Environmental indicator for effective control of COVID-19 spreading

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Abstract

Recently, a novel coronavirus (COVID-19) has caused viral pneumonia worldwide, spreading to more than 200 countries, posing a major threat to international health. To prevent the spread of COVID-19, in this study, we report that the city lockdown measure was an effective way to reduce the number of new cases, and the nitrogen dioxide (NO_2) concentration can be adopted as an environmental lockdown indicator. In China, after strict city lockdown, the average NO_2 concentration decreased 55.7% (95% confidence interval (CI): 51.5-59.6%) and the total number of confirmed new cases decreased significantly. We also determined that the global airborne NO_2 concentration steeply decreased over the vast majority of COVID-19-hit areas based on satellite measurements. We found that if NO_2 emissions significantly decreased, the total number of confirmed new cases reached an inflection point after approximately two weeks. Italy, Germany and France are good examples. Our results suggest that NO_2 satellite measurement can help decision makers effectively monitor control regulations to reduce the spread of COVID-19.

Introduction

Large-scale COVID-19 viral pneumonia through human-to-human transmission poses a severe and acute public health emergency[1,2]. As the epidemic worsened, most countries imposed city lockdown and quarantine measures to reduce transmission to control the epidemic. The Chinese government has gradually implemented a city-wide quarantine of Wuhan and several surrounding cities as of 23 January, flights and trains to and from Wuhan have been suspended, and public transport has been halted[3,4]. The entire northern Italy was quarantined since 9 March 2020, and three days later the government extended it to the whole country[5].The Spanish government declared a 15-day national emergency, starting on 15 March[6]. In the United States, on 19 March, California became the first state to order a lockdown[7]. In Germany, since 18 March, 16 states have closed, public gatherings of more than two people have been banned and most shops except supermarkets and pharmacies have closed[8]. On 23 March, the British government announced a new nationwide restriction allowing residents to only venture outside when absolutely necessary, e.g., to work, buy necessities[9].

The worldwide lockdown, which was imposed to stop the spread of the novel coronavirus, not only caused an economic downturn but also appeared to result in cleaner air in urban areas usually heavily affected by pollution[10]. The most important measure of the lockdown policy was the reduction of traffic and control personnel flow, and traffic pollution is an important factor influencing air quality and public health. Vehicle exhaust and evaporation emissions are the main emission sources of ozone and secondary particle precursors near the ground in cities and regions[11], and the spatial variation of nitrogen dioxide (NO_2), fine particulate matter ($PM_{2.5}$) and black carbon (BC) may also be significant affected by traffic flow density[12]. A study in Los Angeles showed that nitrogen oxides (NO_x) were identified as a source of pollution for light vehicles, with NO_2, NO_x, carbon dioxide (CO_2), BC, and fine particle number (PN_{fine}) identified as diesel exhaust sources[13]. In South Korea, source analysis studies have shown that there is a high correlation between estimated traffic volume and NO_2 concentration[14]. In Britain, road transport accounts for 80% of the NO_x emissions[15]. NO_2 levels can be used as a proxy for exposure to traffic-related composite air pollution and to assess the impact of scenarios designed to reduce traffic-related emissions[16,17].

In this report, we study the parameters of environmental indicators for city lockdown. Using the automatic ground detection data and satellite data to analyze the trend of lockdown and the total confirmed new cases in major cities in China, and using satellite data to further study the impact of lockdown on virus transmission in countries mainly severely affected by the epidemic, in order to help policymakers to formulate effective control measures to reduce the spread of COVID-19.

2. MATERIALS AND METHODS

The ground observation daily data were provided by the China National Environmental Monitoring Centre (http://www.cnemc.cn/). The data from January 24, 2020, to February 23, 2020, are selected as the representative data after the lockdown in Hubei, and the data from December 24, 2019, to January 23, 2020, are selected as the representative data before the lockdown (Figure 1). The NO_2 ground observation data of China is from 1 January 2020 to 1 March 2020. The average concentration of major cities with severe epidemic diseases was selected as the representative of NO_2 concentration of China, including Wuhan, Nanchang, Guangzhou, Hangzhou, Changsha, Beijing, Shanghai, Hefei and Zhengzhou (Fig. 3). All monitoring instruments of the air quality automatic monitoring system operate automatically 24 h a day. The monitoring items are $PM_{2.5}$, particulate matter (PM_{10}), sulphur dioxide (SO_2), NO_2, and carbon monoxide (CO). The automatic monitoring of $PM_{2.5}$ and PM_{10} adopts the micro-oscillating balance method and the β-absorption method, respectively (ambient air quality standards, GB 3095-2012). SO_2 was determined by the ultraviolet fluorescence method, NO_2 by the chemiluminescence method, CO by the nondispersion infrared absorption method and gas filter correlation infrared absorption method.

This paper adopted the level 3 daily global gridded (0.25°×0.25°) nitrogen dioxide product (OMNO2d) provided by the Ozone Monitoring Instrument (OMI) onboard the Aura satellite as the daily NO_2 data, which can be obtained from GES DISC (https://disc.gsfc.nasa.gov/datasets/OMNO2d_003). The Aura satellite was launched by NASA on July 15, 2004, with its overall objective of monitoring the chemistry and dynamics of the atmosphere from the ground to the mesosphere. The OMI is a nadir-viewing charge-coupled device (CCD) spectrometer onboard the Aura satellite, whose observation band is near-UV/visible. We selected the Column Amount NO_2 Trop product to calculate the changes in the tropospheric NO_2 concentration impacted by the control measures in East Asia, Western Europe and North America. The lockdown in East Asia, Western Europe and North America began on 23 January, 10 March, and 16 March, respectively (Figure 2). :

$$VA = \frac{N_2 - N_1}{N_1} \times 100\% \qquad (1)$$

where VA is the relative variation ratio, N1 is the average NO_2 concentration in the troposphere one month before the lockdown, and N_2 is the average NO_2 concentration in the troposphere one month after the lockdown.

The data from 1 January 2020,to 3 March 2020, were selected to analyse the variation in NO_2 over time in China (Figure 3). The NO_2 satellite data of Italy, Germany, France, the United States, Iran and Switzerland is from the time of the first case in each country to 20 April 2020 (Figure 4). Due to the satellite orbit, default values occur among the daily data that were determined via piecewise linear interpolation over time. Border data from the US Centers for Disease Control and Prevention (CDC) (https://www.cdc.gov/epiinfo/support/downloads/shapefiles.html) were selected to obtain the borders of each country. To remove the influence of weather factors, a 7-day moving average was calculated. To compare the relative changes among the different countries, the data for each country were standardized.

The daily total number of new confirmed cases in each country and region was obtained from the Center for Systems Science and Engineering (CSSE) of Johns Hopkins University (https://github.com/CSSEGISandData/COVID-19). The daily total number of new confirmed cases in China was retrieved from the Department Earth System Science of the Tsinghua University shared case database (https://cloud.tsinghua.edu.cn/d/335fd08c06204bc49202/).

3. RESULTS AND DISCUSSION

3.1. The change in pollutant concentration in Hubei Province one month before and after the closure of major cities severely affected by the epidemic. Compared with before the lockdown, NO_2, SO_2, PM_{10}, CO and $PM_{2.5}$ concentrations all decreased to a certain extent, while NO_2 experienced the most notable decrease (Figure 1). Since biomass and coal combustion are major SO_2 and CO sources, they exhibit the lowest rate of improvement[18,19]. Both the $PM_{2.5}$ and PM_{10} concentrations decreased to a certain extent (31.2% and 34.3%, respectively) as a result of the reduction in fugitive dust, particulate matter and important precursors produced by motor vehicles and factories[20]. The monthly average $PM_{2.5}/PM_{10}$ ratio was 0.81 (95% confidence interval (CI): 0.76-0.86), so $PM_{2.5}$ was the main particle pollutant after lockdown. Exhaust emissions contributed only moderately to local levels of the $PM_{2.5}$ total mass, which were mostly derived from other sources, such as biomass combustion and the remote transmission of secondary particles. Therefore, the impact of strict traffic control during the lockdown on $PM_{2.5}$ is not notable, and the spatial difference is large, so $PM_{2.5}$ is not suitable as a city lockdown indicator.

Although the NO_2 emissions per vehicle slightly decreased after the upgrading of the quality standards of petroleum products, the notable growth of vehicle ownership increased the proportion of NO_2 traffic source emissions, in addition, after the implementation of emission standards for coal-fired power plants, multiple technical improvements greatly controlled the NO_2 emissions from coal-fired sources, which all enhanced the correlation between NO_2 and city lockdown effect[21]. The effect of city closure on NO_2 was significantly greater than that on the other pollutants, with an average concentration reduction of approximately 60.3% (95% CI: 56.8-64.0%), which can be applied as an environmental indicator of the lockdown effect.

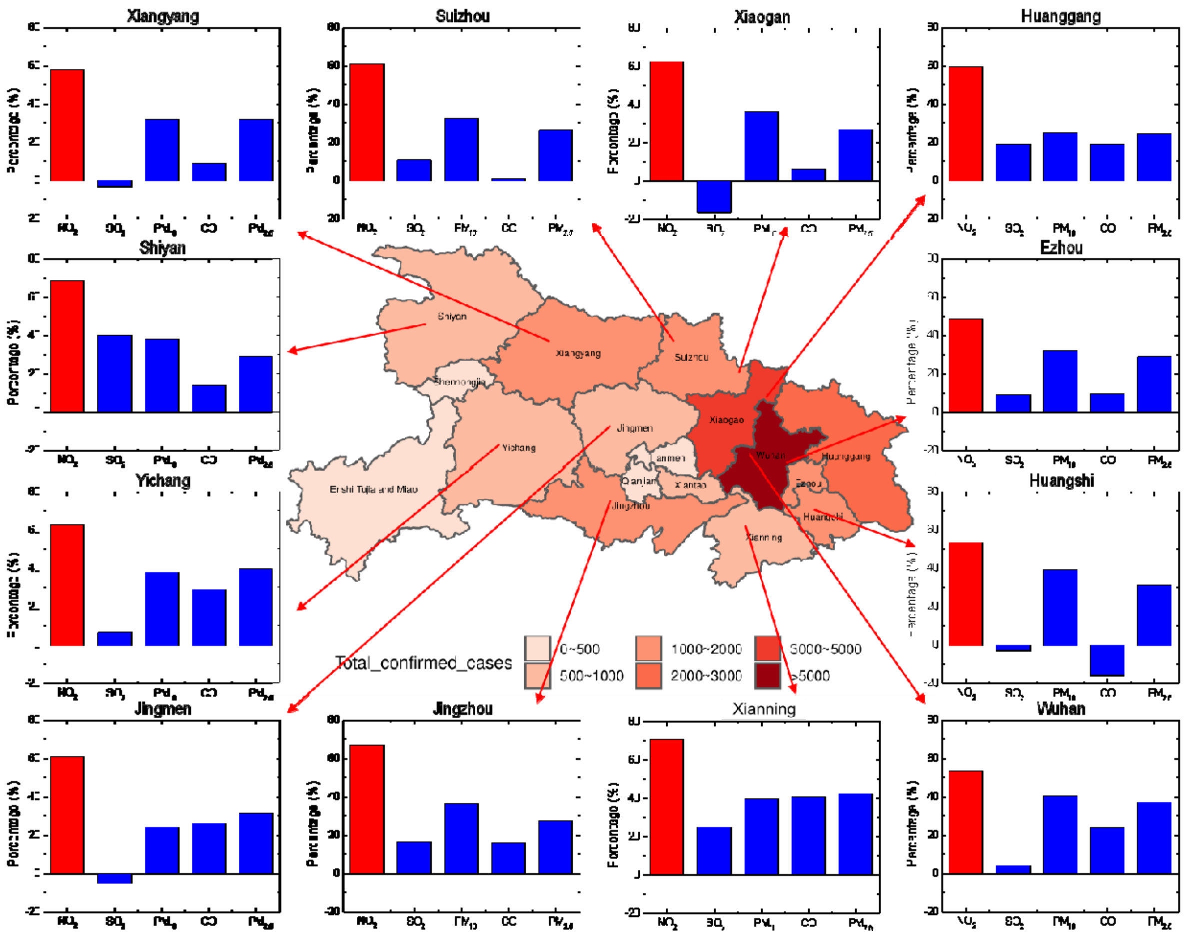

Figure 1. The improvement rate of the major pollutants NO_2 (red), SO_2 (blue), PM_{10} (blue), CO (blue) and $PM_{2.5}$ (blue),and the distribution of the accumulated epidemic numbers in each city of Hubei Province after the lockdown.

3.2. The changes of airborne NO_2 plummets over COVID-19-hit area after lockdown. In East Asia (Figure 2a), satellite images show that compared to before the blockade, the total emissions of NO_2 in eastern China have significantly decreased by approximately 56.6%. In South Korea, the monthly NO_2 emissions have also been reduced by approximately 18.0 %. The local government has implemented the most expansive testing programme and has isolated people infected with the virus without locking down entire cities, and the sharp decrease in NO_2 may be linked to the reduction in local emissions and pollutant transport from surrounding areas[22,23]. Japan has not imposed widespread lockdown policies, and a 4.8% increase in NO_2 may be linked to emissions from power generation and industrial processes[22]. In western Europe (Figure 2b), the monthly NO_2 concentrations have decreased sharply in Italy by 47.5%, particularly in the north (82.4%), where the outbreak is the most severe. This could be due to the reduction in road traffic and the decrease in economic activities in the industrial heartland as a result of the widespread lockdown policy[10]. Other countries such as Germany, Denmark, and Poland also experienced notable reductions. This is consistent with the results of the European Environment Agency (EEA)[24]. However, in certain areas, such as northern and southern Spain, the NO_2 concentration has risen, possibly because of lax closure measures and increased emissions from coal-fired power plants[25]. In the United States (Figure 2c), one month after the lockdown, the overall decline in NO_2 is relatively small. The worst affected states, such as New York, Washington and California, still contain areas with increased NO_2 concentrations, and the NO_2 concentration is increasing significantly in the vast midwestern regions that have not yet been locked down.

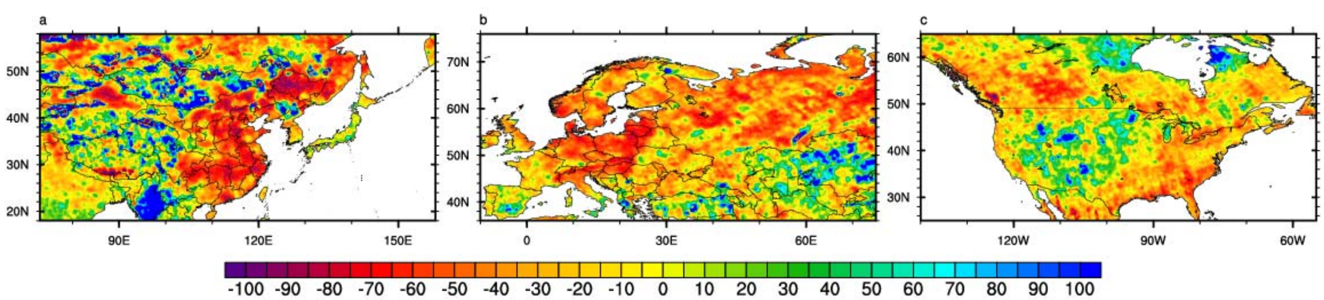

Figure 2. The relative variation in the monthly average tropospheric NO_2 concentration before and after the lockdown. a, Relative variation in East Asia. **b**, Relative variation in Western Europe. **c**, Relative variation in North America. Source: Analysis of data from the NASA Ozone Monitoring Instrument (OMI).

3.3. The temporal evolution of the NO_2 concentration with the total number of confirmed new cases in China. After the strict city lockdown, the NO_2 concentration in the main virus-affected cities in China decreased significantly (Figure 3). Consistent with the satellite data, the ground monitoring results showed that compared to the conditions before the closure, the monthly average NO_2 concentration after the lockdown decreased approximately 55.7% (95% CI: 51.5-59.6%). Since the lockdown, the total number of confirmed new cases reaches an inflection point after approximately two weeks (the incubation period of the virus is 14 days), and compared to the period of 1-15 days after the closure, the total number of confirmed new cases in the 16-30 days after the closure has decreased 73.6% (95% CI: 64.9-81.1%). The most significant improvement was recorded in Hangzhou, where the NO_2 concentration decreased approximately 68.1%, and the total number of confirmed new cases declined the most. Likewise, Zhengzhou, Changsha, Guangzhou, and Nanchang are good examples. Wuhan, the worst virus-affected area in China, also exhibited a downward trend. The total number of confirmed new cases reached 13,436 on February 12 due to the inclusion of clinically diagnosed cases[26], resulting in a new delayed peak in the figure.

The national emergency response has delayed the spread of the epidemic and greatly limited its range. The suspension of intra-city public transport, the closure of entertainment venues and the banning of public gatherings have been linked to a reduction in the incidence of cases. Studies have shown that before emergency response initiation, the (basic) case reproduction number (R_0) is 3.15, and after intervention measures were implemented in 95% of all places, the average R_0 value has dropped to 0.04, the total number of actual cases has decreased 96%[27].

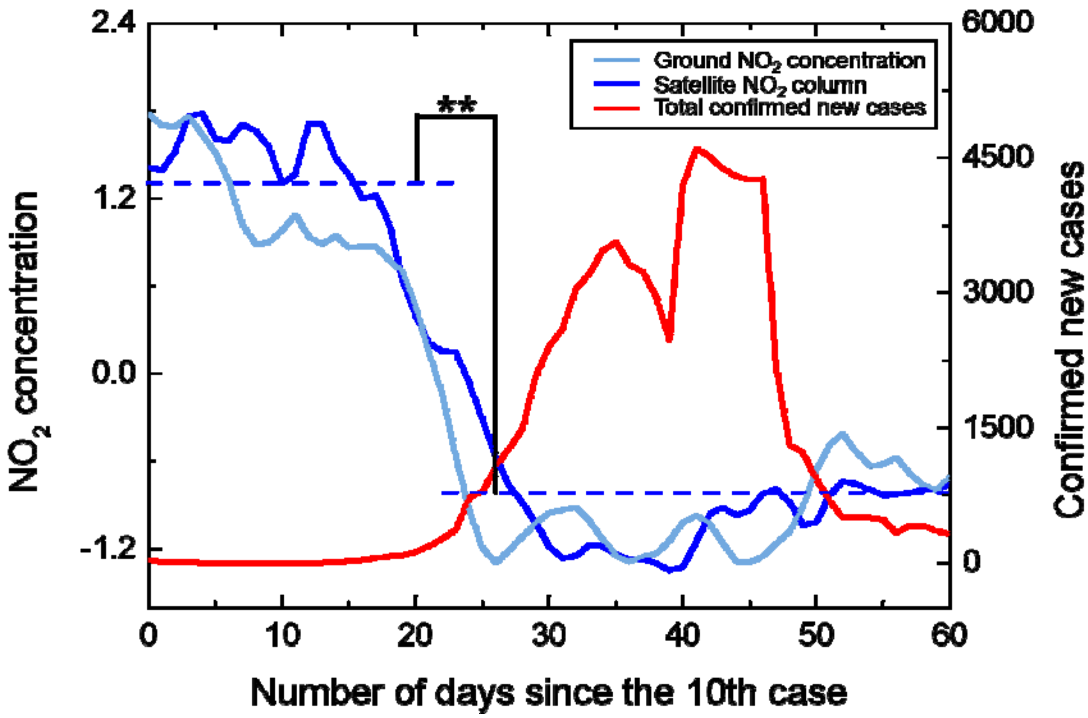

Figure 3. Temporal variation in the NO_2 concentration and number of new cases in China. The dotted line indicates the average value of NO_2 before and after the blockade. ** indicates significant difference at the 0.01 level (bilateral), and * indicates significant difference at the 0.05 level (bilateral).

3.4. The temporal evolution of the NO_2 concentration with the total number of confirmed new cases in the COVID-19-hit areas globally. After the countries severely affected by COVID-19 implemented strict lockdown measures, satellite data showed a significant decline in NO_2 emissions, and the total confirmed new cases decreased after two weeks in most areas (Figure 4). As a result, the strict lockdown of COVID-19-hit areas other than those in China is also effective and easy to implement to prevent the spread of the virus. The lockdown measures might have already prevented tens of thousands of deaths in Europe[28]. In Italy, where the epidemic is widespread, after the lockdown the NO_2 emissions significantly decreased by an average of 36.6%, and the total confirmed new cases reached an inflection point 12 days later, thus verifying that the spread of the virus was effectively controlled. Studies have shown that 38,000 deaths have been averted in this country due to the implemented intervention measures[28]. The occurrence time of the inflection point is mainly related to the magnitude of NO_2 decline. In France, NO_2 declined less (27.1%), and the time for the total number of confirmed new cases to reach an inflection point was delayed. In Germany, the NO_2 emissions decreased the most, by 54.7%, and the total number of confirmed new cases reached an inflection point within 8 days after lockdown, which occurred earlier than in other countries. For Iran and Switzerland, due to the relatively low number of confirmed cases, with the decline of NO_2 after the strict control, confirmed new cases also reached the inflection point earlier. In the the worst-affected states, United States, NO_2 emissions decreased by an average of 43.1% in New York, Washington and California, and the total confirmed new cases dropped significantly, showing signs of easing.

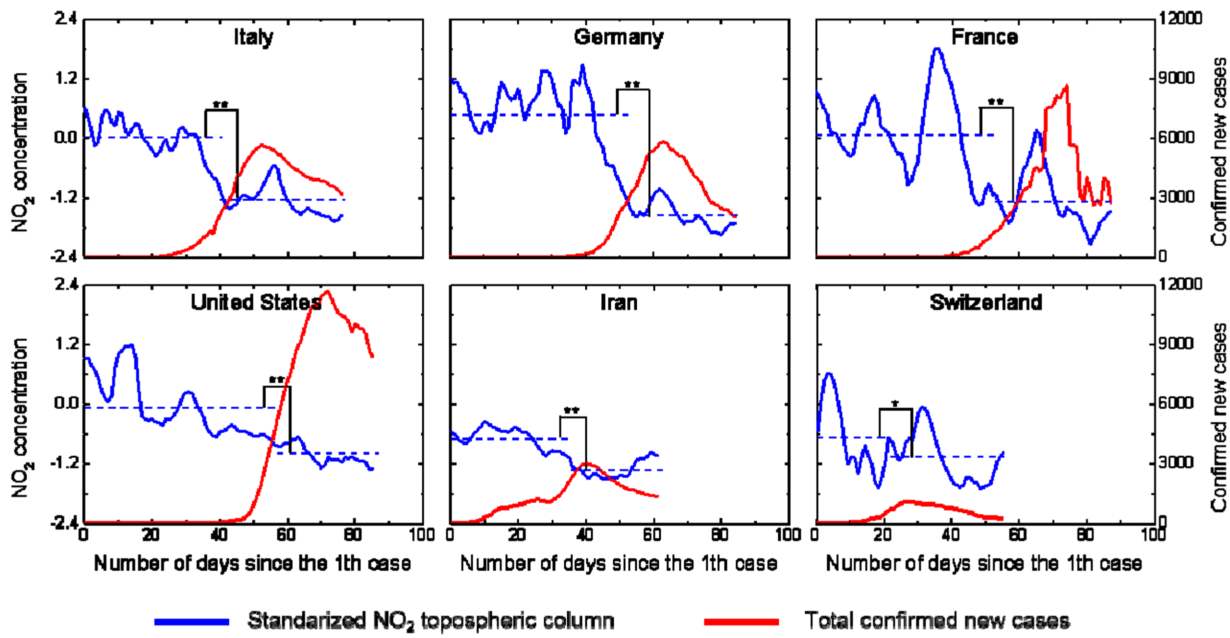

Figure 4. Temporal variation in the NO_2 concentration and number of new cases in the COVID-19-hit areas. The dotted line indicates the average value of NO_2 before and after the blockade. ** indicates significant difference at the 0.01 level (bilateral), and * indicates significant difference at the 0.05 level (bilateral).

Urbanization and rapid transportation system development accelerate the spread of COVID-19, and only strict containment measures can effectively prevent the spread of the virus. The NO_2 concentration can be considered an inexpensive indicator of virus transmission control. As a result of strict control measures and the rapid implementation of first-level emergency measures, the NO_2 emissions and total number confirmed new cases significantly decreased in China, especially in the strictly controlled cities. In many European countries, a strict lockdown is also effective and easy to do to prevent the spread of the virus. But there are also areas such as southern and northern Spain and parts of the United States where the NO_2 level has increased.

Studies have shown that the likelihood of fewer cases in the gradual multi-stage policy is zero, and that such a policy decision implies that the government is willing to risk an increase in COVID19 cases and deaths in exchange for decreased economic and isolation impacts, which may not be desirable from an objective point of view[29]. Although the immediate adoption of a lockdown policy may lead to many people being adversely affected financially, in the short term, the number of new confirmed cases will decline approximately 15 days after policy implementation, and an earlier decline can occur with stricter lockdown measures. International guidance supports a range of mandatory social isolation measures, extensive case detection, and isolation and contact tracing[9]. Compliance with quarantine directives is absolutely critical to saving lives, protecting the most vulnerable in society, and ensuring that the national security system can cope and care for the sick. In such cases, an immediate lockdown policy may be preferred, and NO_2, as an environmental indicator of virus control, can help managers implement effective control measured to curb the spread of COVID-19.

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Acknowledgements

This work was jointly supported by the National Science Foundation of China (41305009 and 41405010). The authors acknowledge the China National Environmental Monitoring Centre for providing the datasets. http://www.cnemc.cn/.

Author Contributions

X. L . and J. H. are first co-author. J. H. designed the study and contributed to the ideas, interpretation and manuscript writing. X. L. L.Z. and W.L. contributed to the data analysis, interpretation and manuscript writing. All of the authors contributed to the data analysis, discussion and interpretation of the manuscript. All of the authors reviewed the manuscript.

Additional information

Competing financial interests: The authors declare no competing financial interests.

Graphics software

All maps and plots were produced using license.