




# COVID-19 Pandemic and City-Level Nitrogen Dioxide (NO<sub>2</sub>) Reduction for Urban Centres of India

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## Abstract

Air pollution poses a grave health risk and is a matter of concern for researchers around the globe. Toxic pollutants like nitrogen dioxide (NO<sub>2</sub>) is a result of industrial and transport sector emissions and need to be analysed at the current scenario. After the world realised the effect of COVID-19 pandemic, countries around the globe proposed complete lockdown to contain the spread. The present research focuses on analysing the gaseous pollution scenarios, before and during lockdown through satellite (Sentinel-5P data sets) and ground-based measurements (Central Pollution Control Board's Air Quality Index, AQI) for 8 five-million plus cities in India (Delhi, Ahmedabad, Kolkata, Mumbai, Hyderabad, Chennai, Bengaluru and Pune). The long-term exposure to NO<sub>2</sub> was also linked to pandemic-related mortality cases across the country. An average of 46% reduction in average NO<sub>2</sub> values and 27% improvement in AQI was observed in the eight cities during the first lockdown phase with respect to pre-lockdown phase. Also, 53% of Corona positive cases and 61% of fatality cases were observed in the eight major cities of the country alone, coinciding with locations having high long-term NO<sub>2</sub> exposure.

**Keywords** COVID-19 · Air pollution · NO<sub>2</sub> · India · Lockdown

## Introduction

The most recently discovered coronavirus disease 2019 (COVID-19) was declared a global public health emergency on January 30, 2020, and a global pandemic on March 11, 2020, by the World Health Organization (2020). As indicated, the contagious nature of the virus is a matter of grave concern worldwide and has shown a manifold increase since its inception in Wuhan, Hubei province in China (Read et al. 2014). When the first COVID-19 patient was diagnosed in India on January 30, 2020, the world had already crossed the count of 8096 cases worldwide, i.e. more than the cases associated with severe respiratory syndrome (SARS) in 2003 (WHO 2004). COVID-19 is a respiratory disorder accompanied by symptoms of fever, dry cough and breathing difficulty subsequently. The virus was not previously associated with disease in humans;

hence, it is also known as novel coronavirus or SARS-CoV-2. Some factors responsible for the susceptibility to novel coronavirus are diagnosed as history of diabetes, heart ailments, exposure to smoking and hypertension (Jiang et al. 2020; Rodriguez-Morales et al. 2020). As of May 18, 2020, the world has recorded 53, 70,375 cases and 3, 44,454 deaths with the highest mortality in the USA; India has witnessed a total of 96,192 cases and 3039 fatalities (WHO 2020). Preliminary analysis reveals that the transmission rate for India is 1.7 (where the value is ranging from 1.5 to 3.5 worldwide) (Ghosh et al. 2020). The respiratory illness symptoms and mortality due to prolonged exposure to gaseous pollutants like nitrogen dioxide (NO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>), particulate matter (PM), carbon monoxide (CO), etc., have been reported earlier in India and around the world in several studies (Abbey et al. 1995; Abbey and Burchette 1996; Balakrishnan et al. 2019; Beeson et al. 1998; David et al. 2019; Faustini et al. 2014; He et al. 2020; Liu et al. 2013; Ogen 2020; Siddique et al. 2011).

The Government of India took note of worsening situation worldwide and to contain the epidemic's effect,

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imposed the first nationwide public curfew on March 22, 2020. It was followed by lockdowns in three phases, viz. (1) March 24 to April 14, 2020, (2) April 15 to May 3, 2020, and (3) May 4 to May 17, 2020. The effect of lockdown is quite evident in the first two phases in terms of considerable reduction in the growth rate of the disease (Myllyvirta and Dahiya 2020). The effect could also be noticed on environmental factors around the globe in terms of decreased haze, improvement in air and water quality exuded by limited anthropogenic activities in transport, industrial and domestic sectors (Muhammad et al. 2020).

The use of satellite remote sensing for understanding the growing air pollution levels within the tropospheric column of Earth has been demonstrated earlier (Liji Mary David and Nair 2013; Fishman et al. 2008; Martin 2008; Sellitto et al. 2011). However, canopy-level near-surface air pollution is seen to have a more adverse impact on human health globally, especially in developing countries. The level of ambient air pollution is poorer in countries such as Nigeria, Bangladesh, India, Pakistan, China, far exceeding the standards set by World Health Organization (WHO) while leading towards numerous deaths (nearly 4.9 million) annually, from all countries around the globe (Health Effects Institute 2019). In India, numerous researches have indicated very high pollutant concentration over the Indo-Gangetic Plain (Acharya and Sreekesh 2013; Prasad et al. 2012; Sellitto et al. 2011; Shastri et al. 2017). The objective of this research was to analyse the effect of lockdown on improving the levels of air pollution in various cities across India using satellite-derived spatiotemporal data sets and ground-based measurements. Additionally, the relationship was explored between mortality and air pollution levels within the selected cities.

## Materials and Methods

The long-term status of NO<sub>2</sub> as a pollutant and the spatial distribution of tropospheric NO<sub>2</sub> for before and during COVID-19 lockdown scenarios were derived using the European Space Agency's (ESA) Sentinel-5 precursor satellite data available through TROPospheric Monitoring Instrument (TROPOMI). Central Pollution Control Board's (CPCB) Continuous Ambient Air Quality Monitoring System (CAAQMS) data set was used to study the effect of lockdown on Air Quality Index (AQI) of Indian cities. The status of mobility and reduction in traffic-induced pollution were recorded using Google-based mobility index report (Google 2020). Additionally, to understand the effect of long term exposure of NO<sub>2</sub> on human health, COVID-19 positive cases and number of deaths was obtained for all districts around the country of India as on 18 May 2020. The data set has been retrieved and analysed using Google

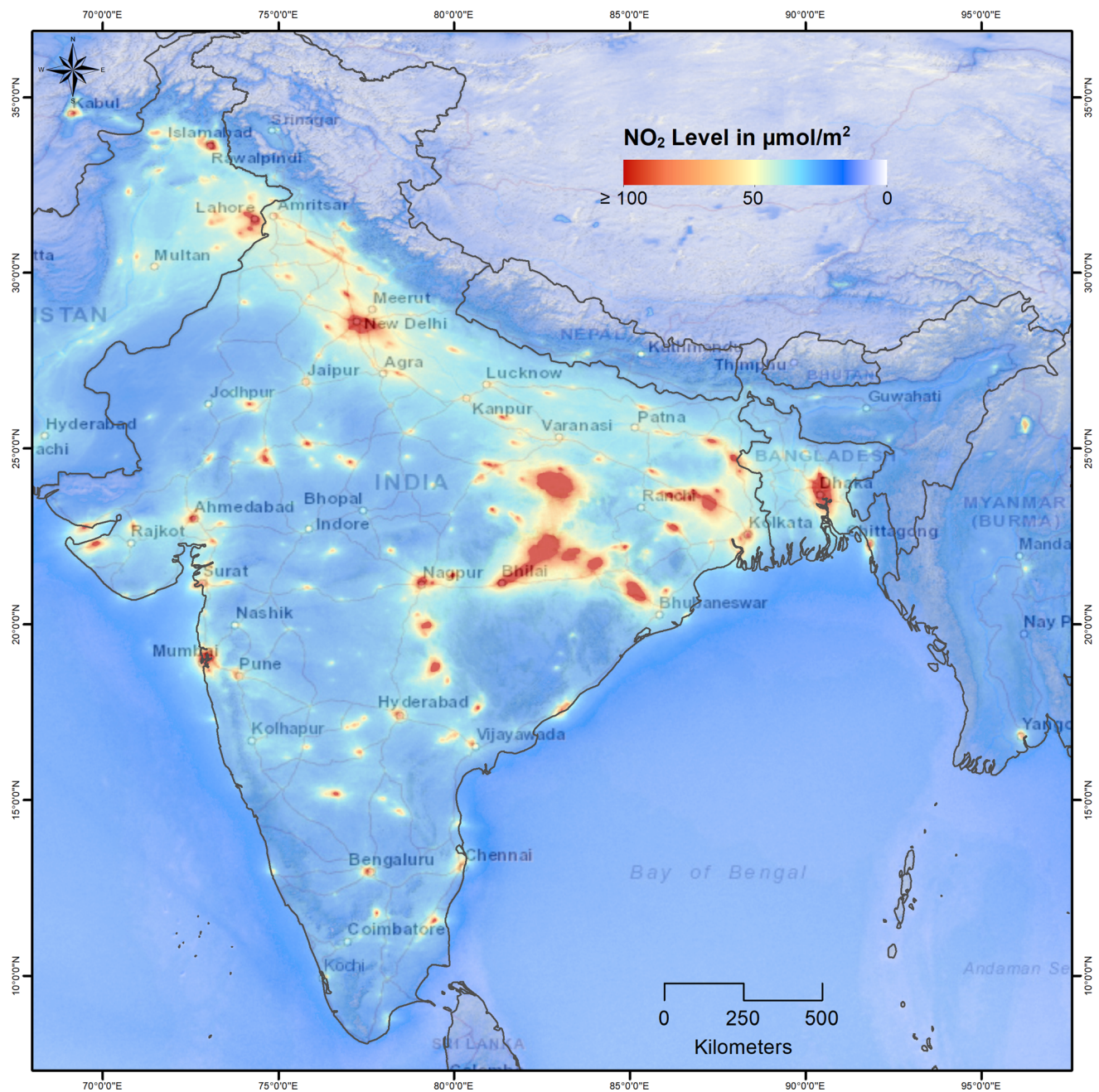
Earth Engine API (Gorelick et al. 2017) and various government websites dispensing information related to COVID-19-related deaths.

The mean values of NO<sub>2</sub> are analysed for pre-lockdown period (March 11–March 23, 2020), lockdown-1 period (LD 1) (March 24–April 7, 2020) and lockdown-2 period (LD 2) (April 8–April 21, 2020) scenarios using Arc GIS 10.1 platform. 8 five-million plus cities were selected for detailed analysis, viz. Delhi, Mumbai, Kolkata, Chennai, Bengaluru, Pune, Ahmedabad and Hyderabad. The urban boundary of the city was delineated using a city clustering algorithm for calculating the mean, maximum and standard deviation for the concentration of the pollutant during the three phases. For analysing the mortality cases due to the pandemic, the temporal mean of NO<sub>2</sub> was obtained using TROPOMI data for the period from March 2018 to February 2020. The maximum values of NO<sub>2</sub> and deaths were extracted corresponding to each district. Since city-level mortality information was not available, the maximum value of NO<sub>2</sub> within the district was assumed to represent the city. It was observed that the 8 five-million plus cities had more concentration of the pollutant as compared to the other fringe areas within the district.

## Results

Long-term analysis of tropospheric column NO<sub>2</sub> (March 2018–February 2020) (Fig. 1) over India indicates hot spots of NO<sub>2</sub> at locations dominated by urbanisation or presence of thermal power plants (TPPs) (both inland and coastal). The major emission hot spots shown in TROPOMI trop. column NO<sub>2</sub> distribution coincide with thermal power plants of capacity more than 2000 MW. The hot spots of NO<sub>2</sub> were reported from most urbanised locations or the locations dominated by the presence of thermal power plants and other industries during the pre-lockdown period. They were identified in Orissa, Chhattisgarh, Madhya Pradesh and Jharkhand during the lockdown phase, since they were operational for catering to the electricity demand of the country. The increased concentration of pollution can be attributed to domestic combustion, agricultural waste burning, incomplete fuel combustion in the transport sector, industrial effluents emitted directly in the atmosphere, power generation, construction activity, etc. to name the most salient factors associated with the anthropogenic activities. These factors have contributed to a large extent to increasing asthmatic and other respiratory symptoms amongst masses.

A detailed analysis of the NO<sub>2</sub> levels for before and during lockdown indicates a 30–50% reduction in the levels of NO<sub>2</sub> across the country. Very high NO<sub>2</sub> values > 100 μmol/m<sup>2</sup> were observed in districts such as



**Fig. 1** Long-term NO<sub>2</sub> levels observed from Sentinel-5P data (March 2018–February 2020)

Sonbhadra (Uttar Pradesh), Singrauli (Madhya Pradesh), several locations in Chhattisgarh (Korba, Balrampur, Bilaspur, Champa, Surajpur, Koriya), West Bengal (Bankura, Murshidabad, Bardhaman, Malda), Odisha (Jharsuguda, Sambalpur, Angul, Dhenkanal), Cuddalore in Tamil Nadu, Singhbhum in Bihar, Bellary in Karnataka, etc., majority being thermal power plant locations in India connected through central grid. Cities including Delhi, Mumbai, Ahmedabad, Kolkata, etc., have shown a considerable decrease in the levels of NO<sub>2</sub> as indicated in Tables 1 and 2 and Figs. 2, 3 and 4. The major reduction

values as observed through Sentinel data can be seen in Delhi where the maximum and average values dropped by 70% followed by Bengaluru (63%), Mumbai (57%), Ahmedabad (56%), Hyderabad (49%), Pune (37%), Kolkata (34%) and Chennai (33%) in maximum NO<sub>2</sub> values (Table 2).

The Air Quality Index (AQI) reported by CPCB suggests 27% average improvement in air quality cumulatively for the eight major cities of India (five million plus cities) alone (<http://www.cpcbenvi.nic.in/>) (Table 1). The

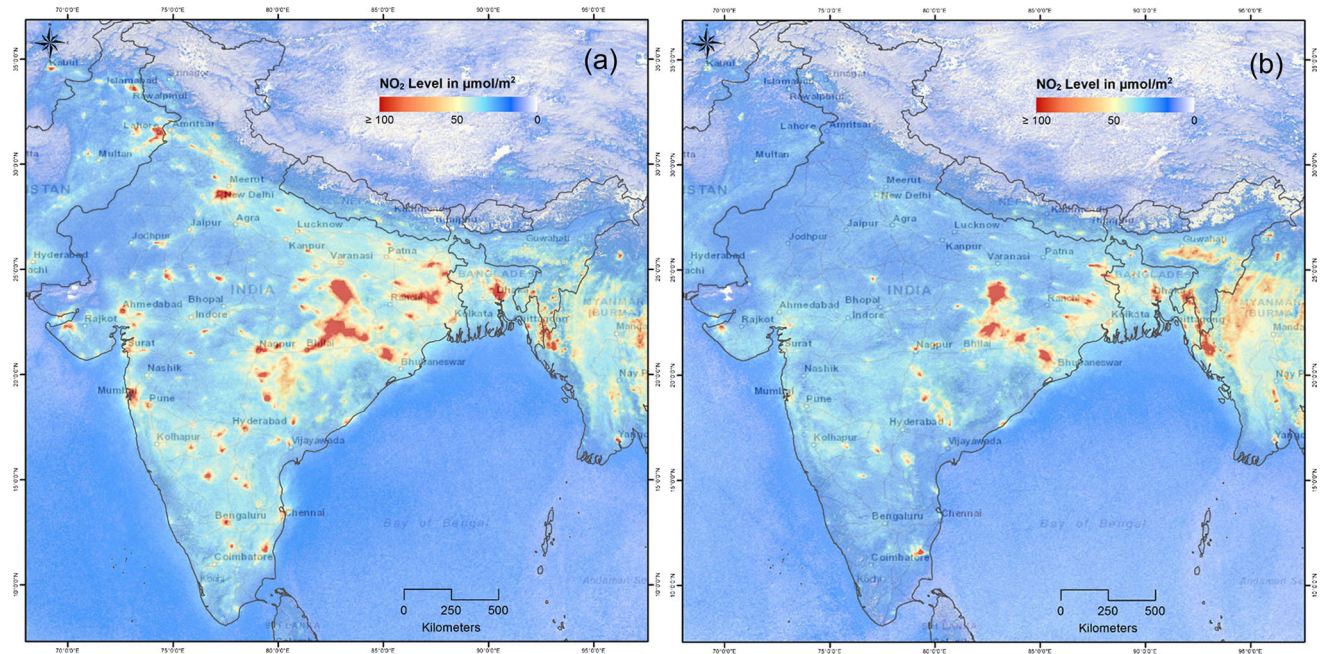


**Table 1** Air Quality Index of major cities in India for pre-lockdown and during-lockdown (1 and 2) scenarios. *Source:* Central Pollution Control Board, State Pollution Control Boards of respective states of cities ([https://app.cpcbcr.com/AQI\\_India/](https://app.cpcbcr.com/AQI_India/))

Sl. no.	Name	Pre-lockdown	During lockdown (Phase 1)	During lockdown (Phase 2)
1	Delhi	150	80	113
2	Ahmedabad	106	91	90
3	Kolkata	121	105	62
4	Mumbai	105	74	76
5	Hyderabad	77	71	63
6	Chennai	63	51	44
7	Bengaluru	80	57	56
8	Pune	92	55	55

**Table 2** Observed values of NO<sub>2</sub> (Sentinel-5 P) for the pre-lockdown and during-lockdown (1 and 2) scenarios (in  $\mu\text{mol}/\text{m}^2$ ). *Source:* Sentinel-5P satellite data analysis

Sl no.	Name	Pre LD Max (mean $\pm$ SD)	During-LD Phase 1 Max (mean $\pm$ SD)	During-LD Phase 2 Max (mean $\pm$ SD)
1	Delhi	163.3 (116.2 $\pm$ 24.3)	49.3 (35.3 $\pm$ 4.5)	53.4 (41.8 $\pm$ 4.4)
2	Ahmedabad	103.7 (84.7 $\pm$ 10.1)	45.1 (38.7 $\pm$ 2.4)	36.8 (30.6 $\pm$ 2.6)
3	Kolkata	93.3 (63.2 $\pm$ 13.5)	61.4 (49.2 $\pm$ 5.1)	57.6 (44.4 $\pm$ 5.6)
4	Mumbai	141.7 (84.1 $\pm$ 23.1)	60.5 (37.6 $\pm$ 5.2)	63.6 (38.5 $\pm$ 9.1)
5	Hyderabad	82.7 (62.1 $\pm$ 9.3)	42.1 (35.3 $\pm$ 3.8)	47.3 (39.4 $\pm$ 3.8)
6	Chennai	55.6 (34.1 $\pm$ 10)	37.4 (21.2 $\pm$ 4.1)	34.4 (21.4 $\pm$ 4.0)
7	Bengaluru	101.4 (67.1 $\pm$ 15.1)	37.7 (32.3 $\pm$ 2.6)	41.8 (33.7 $\pm$ 3.4)
8	Pune	70.7 (59.6 $\pm$ 4.2)	44.2 (38.8 $\pm$ 2.3)	45.9 (38.8 $\pm$ 2.5)



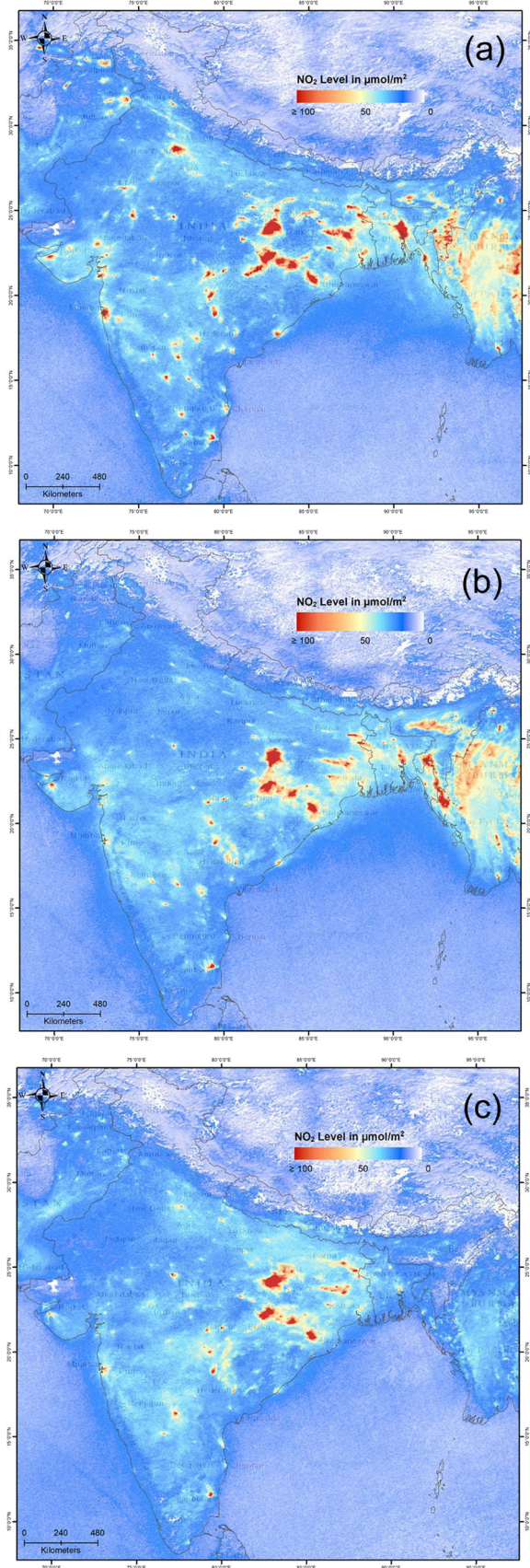
**Fig. 2** NO<sub>2</sub> level during lockdown period from March 24 to April 7, 2020, for **a** 2019, **b** 2020

primary reason behind this reduction is restricted human movement through the motorised mode of transport.

Google-based tracking report on mobility from March 21 to May 02, 2020, also indicates a decrease of 85% in retail and recreation sector and 64% in the transportation sector in India. The baseline value used to calculate the

reduction is the median value for corresponding weekday during January 3–February 6, 2020, and is provided. Citywide detailed analysis is also provided in the report for better understanding. In Delhi, almost 80% of the total pollution is contributed through the transport sector and saw a major drop as indicated through various reports like





◀**Fig. 3** Observed values of  $\text{NO}_2$  for **a** pre-lockdown from March 11 to 24, 2020; during lockdown **b** Phase 1 from March 24 to April 7, 2020 **c** Phase 2 from April 8 to April 21, 2020

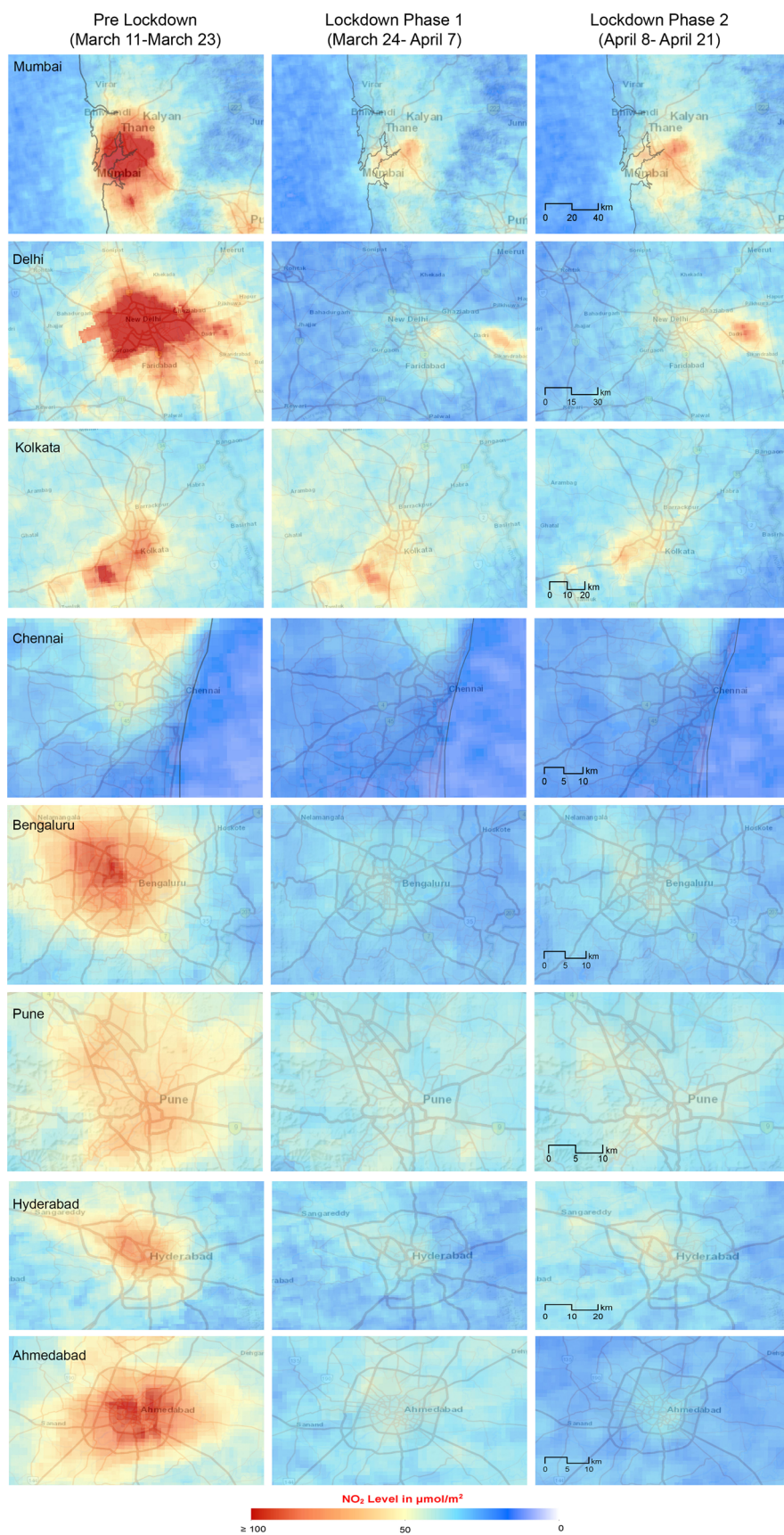
the Automotive Research Association of India (ARAI) and the Energy and Resources Institute (TERI). As per Central Pollution Control Board (CPCB) and Ministry of Environment and Forests (MoEF), the major share of air pollution was attributed to the motorised vehicles ( $\sim 70\%$ ) (Agarwal et al. 2014). Also, termination in construction activities led to reduced dust suspension. Another major reason is the closure of industrial activities around the major cities, which is also a major source of air pollution, particularly  $\text{NO}_2$ . The mixing height increased in several cities, and it helped in vertical dispersion of pollutants, thereby reducing the level of pollution.

It is also evident that the lockdown time, specifically between March 24 and April 7, 2020, could lower the air pollution levels significantly ( $\sim 46\%$ ) which rose to by 5–10% in the case study cities of India during mid-April (Table 2, Figs. 2, 3). The reasons could be due to agricultural waste burning in northern parts of Pakistan and India, which contributed to this elevated effect. It was observed that several power plants were also operational during the lockdown in Madhya Pradesh, Orissa, Chhattisgarh and few other states in the country. The onset of dry conditions due to increasing air temperature after mid-April also led to dust from the Gulf area and elevated the air pollution scenario in the country, primarily in the north in terms of particulate matter (Central Pollution Control Board (CPCB) 2020).

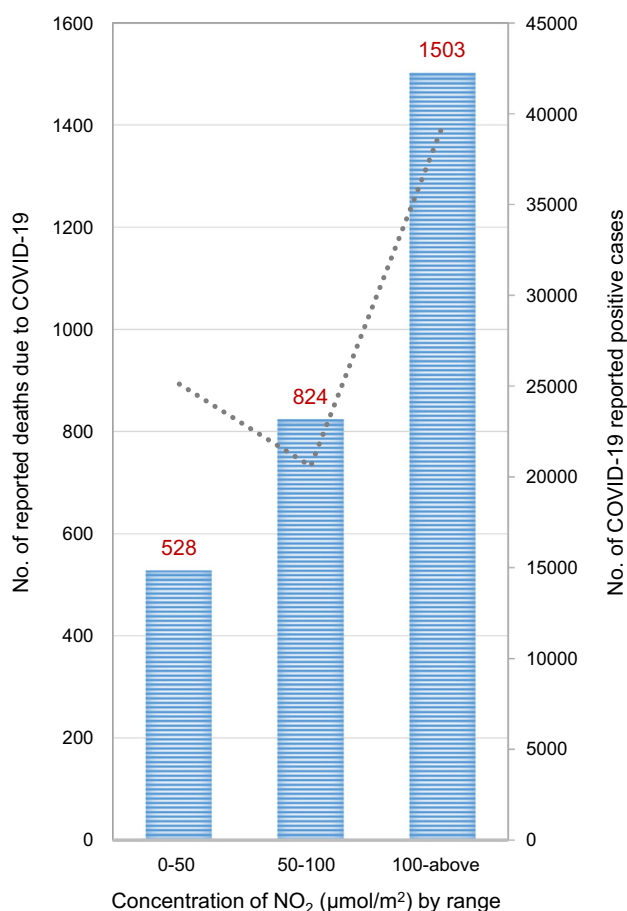
The relationship of  $\text{NO}_2$  with the rate of mortality in India due to COVID-19 pandemic revealed that higher mortality was reported in areas which had a long-term exposure to finer gaseous pollutants (particle size  $< 2.5$  nm) like  $\text{NO}_2$ . It corroborates the fact that long-term exposure to  $\text{NO}_2$  has weakened the immune system and also had profound effect on inflammation of the lungs. Nearly, 53% of total COVID-19 positive cases and 61% of deaths (1859 deaths out of total 3039 deaths in India) were reported in the eight major cities of India as on May 18, 2020 (Fig. 5) (<https://www.covid19india.org/>). COVID-19-related deaths are recorded in 85 districts out of a total of 720 districts in India, the majority of which were reported in major urban centres of the country. The highest deaths were reported in Mumbai, Ahmedabad, Pune, Kolkata and Delhi. Additionally, majority cases were also reported in these major cities indicating a severe impact of air pollution on human health. Therefore, considering the association of high  $\text{NO}_2$  concentration with respiratory mortality (Chen et al. 2007; Ogen 2020), it can be concluded that exposure to toxic components within the air proves fatal in



**Fig. 4** NO<sub>2</sub> levels in Indian cities during pre-lockdown and during-lockdown (1 and 2) scenarios







**Fig. 5** Concentration of NO<sub>2</sub>, reported cases and deaths due to Covid-19 as on May 18, 2020

fighting such diseases and could be one of the major factors for elevating the risk of air pollution-induced mortality. The risk of death in a scenario of cytokine storm syndrome due to inflammatory lungs can lead to death, as seen in cases worldwide (Arden et al. 2002; Beeson et al. 1998; Blomberg et al. 1999; Bowatte et al. 2017; Chen et al. 2007; Patrick 2016). It is also vital to understand that mortality during lockdown scenario may also be dependent upon total COVID-19 tested cases and total reported cases. However, due to restricted and unavailable information, such detailed analysis could not be performed.

## Conclusions

The research aimed at studying the tropospheric NO<sub>2</sub> levels in three phases for India (pre-lockdown and two during-lockdown scenarios of 2-week each duration). Long-term NO<sub>2</sub> spatial analysis using TROPOMI Sentinel-5P data sets could highlight the hot spots of higher concentration due to varied anthropogenic (domestic, vehicular and industrial) and natural reasons. The 2-week mean value of NO<sub>2</sub> spatial

analysis revealed a reduction in the values when compared with status in 2019 (first lockdown period) and when analysed with respect to pre-lockdown scenario (46% reduction in LD 1) which further rose nominally in the LD-2 period (5–10%) for the 8 five-million plus cities alone. AQI for the major cities also showed an improvement of 27% during LD-1 and 29% during LD-2 due to reduction in usage of motorised vehicles and nonoperational thermal power plants. It was also observed that 53% of Corona positive cases and 61% of fatality cases were observed in the eight major cities of the country alone, coinciding with locations having high long-term NO<sub>2</sub> exposure.

The research could have incorporated detailed analysis of all the cities and various other factors leading to high mortality rates in bigger cities including Delhi, Ahmedabad, Kolkata, Mumbai, etc. Factors including testing rate, rate of mortality, urbanisation and congestion parameters, etc., could not be included due to paucity of information during pandemic times. Certainly, the lockdown across the globe and in the Indian subcontinent has helped the environment to regain and to minimise the imbalances.

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## Compliance with Ethical Standards

**Conflict of interest** The author declares no known competing financial interests or personal relationships that could have appeared to influence the work reported in the paper.

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