



Phase wise spatial and temporal variations of nitrogen dioxide during and pre COVID-19 lockdown period in tier-1 cities of India

Kumar Ashwini¹ · Gautam Kumar Saw² · Ajai Singh³

Received: 2 February 2021 / Revised: 2 April 2021 / Accepted: 10 April 2021 / Published online: 15 April 2021
© Korean Spatial Information Society 2021

Abstract The novel coronavirus (COVID-19) pandemic disrupted basic lifestyle of everyone across the globe. To stop the conveyance of the coronavirus into the human body and to flatten the transmission rate curve, almost every country imposed a lockdown. In India, the emergency lockdown was imposed on the 24th of March 2020 which created an economic crisis in the country but proved a boon in disguise for the environment to improve its quality. The study analysed the statuses of air quality with respect to NO₂ in pre and during the COVID-19 lockdown period in eight districts of India where tier I cities are located. Nitrous Oxide concentration was determined through Sentinel 5P satellites imagery and Central Pollution Control Board ground station data. The lockdown across the country has helped the environment to regain, and therefore, more studies are required to assess other parameters to explore the implementation of the provision of the well-planned lockdown of 1-week duration in a year for giving enough time to the environment to recuperate. These results show that the study areas (Ahmedabad, Hyderabad, Delhi, Kolkata, Mumbai, Chennai, Bengaluru,

and Pune) have witnessed a significant drop in nitrogen dioxide (14–62%) as compared to the same period in 2019. This propose an idea that the devilish, COVID-19 lockdown has proved to be an unknown tool for tranquillizing air pollution (NO₂) during a lockdown within the Territory of Indian.

Keywords Sentinel 5P · COVID-19 · Nitrogen dioxide · Lockdown phases · Air pollution · India

Abbreviations

COVID-19	Coronavirus Disease 2019
WHO	World Health Organisation
CPCB	Central Pollution Control Board
NO ₂	Nitrogen dioxide
NO	Nitrogen oxide
SO ₂	Sulphur dioxide
PM	Particulate matters

1 Introduction

COVID-19, primarily a pneumonia symptom disease which bears similarity with early erupted SARS and MERS, emerged in Wuhan city of China in December 2019 [1]. Soon, it became a global public health crisis after World Health Organisation (WHO) announced it as an international public health emergency on 30th January 2020. This categorized COVID-19 into a high-risk disease facing a vulnerable health care system with a mortality rate of 3.4% worldwide [2, 3]. In India, the first case of COVID-19 was officially declared in Kerala on late January 2020 [1].

Many countries including India had implemented lockdown in order to reduce the human-to-human interactions

✉ Ajai Singh
ajai.singh@uj.ac.in

Kumar Ashwini
kumarashwini49@gmail.com

Gautam Kumar Saw
gautamcuj2015@gmail.com

¹ Department of Civil Engineering, National Institute of Technology, Silchar,, Silchar, Assam 788010, India

² Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi, Delhi 110016, India

³ Department of Water Engineering and Management, Central University of Jharkhand, Ranchi, Jharkhand 834205, India

and prevention of the transmission of the virus [4]. Epidemic Diseases Act, 1897 was invoked by the Government of India under this pandemic scenario, and different activities such as large scale public gathering were not allowed; private and public transportation was restricted; all the academic institutions, industries, and markets were closed; fourteen days strict quarantine system was imposed for the suspected as well as infected persons; social distancing and many other strict measures were implemented for flattening the transmission rate curve. This resulted in a decrease in the production from different power plants and industries, which negatively affected the country's social and economic structure, but at the same time, many positive effects, e.g. improvement in air quality, water quality, noise, and land surface temperature have also been observed in the country [5]. As per the reports of WHO, more than seven million deaths are attributed each year around the world due to air pollution, and majority of them belong to developing countries such as India and China where air pollution levels are high. It is intriguing to study the air quality statuses during the lockdown period implemented in different cities of India.

Among all the gases present in both troposphere and stratosphere, Nitrogen dioxides and Nitrogen oxides (NO_2 and NO) are one of the important type of gases found within the atmosphere of Earth [6]. They enter the atmosphere as a result like wildfires, lightning, and microbiological processes in soils which comes under anthropogenic activities and natural processes [7, 8]. It alters the atmospheric chemistry by particulate formation mechanism, produces ozone, and contributes to acid rain [9]. Nitrogen dioxide (NO_2) is a noxious pollutant and a result of the combustion of fossil fuels (coal, gas, and oil), welding and explosives, refining of petrol and metals, and manufacturing units. In the present study, the impact of the lockdown measure due to COVID-19 outbreak in India, which caused reduced economic activity to an extremely low level from March 2020 to May 2020 and ultimately had tremendous effects on tropospheric and ground Nitrogen Dioxide (NO_2) concentration in eight districts of India namely; Delhi, Mumbai, Kolkata, Chennai, Pune, Bengaluru, Ahmedabad, Hyderabad where tier-I districts of India are situated, was analyzed. The hot spots of NO_2 are normally reported from most urbanized locations. Though Siddiqui et al. [10] analyzed the air pollution conditions, during and before lockdown through Sentinel-5P data sets and ground-based measurements (Central Pollution Control Board's Air Quality Index) for 8 major cities in India, the study of NO_2 concentration based on different phases of lockdown in India and comparison with the same periods in the year 2019 is the mainstay of the paper. We thought it would be interesting to explore the impact of lockdown when compared with the previous year's data. The analysis is based

on the Sentinel 5-P satellite observation and validated using ground-based air quality monitoring stations of India.

The effect of complete lockdown was realized on the many environmental factors across the globe in terms of improved air and water quality [11]. Once the international event of Trump's Visit to India got over, the entire focus of Central Govt. shifted to the catastrophic pandemic which was surmounting on the sub-continent. Succeeding Janta Curfew on 22/03/2020, a historic national wide lockdown was declared on 24/03/2020 which lasted for 21 days. It was extended first, on 14.04.2020, Phase-II, and then on 03.05.2020, Phase-III whereas the second extension allowed some restricted activities as a relief to the common people. To monitor 733 districts of India, the policymakers divided the whole nation into three zones; Red Zones-bearing the strictest sanctions of public activities, Orange Zones-bearing the stricter sanctions, and the Green Zones-most liberal one, but with precautionary guidelines. The red zones proved a nightmare for the unorganized sector vis-à-vis commercial activities including e-commerce due to various restrictions, delivery time, and strict guidelines. Only, Phase-IV delegated power to states and local authorities to undo or alter the earmarked zones and relax the activities accordingly. The earlier phases had broken the spine of people like daily wage laborers, street vendors, farmers (due to restrictions on inter-state movement), and local suppliers, etc.

2 Material and methods

TROPOMI, a low-earth orbit (825 km), sun-synchronous, with an equator overpass time of approximately 13:30 local solar time, was launched by the European Space Agency (ESA) on October 13, 2017, for the European Union's Copernicus Sentinel 5 Precursor (S5p) satellite mission. It measures the total column amounts of several trace gases like SO_2 , NO_2 , CO , HCHO in the UV-Vis-near infrared-shortwave infrared spectral regions. It has a spatial and temporal resolution of $3.5 \times 7.2 \text{ km}^2$ and 101 min, respectively with swath coverage of 2600 km. In this study, tropospheric vertical column density of near real-time NO_2 data was used. It represents vertically integrated number of NO_2 molecules per unit area between the surface and the tropopause. Downloading, data processing, and geospatial analysis of S5P satellite data were carried out by a cloud-based platform, i.e., Google Earth Engine. The Earth Engine consisted of a multi-petabyte analysis-ready data catalog co-located with intrinsically parallel computation and high-performance service. It was associated with a web-based interactive development environment (IDE) that enables rapid prototyping and visualization of processed results. The S5P data was further rescaled into $30 \times 30 \text{ m}^2$

resolution spatial analysis work was done by using ArcGIS and SPSS software. For ground-based NO₂ measurement (unit microgram per m³), data were collected from the Central Pollution Control Board (CPCB) for all the locations used in the study regions.

The phase-wise mean of Nitrogen Dioxide emission was determined. Emission of NO₂ was measured by Sentinel-5P during and pre lockdown 2019–2020 for the monitoring stations. Figure 1 shows the location of the study area indicating the eight districts where Tier I cities of India are located. The study periods were categorised into five different categories such as (a) February 01, 2020 to February 29, 2020; (b) March 01, 2020 to March 23, 2020 (before lockdown); (c) March 25, 2020 to April 14, 2020, phase-I; (d) April 15, 2020 to May 03, 2020 phase-II; and (e) May 04, 2020 to May 17, 2020, Phase-III (after lockdown). Data from ground stations were collected for the same periods for better comparison.

3 Results and discussion

The percentage change in NO₂ concentrations in five different scenarios as mentioned in the above section was determined by using Sentinel 5 P satellite data (Table 1).

Further, the percentage change in NO₂ concentrations was calculated with the help of data obtained from air quality monitoring ground stations under the control of CPCB for the same districts (Table 2). As per CPCB ground monitoring stations data, in Ahmedabad, Hyderabad, Delhi, Kolkata, Mumbai, Chennai, Bengaluru, and Pune, the mean NO₂ concentration during the lock-down period (from 25 March 2020 to 17 May 2020) was 41, 16, 19, 15, 7, 5, 9, 16, and 18 (µg/m³), respectively. In both cases, the percentage change was determined by comparing the periods from February 2020 to May 14, 2020, with the same period in 2019. Satellite-based NO₂ monitoring shows great decrease of overall NO₂ concentration (compared with 2019) for Chennai (− 62.53%) followed by Bengaluru (− 53.85%), Hyderabad (− 49.46%), Delhi (− 49.01%), Kolkata (− 40.14%), Mumbai (− 36.03%), Pune (− 24.93%) and Ahmedabad (− 14.97%). Whereas ground-based NO₂ monitoring stations shows highest decrease in NO₂ concentration is for Ahmedabad (− 119.36%) followed by Bengaluru (− 114.92%), Chennai (− 58.59%), Delhi (− 58.28%), Kolkata (− 45.35%), Hyderabad (− 39.44%), with increment in NO₂ concentration in Mumbai (27.26) and Pune (24.6%). This huge difference in satellite-based measurement and ground-based measurement of NO₂ can be attributed to the functioning of a varying number of the

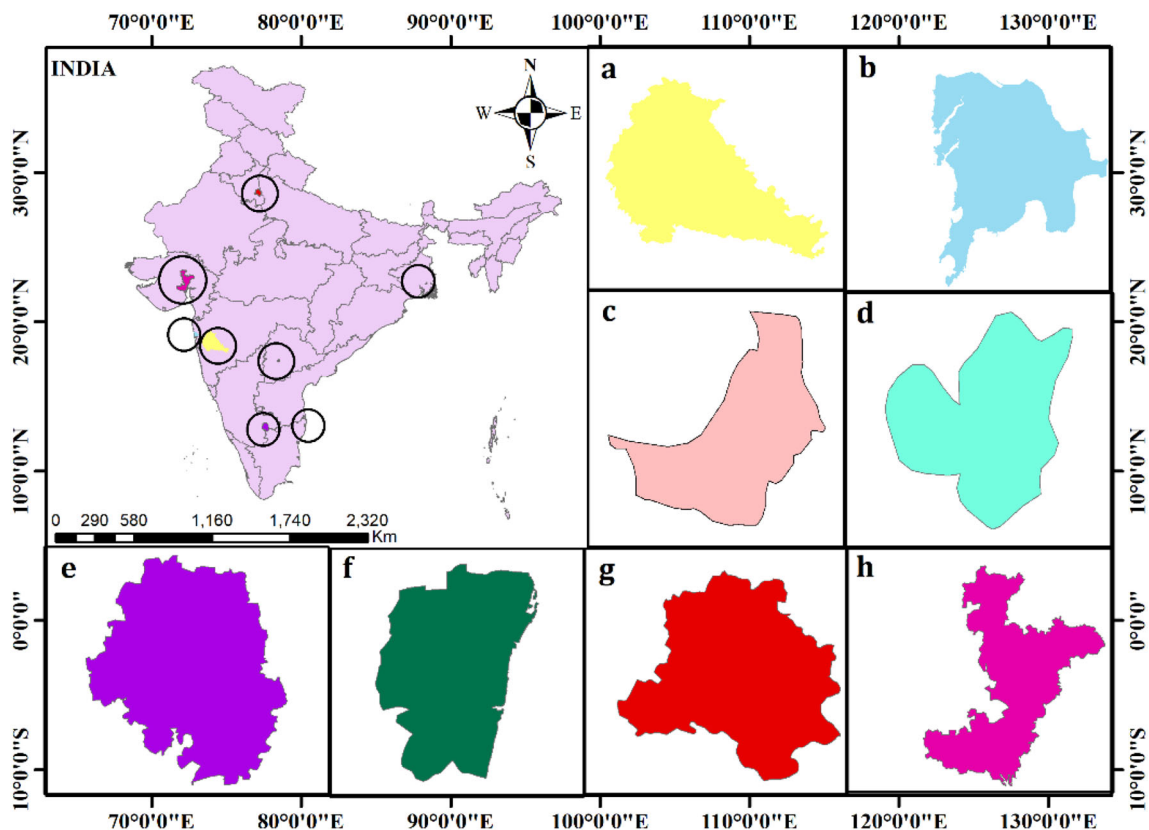


Fig. 1 Study area showing 8 tier-I districts of India **a** Pune, **b** Mumbai, **c** Kolkata, **d** Hyderabad, **e** Delhi, **f** Chennai, **g** Bengaluru, **h** Ahmedabad

Table 1 Phase wise percentage change of NO₂ in 2019–2020 from satellite data

Tier-1 cities	Satellite based (2019–2020 change %)					
	February	Prelock	Phase1	Phase2	Phase3	Overall
Delhi	– 48.81	25.52	– 259.86	– 94.13	– 37.46	– 49.01
Mumbai	– 2.07	– 20.34	– 130.9	– 96.28	– 43.62	– 36.03
Kolkata	– 12.9	– 62.42	– 49.82	– 60.78	– 35.88	– 40.14
Chennai	– 23.62	– 13.31	– 131.42	– 49.19	– 156.96	– 62.53
Bengaluru	– 8.62	– 38.61	– 121.76	– 96.57	– 44.95	– 53.85
Hyderabad	– 15.45	– 10.44	– 114.27	– 92.65	– 60.59	– 49.46
Pune	– 12.87	– 31.01	– 45.86	– 38.22	– 1.94	– 24.93
Ahmedabad	– 1.21	– 4.16	– 30.73	– 36.1	– 13.61	– 14.97

Table 2 Phase wise percentage change of NO₂ in 2019–2020 from CPCB data

Tier-1 cities	Ground based (2019–2020 change %)					
	February	Prelock	Phase1	Phase2	Phase3	Overall
Delhi	11.51	– 17.92	– 169.49	– 153.67	– 127.61	– 58.28
Mumbai	55.19	70.14	– 73.37	– 535.17	– 113.01	27.26
Kolkata	– 27.09	– 37.77	– 112.84	– 98.38	– 26.17	– 45.35
Chennai	4.78	– 45.46	– 63.55	– 70.12	– 26.17	– 58.59
Bengaluru	– 6.28	– 64.95	– 294.31	– 285.42	– 26.17	– 114.92
Hyderabad	– 0.72	– 13.8	– 62.51	– 60.67	– 26.17	– 39.44
Pune	32.4	12.42	– 5.4	– 13.15	– 26.17	24.6
Ahmedabad	– 15.54	– 109.85	– 154.66	– 276.66	– 26.17	– 119.36

ground-based monitoring instrument. Further, the availability of a smaller number of ground-based monitoring station data may be another reason. For example, in Pune, Mumbai, Ahmedabad, only one monitoring station data was available; in Chennai and Kolkata, two stations data was available whereas some districts and union territories like Hyderabad, Bengaluru, and Delhi had more than four ground station data which helped in improving the results when compared with satellite data.

Figures 2, 3, 4, 5, 6, 7, 8 and 9 represents the NO₂ concentration observed in eight districts of India from the period of February 01, 2019, to May 17, 2019. From Fig. 2, it has been observed that a significant change from phase I period of 2019 to the same phase I of 2020 was noticed for all the eight districts of India. This was the phase when the strict and complete lockdown was implemented in the country. Figures 10 and 11 demonstrate the graphical comparisons of NO₂ concentration derived from satellite-based (mol/m²) and ground-based (µg/m³) data in eight districts of India. From the above satellite-based monitoring graph, which represents total tropospheric NO₂ column density concentrations, it is observed that every study region showed substantial declines in different phases (from phase-I to Phase-III) of lockdown (Fig. 10). From the ground-based monitoring graph, this was noticed that overall NO₂ concentration has decreased except for

Mumbai and Pune (Fig. 11). Mumbai showed an overall increase in NO₂ concentration, mainly because of an increase in concentration from 1st February 2020 to 23 March 2020 as compared with the same period in the year 2019. But during the COVID 19 lockdown period, i.e. 25 March 2020 to 17 May 2020, the concentration has significantly decreased as compared with the previous year's concentration. Whereas in the case of Pune, it is the phase-III, which showed an increase in concentration.

4 Conclusions

The pandemic due to SARS-CoV-2, a novel coronavirus has a far-reaching effect on every person around the world. It showed a drastic effect on every sector of the economy. Lockdown caused due to COVID 19 impacted the economic circulation around the world, which resulted in shut down of production units, business at national and international level. In this study, the possible significant impacts of phase-wise lockdown due to COVID-19 on NO₂ concentration in eight districts of India using Sentinel 5 P satellite images of the European Space Agency and CPCB ground-based monitoring stations data were analyzed and compared with the same periods in 2019. The results demonstrated a drastic reduction in the levels of NO₂

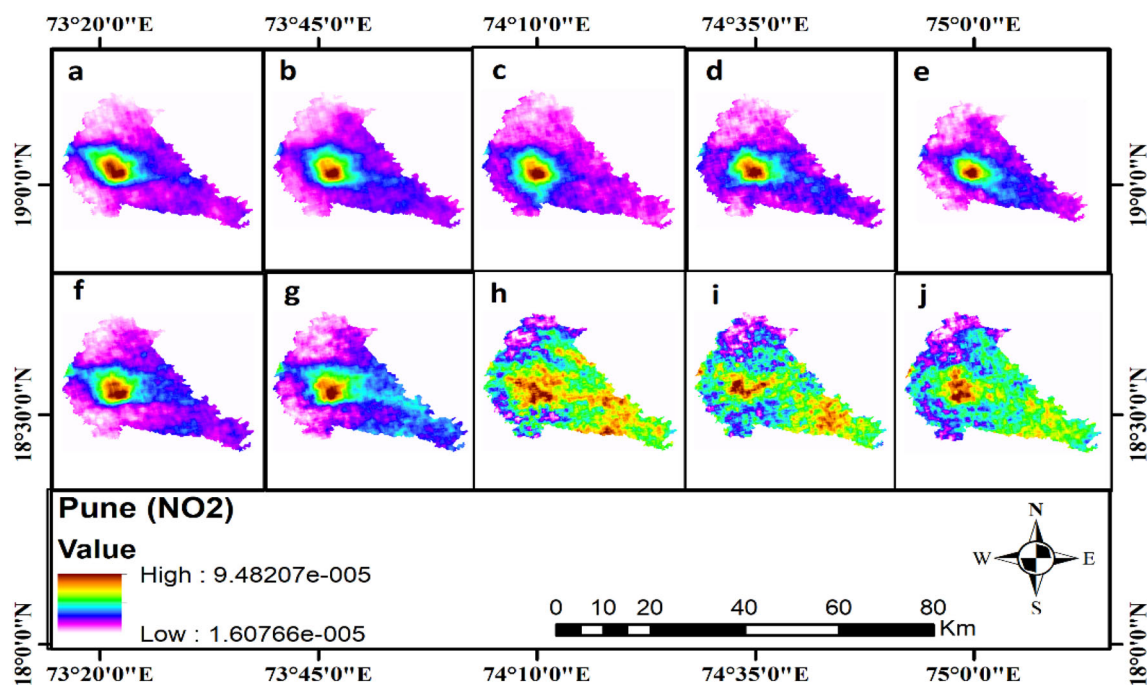


Fig. 2 Spatial distribution of NO₂ for Pune during the study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

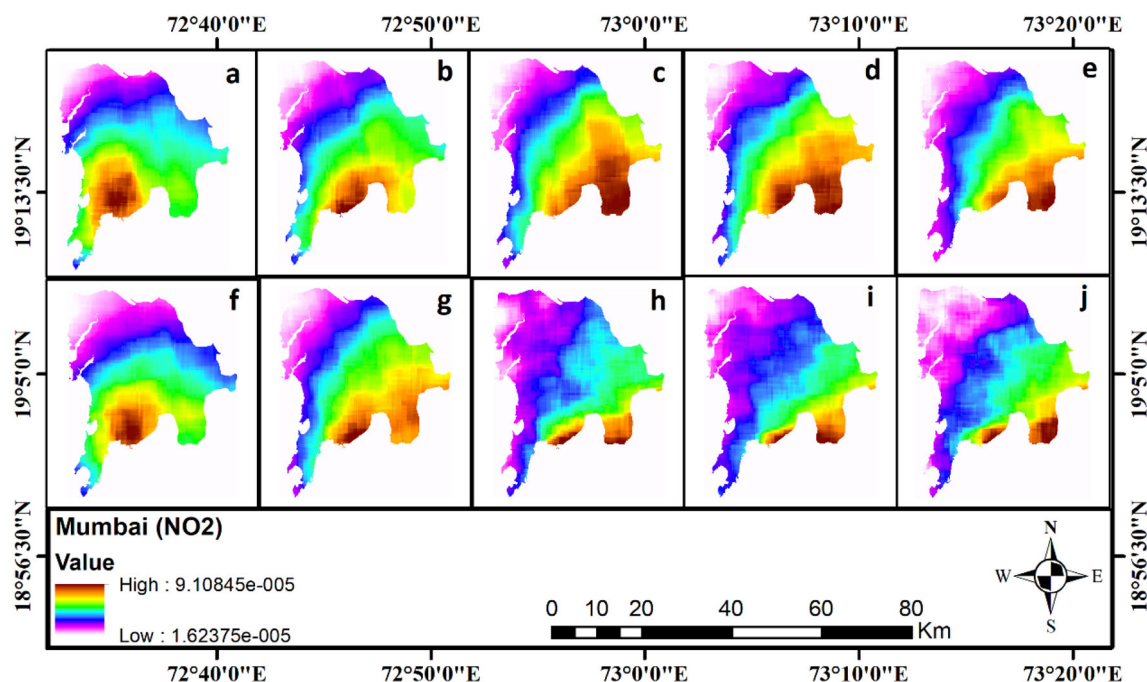


Fig. 3 Spatial distribution of NO₂ for Mumbai during the study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

concentration in these regions. It was observed that the data obtained from the satellite-based monitoring system differed from ground station data for few study regions. If sector-specific (power plants, industries, transportation, construction) emission and production data become

available during the lockdown period, then many cost specific air pollution policies could be formulated. Future research on these issues is warranted to understand the full implications and draw valuable policy lessons from this unprecedented event.

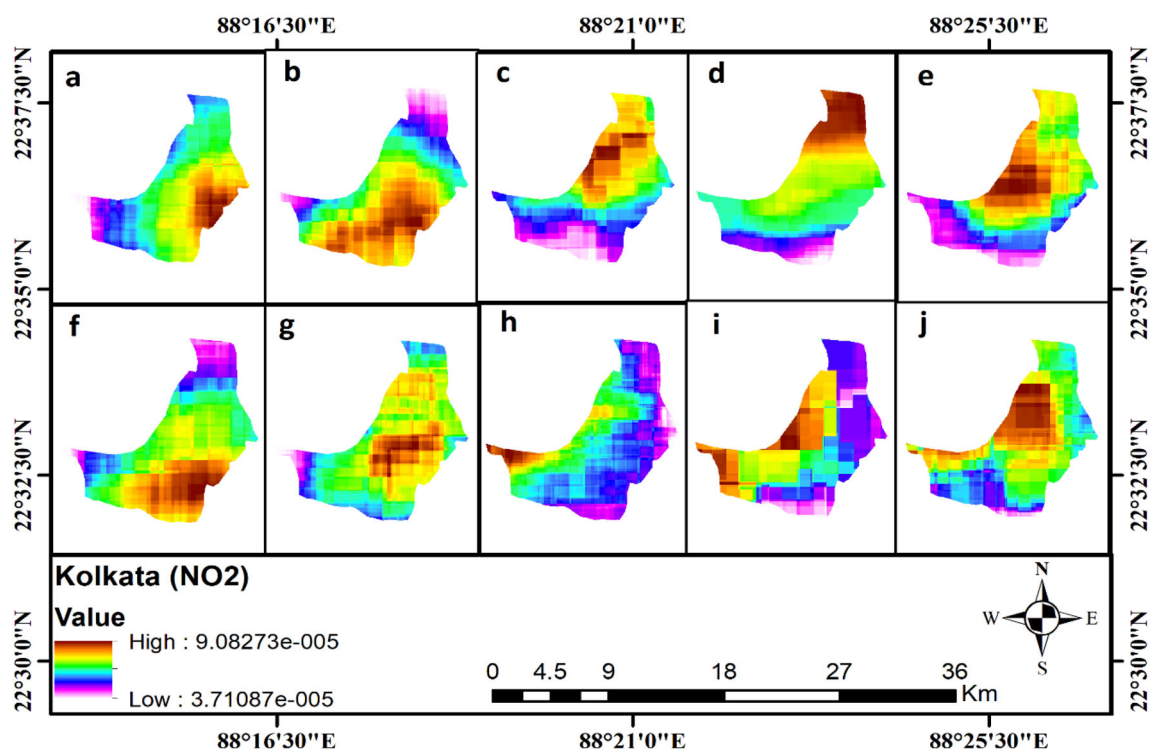


Fig. 4 Spatial distribution of NO_2 for Kolkata during study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

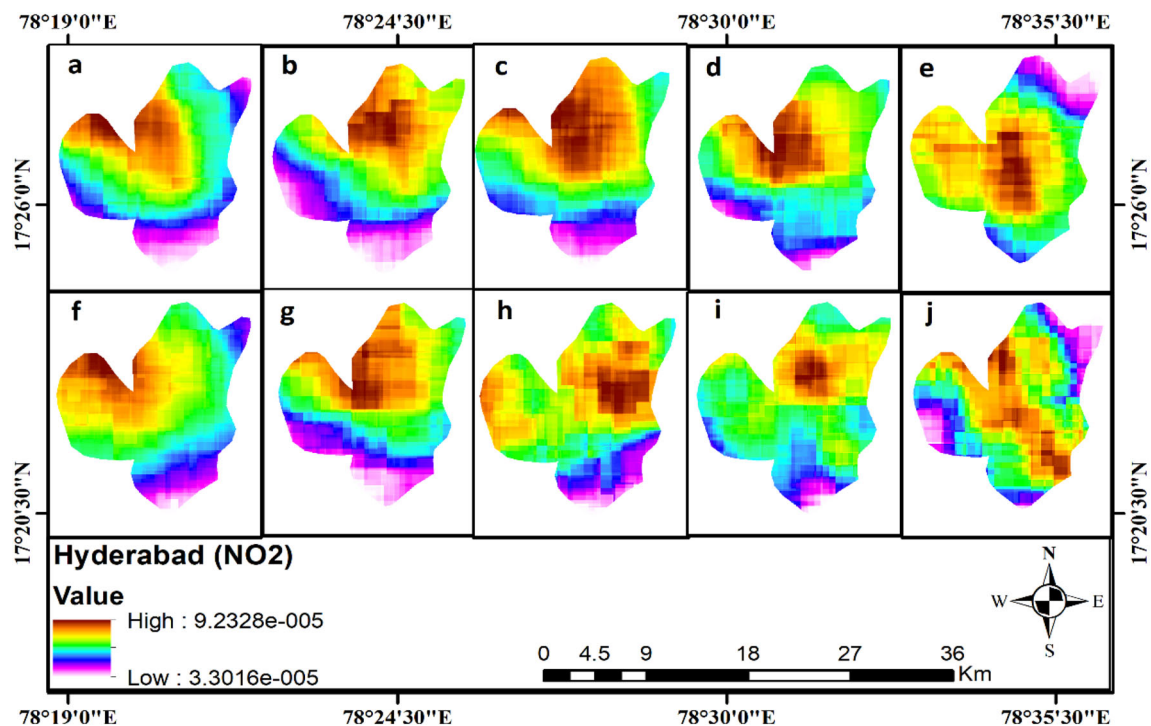


Fig. 5 Spatial distribution of NO_2 for Hyderabad during study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

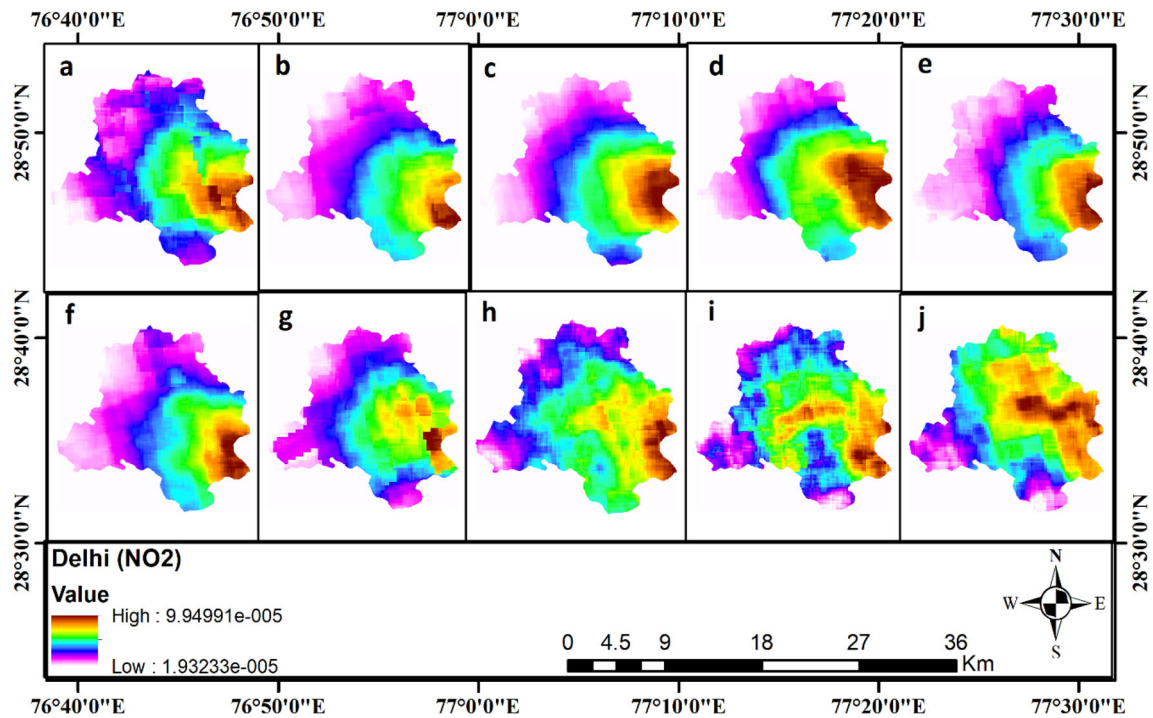


Fig. 6 Spatial distribution of NO_2 for Delhi during study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

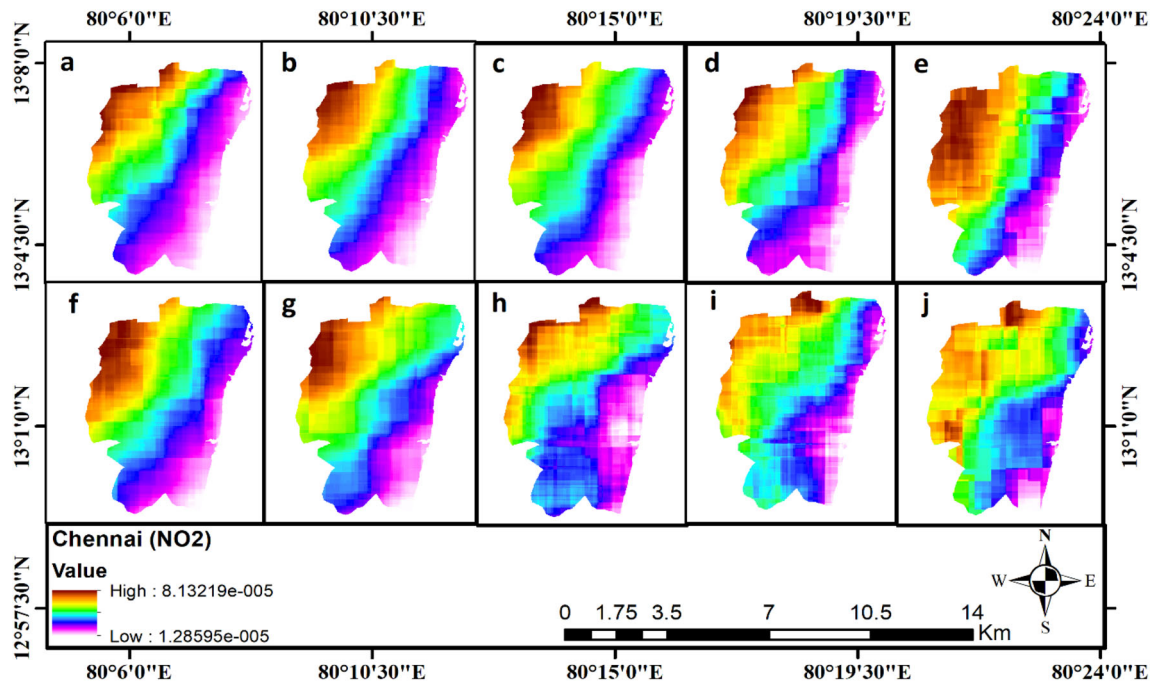


Fig. 7 Spatial distribution of NO_2 for Chennai during study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

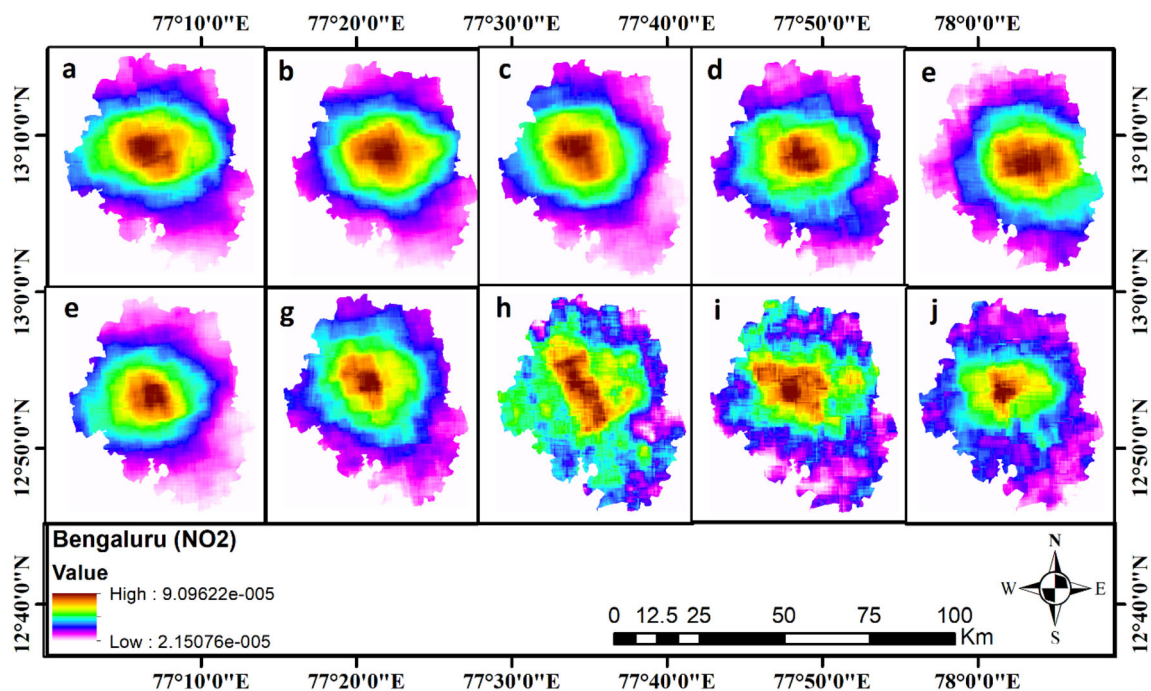


Fig. 8 Spatial distribution of NO₂ for Bengaluru during study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

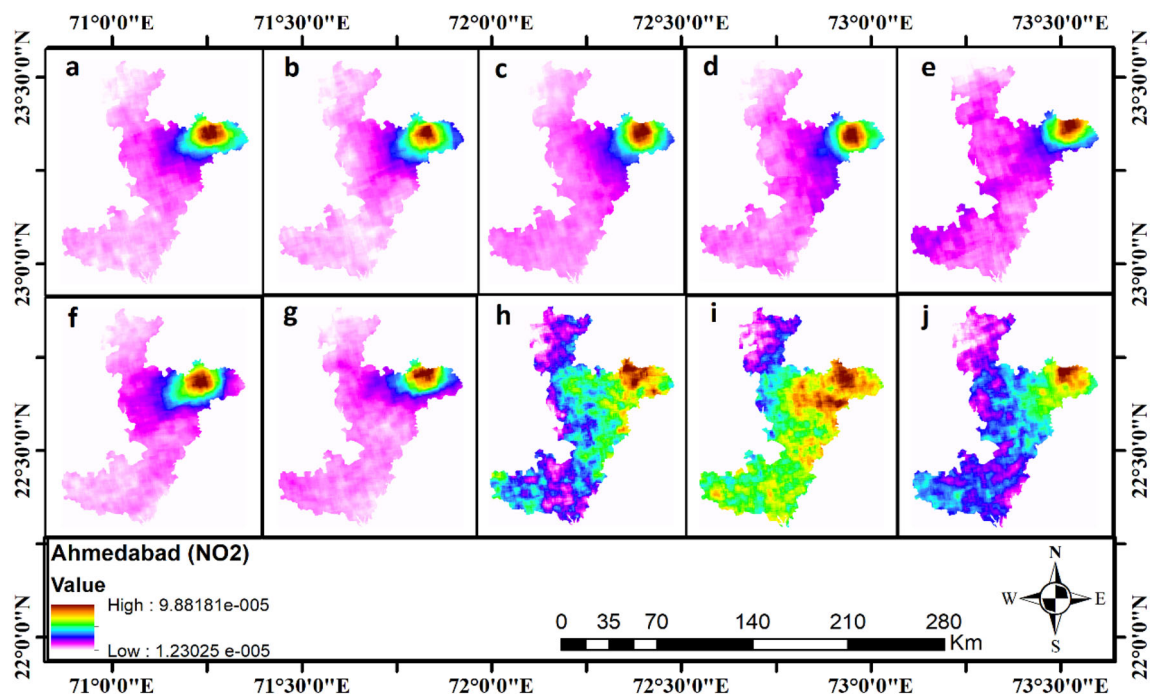


Fig. 9 Spatial distribution of NO₂ for Ahmedabad during study period **a** February 2019, **b** Prelock 2019, **c** Phase I (2019), **d** Phase II (2019), **e** Phase III (2019), **f** February 2020, **g** Prelock 2020, **h** Phase I (2020), **i** Phase II (2020), **j** Phase III (2020)

Fig. 10 Phase wise NO₂ concentration change monitoring based on satellite data

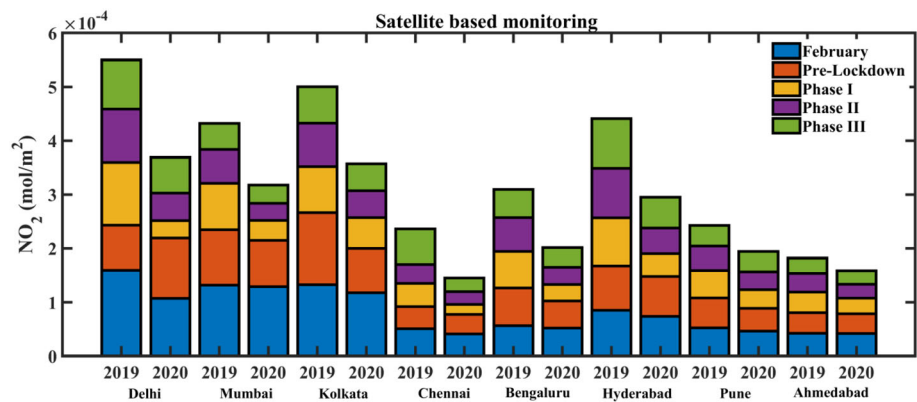
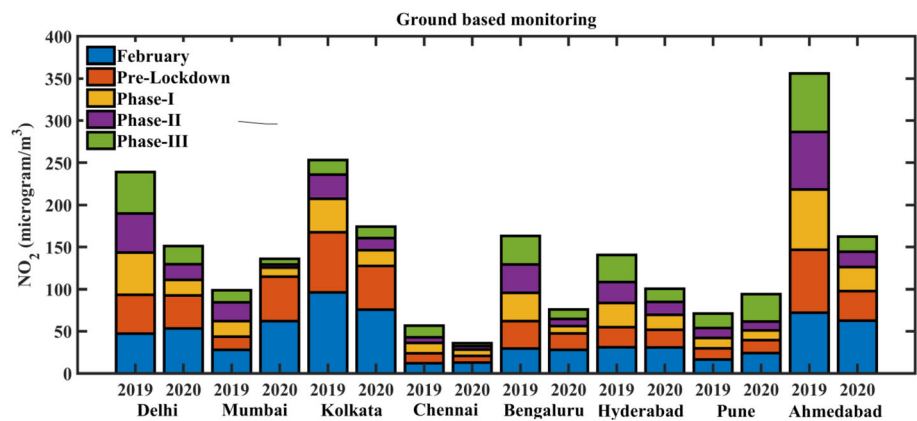


Fig. 11 Phase wise NO₂ concentration change monitoring based on ground station data



Declarations

Conflict of interest The authors reported no potential conflict of interest.

References

- Gautam, S., & Hens, L. (2020). SARS-CoV-2 Pandemic in India: what might we expect?
- Baud, D., Qi, X., Nielsen-Saines, K., Musso, D., Pomar, L., & Favre, G. (2020). Real estimates of mortality following COVID-19 infection. *The Lancet Infectious Diseases*, 20(7), 773. [https://doi.org/10.1016/S1473-3099\(20\)30195-X](https://doi.org/10.1016/S1473-3099(20)30195-X)
- Shehzad, K., Sarfraz, M., & Shah, S. G. M. (2020). The impact of COVID-19 as a necessary evil on air pollution in India during the lockdown. *Environmental Pollution*, 266, 115080
- Vadrevu, K. P., Eaturu, A., Biswas, S., Lasko, K., Sahu, S., Garg, J., & Justice, C. (2020). Spatial and temporal variations of air pollution over 41 cities of India during the COVID-19 lockdown period. *Science and Reports*, 10, 1–15
- Mandal, I., & Pal, S. (2020). COVID-19 pandemic persuaded lockdown effects on the environment over stone quarrying and crushing areas. *Science of the Total Environment*, 732, 139281
- Zhang, C., Liu, C., Chan, K. L., Hu, Q., Liu, H., Li, B., Xing, C., Tan, W., Zhou, H., & Si, F. (2020). First observation of tropospheric nitrogen dioxide from the Environmental Trace Gases Monitoring Instrument onboard the GaoFen-5 satellite. *Light: Science and Applications*, 9, 1–9
- Castellanos, P., & Boersma, K. F. (2012). Reductions in nitrogen oxides over Europe driven by environmental policy and economic recession. *Science and Reports*, 2, 265
- Judd, L. M., Al-Saadi, J. A., Szykman, J. J., Valin, L. C., Janz, S. J., Kowalewski, M. G., Eskes, H. J., Veeffkind, J. P., Cede, A., & Mueller, M. (2020). Evaluating Sentinel-5P TROPOMI tropospheric NO₂ column densities with airborne and Pandora spectrometers near New York City and Long Island Sound. *Atmospheric Measurement Techniques*, 13, 6113–6140
- Valin, L. C., Russell, A. R., Hudman, R. C., & Cohen, R. C. (2011). Effects of model resolution on the interpretation of satellite NO₂ observations. *Atmospheric Chemistry and Physics*, 11, 11647–11655
- Siddiqui, A., Halder, S., Chauhan, P., & Kumar, P. (2020). COVID-19 pandemic and city-level nitrogen dioxide (NO₂) reduction for urban centres of India. *Journal of the Indian Society of Remote Sensing*, 48, 999–1006
- Muhammad, S., Long, X., & Salman, M. (2020). COVID-19 pandemic and environmental pollution: A blessing in disguise? *Science of the Total Environment*, 728, 138820

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.