

CHANGE IN NITROGEN DIOXIDE (NO₂) CONCENTRATION DUE TO THE LOCKDOWN AMID THE COVID-19 PANDEMIC IN INDIA

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ABSTRACT. The study aimed to examine the change in the concentration of nitrogen dioxide due to the lockdown amid the COVID-19 pandemic in India at the district level using Sentinel-5P TROPOMI. The spatio-temporal characteristics of the tropospheric column NO₂ concentration during 45 days of the lockdown were compared with the same days of 2019. Further, to model spatially varying relationships of NO₂ during the lockdown period, it was given as a dependent variable whereas NO₂ during the pre-lockdown period was considered as an independent variable. Results show that the mean NO₂ concentration was reduced from 0.00406 mol/m² before the lockdown (2019-03-25 to 2019-05-10) to 0.0036 mol/m² during the lockdown period (2020-03-25 to 2020-05-10). The maximum decline of NO₂ concentration was observed in Gautam Buddha Nagar and Delhi. This indicates the high level of atmospheric pollution due to the excess use of fuel in human activities. The results of the Ordinary Least Squares (OLS) method show a strong positive relationship between both variables. Positive standard residuals indicate that the concentration of NO₂ has reduced more than expected as per the OLS model. The z-score (24.11) was obtained from spatial autocorrelation. It indicates that residuals are highly clustered and there is less than a 1% likelihood that this clustered pattern could be a result of a random chance. The highest decrease was observed in districts/urban agglomerations of Gautam Buddha Nagar (-40%), Delhi (-37%), Greater Bombay (-31%), Hyderabad (-29%), Faridabad (-29%), Bangalore Urban (-28%), Gandhinagar (-27%), Chennai (-27%) and Gurgaon (-26%) respectively.

KEYWORDS: COVID-19, Coronavirus, Nitrogen dioxide (NO₂), Sentinel-5P

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INTRODUCTION

Nitrogen dioxide (NO₂) is an ambient trace gas which originates from both natural and anthropogenic processes. Long-term exposure to NO₂ may cause a wide spectrum of severe health problems such as hypertension, diabetes, heart and cardiovascular diseases and even death (Ogen 2020). Breathing air with a high concentration of NO₂ can damage human respiratory system. Such exposure over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms such as coughing, wheezing or difficult breathing. Longer exposure to an elevated concentration of NO₂ may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with

asthma, children and the elderly are generally at greater risk to the elevated NO₂ concentration (US EPA OAR 2016). COVID-19 originated from Wuhan city of Hubei Province in China in December 2019. Since then, it has spread in more than 210 countries. It is a viral disease due to the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). The patients show flu-like symptoms with a dry cough, sore throat, high fever, and breathing problems (Ali & Alharbi 2020). WHO continues to provide updated information (World Health Organization: WHO 2020). More than 4.3 million cases of Covid-19 have been recorded worldwide, including at least 297,000 deaths as of 7th April 2020. According to the tally of deaths by Johns Hopkins University at least 300,074 people have died from COVID-19 across the world (Renton 2020).

The first confirmed case in India was reported on January 30 2020. A university student studying in Wuhan, China, had travelled back home to Kerala, a state on India's southern tip, during vacation. Over the next four days, two more people in Kerala tested positive for the disease (Ward 2020). The latest figures from the Health Ministry of India showed that the total number of coronavirus cases in India jumped by 3,722 over the past 24 hours, increasing the total number of confirmed COVID-19 cases as of 13th May 2020 to 78,003. The Health Ministry says that 70% of deaths occur due to co-morbidities.

A three-week lockdown in India started from 24th March 2020, which was an important initiative to control the spread of the coronavirus (Gettleman and Schultz 2020). India, which has the 2nd highest population, where the healthcare system is underdeveloped and the major portion of the population follow an unhygienic lifestyle, was able to restrict the rate of both infection and death of its citizens from COVID-19 (Paital et al. 2020).

According to a December 2019 report by the Global Alliance of Health and Pollution, India accounts for the highest number of pollution-related deaths in the world with more than 2 million people every year (Guardian 2019). Data from the Central Pollution Control Board (CPCB) showed, that the water quality of rivers in India has improved considerably during the lockdown, especially in industrial towns through which they pass. CPCB has three real-time monitoring stations in Kanpur, India. One is located upstream of the Ganga Barrage, the second is downstream of the barrage, and the third is at Shuklagunj. The monitoring station located upstream reported that the level of dissolved oxygen on March 28 was 8 mg/litre, BOD was 2.1 mg/litre, pH was 7.90 and ammonia was 0.49 mg/litre (Naqvi and Kumar 2020). Ray et al. (2021) studied carbon emissions of selected 184 countries and found that it is reduced by 438 Mt in 2020 than in 2019.

Venter et al. (2020) tested the hypothesis that lockdown has reduced tropospheric and ground-level air pollutant concentrations using satellite data and a network of >10,000 air quality stations. After accounting for the effects of meteorological variability, they found a decline in the population-weighted concentration of ground-level nitrogen dioxide. Research based on satellite data across India has shown a 15% reduction in NO₂ concentration level around the time of the shutdown (March 15 to April 30) compared to the same period in 2019. This was largely due to a temporary halt of vehicular traffic, which is one of the main sources of NO₂ emissions, due to the lockdown (World Bank 2020).

The main objective of this work was to measure the effect of lockdown amid the COVID-19 pandemic on the concentration of NO₂ in India. To meet the general objective, three specific objectives were set as (i) to study the tropospheric concentration of NO₂ during the pre-lockdown period from 2019-03-25 to 2019-05-10, (ii) to study the tropospheric concentration of NO₂ during the post-lockdown period from 2020-03-25 to 2020-05-10, and (iii) to study the change in the tropospheric concentration of NO₂ from pre-lockdown period (2019) to post-lockdown period (2020).

MATERIALS AND METHODS

DISTRICTS DATABASE

For districts vector data the Global Administrative Unit Layers (GAUL) were used. This data is prepared and provided by the Food and Agriculture Organization of

the United Nations. It compiles and disseminates the best available information on administrative units for all the countries in the world, contributing to the standardization of the spatial dataset representing administrative units (FAO 2015).

NO₂ DATA

For the NO₂ concentration in the troposphere (from the surface up to ~10 km), the Sentinel-5 Precursor space-borne satellite (spatial resolution of 5.5 km), which is operated and managed by the European Commission under the «Copernicus» program, was used (Ogen 2020). Sentinel-5 Precursor is a satellite launched on 13 October 2017 by the European Space Agency to monitor air pollution. The onboard sensor is frequently referred to as Tropomi (Tropospheric Monitoring Instrument). The TROPOMI NO₂ processing system is based on the algorithm developments for the DOMINO-2 product (TROPOMI 2021) and the EU QA4ECV NO₂ reprocessed dataset for OMI, and has been adapted for TROPOMI. This retrieval-assimilation-modelling system uses the 3-dimensional global TM5-MP chemistry transport model at a resolution of 1x1 degree as an essential element (Sentinel-5P NRTI NO₂; Near Real-Time Nitrogen Dioxide 2018).

STATISTICAL ANALYSIS

The Ordinary Least Squares (OLS) method was applied to model the tropospheric concentration of NO₂ during the 2020 lockdown period (dependent variable) in terms of its relationship to tropospheric concentration of NO₂ during the 2019 pre-lockdown period (independent variable). The mean tropospheric concentration of NO₂ from 25th March to 25th April 2020 was given as a dependent variable and the mean tropospheric concentration of NO₂ from 25th March to 25th April 2019 was given as an independent variable.

$$y = \beta + \beta x + \varepsilon \quad (1)$$

Where y is the dependent variable, x is the independent/explanatory variable, β is the Regression coefficient (β) & ε is the Residual/random error.

Spatial Autocorrelation (Moran's I) Tool was used to identify the spatial pattern of the residuals (Islam et al. 2021).

The Moran's I statistic for spatial autocorrelation is given by Eq.2:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} z_i z_j}{\sum_{i=1}^n z_i^2} \quad (2)$$

Where z_i is the deviation of an attribute for feature from its mean ($x_i - \bar{X}$), w_{ij} is the spatial weight between feature i and j, n is the total number of features, and S_0 is the aggregate of all spatial weights:

$$S_0 = \sum_{i=1}^n \sum_{j=1}^n w_{ij} \quad (3)$$

The z_i-score for the statistic is computed as:

$$Z_I = \frac{I - E[I]}{\sqrt{V[I]}} \quad (4)$$

Where:

$$E[I] = -1 / (n-1) \quad (5)$$

$$V[I] = E[I^2] - E[I]^2 \quad (6)$$

For conceptualization of spatial relationships among features, the inverse distance was used so that nearby

neighbouring features have a larger influence on the computations for a target feature than features that are far away.

Euclidean distance method was used to calculate the distance from each feature to its neighbouring features. The distance threshold was set as 535109 m to cut off distance for the inverse distance options. Features outside the specified cutoff for a target feature were ignored in analyses for that feature.

For the Global Moran's I statistic, the null hypothesis (H0) stated that the residuals being analysed are randomly distributed among the features in the study area.

RESULTS

TROPOSPHERIC NO₂ CONCENTRATION

The mean tropospheric concentration of NO₂ was 0.00406 mol/m² during the pre-lockdown period in India. The major hot spots were observed in the National Capital Region (NCR), parts of certain states such as Chhattisgarh, Orissa, West Bengal, and metropolitan cities namely Ahmadabad, Greater Mumbai and Bangalore (Figure 1). The mean tropospheric concentration of NO₂ during the lockdown period were reduced to 0.0036 mol/m². Major

changes were observed in urban agglomerations of Ahmadabad, Greater Mumbai and Bangalore (Figure 1). Table 1 shows the number of districts with different mean NO₂ concentration (mol/m²) during the pre-lockdown and lockdown period.

CHANGE IN THE TROPOSPHERIC NO₂ CONCENTRATION

Figure 2 shows the change in tropospheric concentration of NO₂ in India during the lockdown period in 2020 compared to the same period of 2019. Tropospheric concentrations of NO₂ during the lockdown period was decreased in 540 districts (Table 2). The highest decrease was observed in districts namely Gautam Buddha Nagar (-40.47%), Delhi (-37.54%), Greater Bombay (-31.47%), Hyderabad (-29.53%), Faridabad (-28.60%), Bangalore Urban (-27.97%), Gandhinagar (-27.09%), Chennai (-26.52%) and Gurgaon (-26.39%) (Figure 2). The results were validated by the nitrogen dioxide concentration over India studied by the European Space Agency, which reported the new satellite maps, produced using data from the Copernicus Sentinel-5P satellite and showing average nitrogen dioxide concentrations over India from 1 January to 24 March 2020 and 25 March (the first day of the lockdown) to 20 April 2020 compared to the same period of the previous year. A significant reduction in the concentrations of NO₂ was

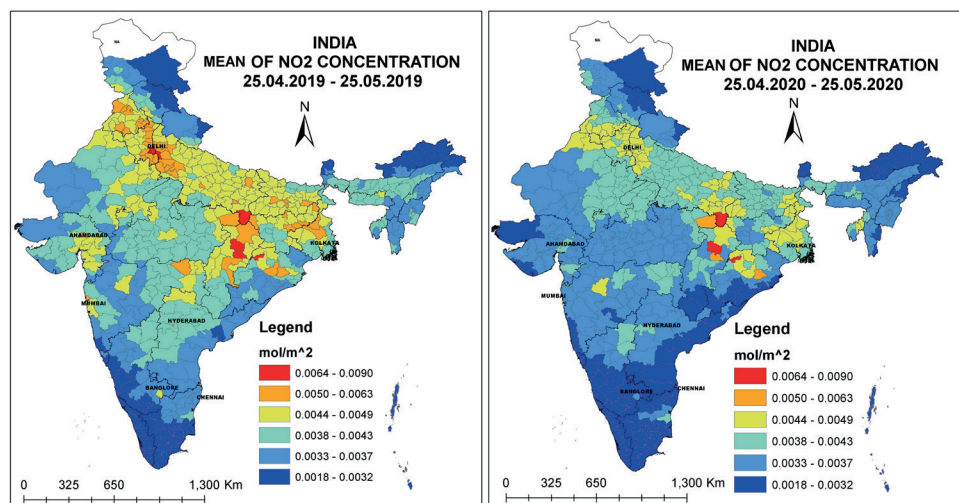


Fig. 1. Concentration of NO₂ during the pre- and post-lockdown period, large cities are shown in the map

Table 1. Number of districts with different mean NO₂ concentrations (mol/m²)

Bin	Pre-lockdown period	Lockdown period
0.003161	71	129
0.003747	125	204
0.004256	170	171
0.00494	164	78
0.006278	51	3
0.008994	6	3
More	1	0

Data source: COPERNICUS_S5P_NRTI_L3_NO2

Table 2. Number of districts with different changes in tropospheric concentrations of NO₂ during the 2020 lockdown period compared to 2019

Change (%)	-26.4	-18.4	-14.8	-12.2	-9.8	-7.5	-4.8	1.9	0	12.3
Districts	9	35	76	80	93	101	90	56	14	34

Data source: COPERNICUS_S5P_NRTI_L3_NO2

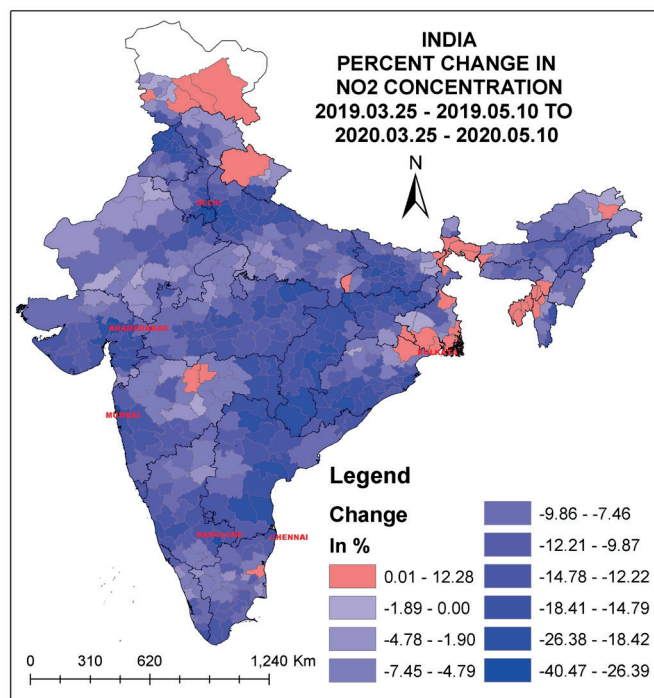


Fig. 2. Change in the concentrations of NO₂ during the pre- and post-lockdown period

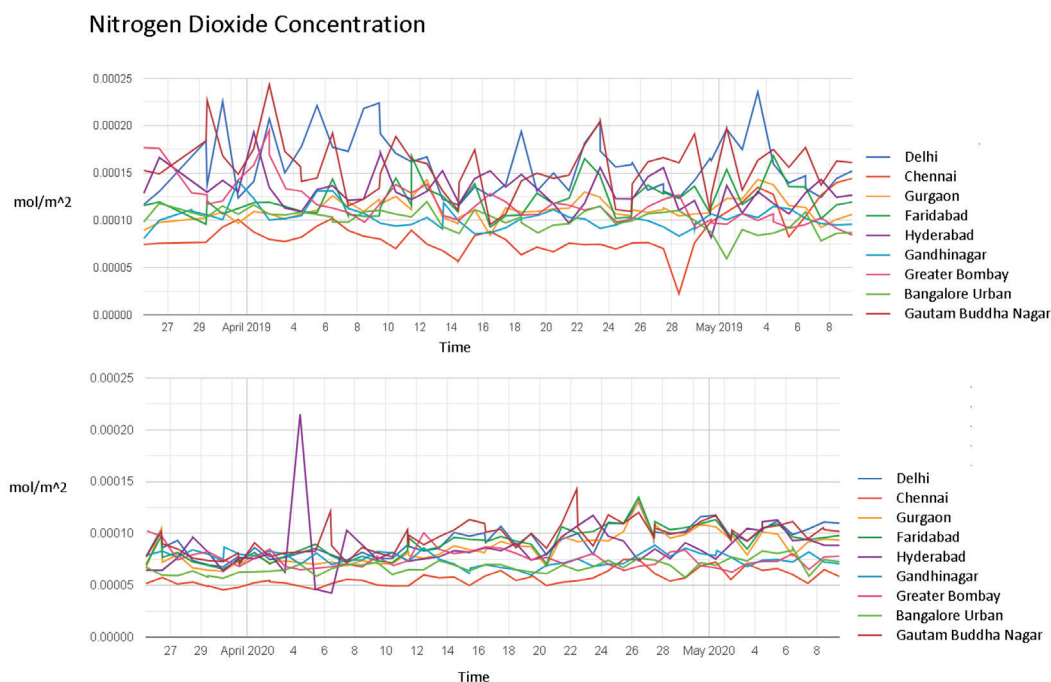


Fig. 3. Change in the mean nitrogen dioxide concentration in Indian mega cities

seen over major cities across India. Mumbai and Delhi saw drops of around 40-50% compared to last year (ESA 2020). Table 2. Number of districts with different changes in tropospheric concentration of NO₂ during the 2020 lockdown period compared to 2019

NO₂ CONCENTRATION DURING PRE-LOCKDOWN AND LOCKDOWN PERIOD

The results of the Ordinary Least Squares (OLS) linear regression show a positive and strong relationship between both variables. The coefficient of the dependent (intercept) variable of -0.000094 and the coefficient of the independent variable of 1.142266 represent a positive and strong relationship between the explanatory and dependent variables. The results of probability ($p < 0.0000$) and Robust Probability ($p < 0.000000$) analysis indicate that these coefficients are statistically significant. The Koenker (BP)

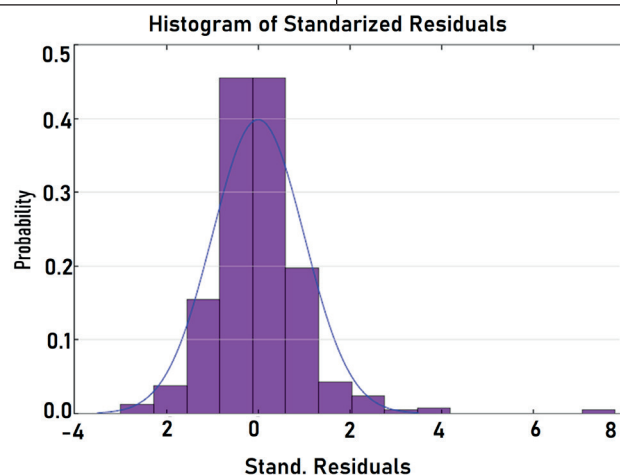
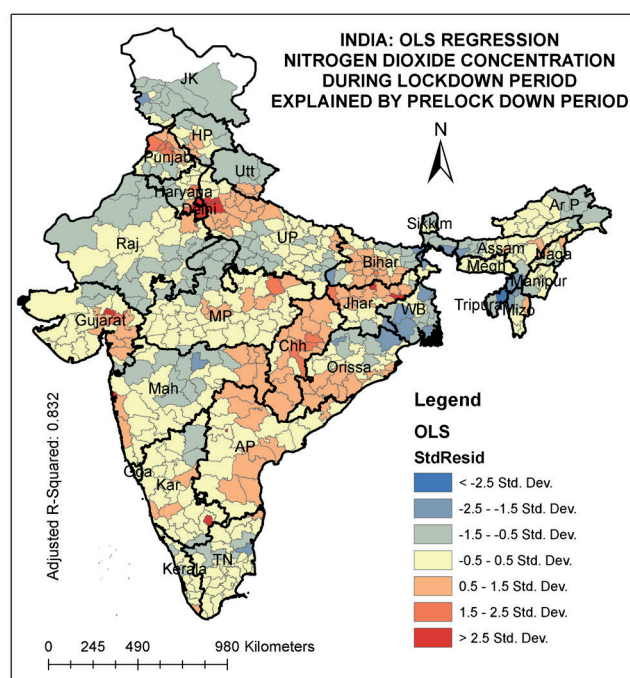
statistic test is not statistically significant ($p = 24.68$), which means that the modelled relationship is consistent. Jarque-Bera statistic test is also not statistically significant ($p = 3280.74$) meaning that the model predictions are not biased (the residuals are close to the normal distribution) (Figure 4). Table 3 shows the number of districts belonging to different standard residual classes. Figure 5 helps to understand the spatial variation in the NO₂ concentration change during the lockdown (2020-03-25 to 2020-05-10) in relation to the pre-lockdown period (2019-03-25 to 2019-05-10).

SPATIAL PATTERN OF THE RESIDUALS

The computed z-score of 24.1 indicates that there is less than a 1% likelihood that this clustered pattern could be a result of a random chance (Table 4). Figure 6 shows the pattern of the NO₂ change in India at the district level.

Table 3. Number of districts belonging to different standard residual classes

Standard residual class	Districts
< -2.5 Std. Dev.	03
-2.5 - -1.5 Std. Dev.	21
-1.5 - -0.5 Std. Dev.	135
-0.5 - 0.5 Std. Dev.	291
0.5 - 1.5 Std. Dev.	114
1.5 - 2.5 Std. Dev.	13
> 2.5 Std. Dev.	12

**Fig. 4. Histogram of residuals****Fig. 5. NO₂ concentration during the lockdown in relation the pre-lockdown period****Table 4. Global Moran's I statistics**

Moran's Index	0.158480
Expected Index	-0.001704
Variance	0.000044
z-score	24.115897
p-value	0.000000

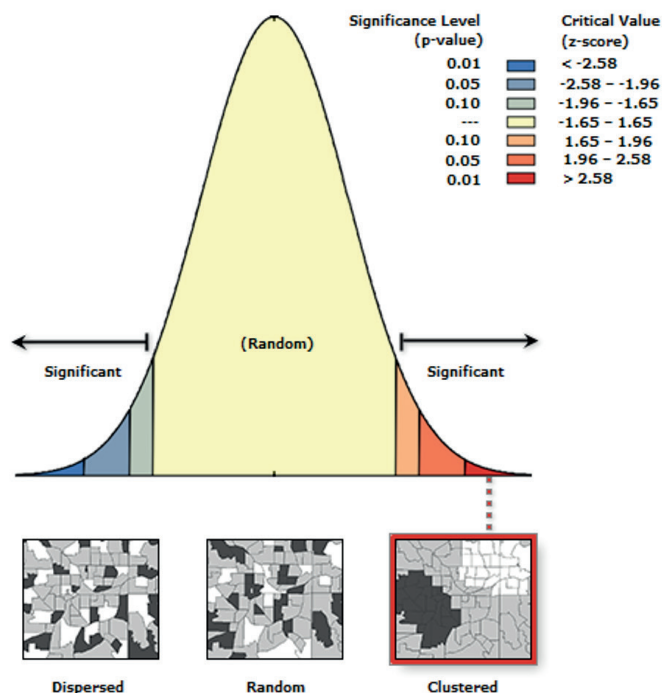


Fig. 6. Pattern of the NO₂ change in India at the district level

DISCUSSION

Describing air pollution due to COVID-19 has perhaps offered up hope of a practical way to reduce the effects of the virus, even if the change in outcomes is highly uncertain (Lewis 2020). The indirect impact of the virus on the environment has been little analysed. The first studies estimated a positive indirect impact on the environment (Zambrano-Monserrate et al. 2020). Satellite images have already revealed a dramatic reduction in concentrations of pollutant nitrogen dioxide in China and northern Italy, which coincided with lockdowns imposed to tackle the coronavirus pandemic (Gatenby 2020).

In highly populated areas the change in NO₂ was higher than predicted while in some areas this change was lower than predicted. Underpredicted areas, such as West Bengal, Northern Orissa, Maharashtra and Tamil Nadu, India, are known for the presence of heavy industries and thermal power stations. Heavy industries and thermal power stations were functioning during the lockdown period so the change there was lower than predicted. Misra et al. (2021) also presented similar results. They found a sharp decline in NO₂ in urban areas at Phase 1 and a slow recovery in subsequent phases. During Phase 1 of the lockdown, overall densities decreased substantially with a large negative mean anomaly ($-33.7\% \pm 12.1\%$), going as low as -76.8% over central urban Delhi. Apart from urban areas, negative anomalies were also found above power plants and industries suggesting reduced emissions compared to 2019, which, however, were not as high as in densely populated areas (Misra et al. 2021).

CONCLUSION

Nitrogen oxides (NO₂ and NO) are important trace gases in the Earth's atmosphere, present in both the troposphere and the stratosphere. They enter the atmosphere as a result of anthropogenic activities (notably fossil fuel combustion and biomass burning) and natural processes (wildfires, lightning, and microbiological processes in soils). In this paper GIS and remote sensing techniques were used to find the change in the concentration of NO₂ during the pre-lockdown and lockdown period in India at the district level. To estimate the spatial variation in the NO₂ decline during the lockdown (2020), the same period was used from the previous year (2019). It was found that NO₂ concentration has decreased significantly due to the lockdown amid the COVID-19 pandemic in India. There is a spatial variation in this change; NO₂ concentration has decreased more (around 30 to 40%) in larger urban agglomerations. The results indicate that NO₂ concentration in highly populated areas was reduced more than in mineral-based industrial regions, as well as in remote, forested, mountainous and plateau regions of India. This change may be temporary but governments must plan to sustain this lower level of NO₂ concentration. The initiatives and planning to restart human activities in the post-lockdown period especially in megacities may be a benefit for public health and environmental sustainability. ■

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