig. 2.

Considering the effects of heating, Spring Festival and lockdown on atmospheric pollutant concentration, this paper selects data from January 24 to March 15, 2020 and the same period in 2019 for analysis (Fig. 3). In addition, special factors such as fireworks during Spring Festival and unfavorable meteorological diffusion conditions often cause the concentration of pollutants in the atmosphere to rise sharply, which is not conducive to making a correct judgment on the trend of changes in the concentration of atmospheric pollutants. Therefore, this paper excludes special dates, when the PM2.5 concentration is greater than 100 μg/m³, during the period from January 24 to March 15.

In this study, the concentration data of atmospheric pollutants in Beijing, which include PM2.5, NO₂, O₃, SO₂ and CO, were obtained from the China Air Quality Online Monitoring & Analysis Platform (see http://www.aqistudy.cn). On this platform, all test items are updated every hour.

The “Baidu Maps Spring Festival Population Migration Big Data” (see http://qianxi.baidu.com) project launched by Baidu provides us with data on the Migration Scale Index (MSI) and the Intracity Migration Index (IMI) for Beijing. MSI is the indexation result of the ratio of the number of people who have moved into Beijing to the total number of residents in Beijing. IMI is the indexation result of the ratio of the number of people traveling in Beijing to the total resident population in Beijing.

Weather conditions influence the formation and diffusion of air pollutants (Kallos, Kassomenos, & Pielke, 1993; Yen et al., 2013). Monitoring data on the outdoor ambient temperature, relative humidity, wind speed and days of rainfall and snowfall (Table 2) are obtained from the website http://rp5.kz. The weather station is located at the Beijing Capital International Airport, 116.36 east longitude, 40.04 north latitude, 30.4 m above sea level.

It can be seen that the average temperature and average wind speed from January 24 to March 15, 2020 and the same period in 2019 are similar. The number of days of rainfall and snowfall (10 days) from
January 24 to March 15, 2020 is double that of the same period in 2019. The cleansing effect of rainfall and snowfall can reduce the concentration of pollutants in the atmosphere. Therefore, the weather conditions in 2020 were more conducive to reducing the concentration of pollutants in the atmosphere compared with the same period in 2019.

4. Results

4.1. Impact of the lockdown on industry and households

According to the “Beijing Environmental Statistics Annual Report of 2018” issued by the Beijing Municipal Bureau of Ecology and Environment, atmospheric pollution sources mainly come from three areas: industry, households and road traffic (see http://sthjj.beijing.gov.cn/). As shown in Table 3, SO2 mainly comes from industry and households,
while PM2.5 and NO2 mainly come from industry, households and road traffic.

By analyzing the concentration of SO2 in the atmosphere, the average concentration of SO2 in the atmosphere from January 24 to March 15, 2020 was 37.4 % lower than the same period in 2019. This change is mainly caused by the reduction of industrial and residential emissions. As shown in Fig. 4, according to the statistics of the National Bureau of Statistics (see http://data.stats.gov.cn), the industrial output value of Beijing in February and March 2020 decreased by 2.8 % and 2.9 % in comparison with the same period last year. It can be seen that the impact of the lockdown on industry is not significant, which means that the reduction in SO2 concentration during the lockdown may relate more to households. Many people chose to leave Beijing to go home for the Spring Festival, and many people were unable to easily return to Beijing because of the lockdown. As shown in Fig. 5, the number of people entering Beijing from January 24 to March 15, 2020 decreased by 75.5 % compared with the same period in 2019.

4.2. MPCR of road traffic to PM2.5 and NO2

Fig. 6 shows the trend of IMI in Beijing from January 24 to March 15, 2020 and in the same period in 2019. Affected by the Spring Festival and the lockdown, the IMI in Beijing decreased by 46.9 % compared with the same period in 2019.

Table 4 lists the average concentrations of PM2.5 and NO2 from January 24 to March 15, 2020 and in the same period in 2019. Compared with the same period last year, the average PM2.5 concentration and the average NO2 concentration during the lockdown have decreased by 5.6 % and 29.2 %, respectively.

From Section 4.1, it can be seen that air pollutants from industry and residential buildings have decreased during the lockdown. Therefore, the reduction in concentrations of PM2.5 and NO2 are not only caused by the decline in road traffic, but are also related to their reduction from industry and households. If it is assumed that the reduction of concentrations of PM2.5 and NO2 are caused solely by less road traffic, the MPCR of road traffic to the concentrations of PM2.5 and NO2 are 11.9 % and 62.3 % (Fig. 7), respectively.

Table 2
Meteorological monitoring data from Beijing Capital International Airport.

| Average temperature (°C) | Average relative humidity (%) | Average wind speed (m/s) | Rainfall and snowfall (days) |
|--------------------------|-------------------------------|--------------------------|-----------------------------|
| January 24 to March 15, 2020 | 2.2                           | 54.2                     | 3.0                          | 10                           |
| January 24 to March 15, 2019  | 1.4                           | 31.1                     | 3.4                          | 5                            |

Table 3
Sources of different atmospheric pollutants in Beijing.

| Types of Pollutants | SO2 | PM2.5 | NO2 |
|---------------------|-----|-------|-----|
| Pollution Sources   | Industry | Industry | Industry |
|                      | Households | Households | Households |
|                      | Road traffic | Road traffic | Road traffic |

Fig. 4. Industrial output value in Beijing in February and March 2020 and in the same period in 2019.

Fig. 5. The trend of MSI in Beijing from January 24 to March 15, 2020 and in the same period in 2019.

Fig. 6. The trend of IMI in Beijing from January 24 to March 15, 2020 and in the same period in 2019.

Table 4
Variations of concentrations of PM2.5 and NO2 from January 24 to March 15, 2020 and in the same period in 2019.

|               | PM2.5 (µg/m³) | NO2 (µg/m³) |
|---------------|---------------|-------------|
| January 24 to March 15, 2020 | 36.9          | 22.3        |
| January 24 to March 15, 2019  | 39.1          | 31.5        |
| Percentage change             | −5.6%         | −29.2%      |
4.3. Concentrations of O$_3$

Some studies have found that the impact of lockdown on the environment is not entirely positive. It not only reduces the concentrations of PM2.5 and NO$_2$, but also increases the concentration of O$_3$ (Maria, Roxana, Dan, & Marina, 2020; Pierre et al., 2020; Sharma et al., 2020). This is because the reduction of NO$_2$ concentration will weaken the titration effect of O$_3$, which leads to the increase of O$_3$ concentration. In this paper’s research findings, the O$_3$ concentration in Beijing from January 24 to March 15, 2020 only increased by 1.0 % compared with the same period last year (Table 5).

5. Discussion

According to the research results in Section 4.2, the contribution rate of road traffic to PM2.5 and NO$_2$ in Beijing will not exceed 11.9 % and 62.3 %, respectively. Road traffic is the most important pollution source of NO$_2$, but not the most important pollution source of PM2.5. Some studies have found that road traffic emissions account for 10 %–20 % of total PM2.5 emissions of the city (Huang, Zhang, & Bozetti, 2014; Li, Zhang, & Zhang, 2015; Yang, Chen, & Wen, 2016). This is consistent with the MPCR of Beijing road traffic to PM2.5 obtained in this paper. In addition, some studies have found that the contribution rate of road traffic to NO$_2$ is about 50 % (Frey, Zhang, & Rouphail, 2010; Shon, Kim, & Song, 2011), which is also close to the MPCR of Beijing traffic to NO$_2$ obtained in this paper. This shows that the conclusions drawn in this paper are reasonable.

In this paper’s research findings, the O$_3$ concentration in Beijing increased during the lockdown and the same phenomenon also appeared in other cities that implemented the lockdown. This may be related to the reduction of PM and NO$_2$ concentration (Laurent et al., 2020; Pierre et al., 2020). The concentration of O$_3$ did not increase significantly mainly due to the following reasons: (1) there was more rain and snow during lockdown, and the cleansing effect of rain and snow would reduce the O$_3$ concentration in the atmosphere; (2) during the lockdown, the CO concentration dropped by 9.1 % compared with the same period in the previous year’s Table 5. As one of the important precursors of O$_3$, the decrease of CO concentration will inhibit the production of O$_3$.

6. Conclusion

This article creatively puts forward the concept of MPCR. When a major change occurs in a pollution source, if other influencing factors have a positive impact on a pollutant, the change in the concentration of this pollutant can be regarded as having been completely caused by this pollution source. The MPCR of this pollution source to the pollutant can be obtained. Using this method and taking advantage of the rapid decline in the number of road traffic in Beijing during the lockdown, this paper studied the MPCR of Beijing’s road traffic on PM2.5 and NO$_2$. In order to minimize the impact on climatic conditions, this paper chose to compare the concentration of atmospheric pollutants during the lockdown with the same period in 2019. However, the climatic conditions in both years were not exactly the same. Compared with the same period in 2019, the weather conditions in 2020 were more conducive to reducing the concentration of pollutants in the atmosphere. In addition, during the lockdown, the SO$_2$ concentration dropped by 37.4 %. Through the analysis of pollution sources, it is inferred that the pollutants discharged into the atmosphere by industry and households during the lockdown have been reduced.

During the lockdown period of this study, travel intensity in Beijing was reduced by 46.9 %, while the PM2.5 concentration and NO$_2$ concentration in the atmosphere were reduced by 5.6 % and 29.2 %, respectively. When it is assumed that the decrease of PM2.5 and NO$_2$ concentrations is caused entirely by the decrease of road traffic, the MPCR of road traffic to PM2.5 and NO$_2$ concentrations is 11.9 % and 62.3 %, respectively. Road traffic is the most important pollution source of NO$_2$, but not the most important pollution source of PM2.5.

In addition, this paper also found that although the concentration of PM and NO$_2$ decreased significantly during the lockdown, the concentration of O$_3$ only increased by 1.0 %. Therefore, reducing the concentration of PM and NO$_2$ does not necessarily cause a substantial increase in the O$_3$ concentration, but it also depends on the weather conditions and changes in the concentration of O$_3$ precursors.

The research results of this paper provide an important reference for Beijing to formulate reasonable emission reduction policies. At the same time, the research method adopted in this paper has good versatility and is suitable for carrying out research on the contribution rate of pollutants in different cities. It greatly simplifies the calculation process, and can prevent cities from overestimating the impact of a certain pollution source in the process of formulate emission reduction policies.

Declaration of Competing Interest

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

References

Aiymgul, K., Nastisha, B., Olga, P. I., Basyryzhan, B., Bulat, K., Pavel, P., et al. (2020). Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan. The Science of the
Yang, H., Chen, J., Wen, J., et al. (2016). Composition and sources of PM2.5 around heating periods of 2013 and 2014 in Beijing: Implications for efficient mitigation measures. *Atmospheric Environment*, 124, 378–386. https://doi.org/10.1016/j.atmosenv.2015.05.015

Yen, M. C., Peng, C. M., Chen, T. C., Chen, C. S., Lin, N. H., Tseng, R. Y., et al. (2013). Climate and weather characteristics in association with the active fires in northern Southeast Asia and spring air pollution in Taiwan during 2010 7SEAS/Dongsha experiment. *Atmospheric Environment*, 78, 35–50. https://doi.org/10.1016/j.atmosenv.2012.11.015

Zhang, L., An, J., Liu, M., Li, Z., Liu, Y., et al. (2020). Spatiotemporal variations and influencing factors of PM2.5 concentrations in Beijing, China. *Environmental Pollution*, 262, Article 114276. https://doi.org/10.1016/j.envpol.2020.114276

Zhao, J., Zhang, J., Sun, L., Liu, Y., Lin, Y., Li, Y., et al. (2018). Characterization of PM2.5-bound nitrated and oxygenated polycyclic aromatic hydrocarbons in ambient air of Langfang during periods with and without traffic restriction. *Atmospheric Research*, 213, 302–308. https://doi.org/10.1016/j.atmosres.2018.06.015

Further reading

Reliable Prognosis. http://rp5.kz/ Accessed 5 November 2020.