



Impact of COVID-19 outbreak on tropospheric NO₂ pollution assessed using Satellite-ground perspectives observations in India

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Abstract

The global outbreak of Novel Corona Virus 2019 (SARS-CoV-2) has made worldwide lockdown including India since March 24, 2020. The current research aims at the improvements of nitrogen dioxide (NO₂) during the COVID-19 lockdown in India. This research has been done using both the open source data sets taken from satellite and ground based for better analysis. For the satellite-based analysis, the Sentinel 5 Precursor's Tropospheric NO₂ from the European Space Agency and for the ground-based numeric data sets from Central Pollution Control Board (CPCB) has been used. During the COVID-19 disease, outbreak the world has set in quarantine and as an overcome air quality improved in Asian countries after national lockdown, the average NO₂ rates plummeted calculated by 40–50%. Similarly, it dramatically decreased in Asia during the COVID-19 pandemic quarantine period. The basic statistical patterns of the NO₂ concentration spectrum of historical data sets (2018–2020) bi-weekly showed during October to March were seen higher in each year. Related with National Ambient Air Quality Standards of mean of NO₂ in India our result shown in the NO₂ levels fall in 21 µg/m³ during the national lockdown, from the Central Pollution Control Board's air quality standards it almost decreased 50% of the hourly mean in India. This caused by the sudden restriction to the development of manufacturing and the transportations which ultimately minimized the fossil fuel burning which cause the most of the NO₂ releases to the atmosphere. Nowadays, people are aware about comparatively prosperous future with clear blue skies and uses of renewable energy sources from the nature.

Keywords Tropospheric NO₂ · Air quality improvements · Sentinel-5P satellite · Ambient air quality · SARS-CoV-2 epidemic

Introduction

Nitrogen dioxide emission have the closest connection with the anthropogenic fossil burning. Air pollution can be referred to as the release of pollutants into the air that may be injurious to the people's health as well as the environment. Some ground-based studies found that national lockdown by the COVID-19 outbreak condition has slowed down the air pollution process all over the world (Halder et al. 2021; Ganiny and Nisar 2021). The first report of

COVID-19 outbreak recorded in Wuhan, China and affirmed as anthroponoses causing difficulty breathing, aches and pains and SARS (WHO 2020). To mitigate from the situation, lockdown policies were implemented by various countries and regions by closing the international and national boundaries and stopped the public activities (WHO 2020; Mansouri Daneshvar et al (2021). As days move, the virus spread increased all over the world including India (Bharath et al. 2020; Chen et al. 2020a, b). To combat the spread of coronavirus, the lockdown measures were taken in India on March 24, restricting people from stepping out of home (The Hindu 2020). Recent study by Center for Pollution Control Board (CPCB) on effects of 'Janata Curfew' found that the decrease in the number of vehicular transportation contributed to a reduction in nitrogen oxide (NO_x) nearly 50% and Carbon Dioxide (CO₂) nearly 30% during 22–23rd march 2020 compared to the normal days (CPCB 2020). National Ambient Air Quality Standards (NAAQS) has said that the air pollution in certain cities have recorded below

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the prescribed of $60 \mu\text{g}/\text{m}^3$ which is still higher than the prescribed World Health Organization's (WHO) standards of $25 \mu\text{g}/\text{m}^3$ (Behnam and Jahanmahin (2021)). The decision to dilute standards has come as soon as India's government has already moved the deadline of the introduction of NOx standards in power plants to 2022, after their inability to reach the revised requirements in their original December 2017 deadline (Jain and Sharma 2020; Huan Zhang et al. 2019). Even after the extension, more than half of the coal-fired power stations in India were predicted to meet their pollution limit deadline. Various researches and studies conducted using satellite-based continuous monitoring of air pollution analyzed by the European Space Agency's (ESA) Sentinel 5 Precursor satellite that measures the pollution in atmosphere at various layers (Lauri Myllyvirta et al. 2020; Selvam et al. 2020). Since the COVID-19 crisis, the officials are planning about the pollution emissions, to execute the limitations for pollution for major resources rather than close down notable outcomes of the nation's economy (UNEP 2020; TWC 2020; IQAR 2020). NOx are a highly toxic and reactive gaseous substance that can induce headache, eye irritation, chronically reduced lung function and sometime death in severe condition. India places one of the top in NO₂ pollution and power plants and are one of the India's biggest polluters. 83,000 deaths were reported on 2019 in India that has direct connection with pollution-related health risks. By 2030, India is estimated its coal production to be more than twice as much as 450 GW (the existing 197 GW) and may cross 186,500–229,500 deaths annually (MOHFW 2020). The combustion process of coal to derive energy and electricity causes the releases of nitrogen gasses from the coal such as nitric oxide (NO), nitrogen dioxide (NO₂), and nitrous oxide (N₂O) (Ogen et al. 2020). These like nitrogen oxides (NOx) is a hazardous pollutant; in India, these harmful releases of pollutants altogether cause nearly 3.5 lakhs childhood ashtma and 16,000 premature deaths (Bharath et al. 2020). India's unexpected lockdown policies regulated by forming restrictions of anthropogenic activities that made notable enhancement in the environment (Asheshwor Shrestha et al. 2020; Li et al. 2020). This result amazed people in COVID-19 outbreak, since India places among top polluted cities and towns (IQAIR 2019). Many researchers investigated the spatial variability of health risk and its dynamics with the help of GIS tools and remote-sensing techniques (Bagyarai et al. 2020; SAR Khan et al. 2019; Parthasarathy et al. 2020; Wang et al. 2020).

In the course of the pre-lockdown period, the clusters of NO₂ pollution were reported from well-known cities or the regions where the thermal power plants and other industry's activities are high. Though the lockdown was present, some power plants still worked as the electricity and power demand of the country such in states are Chhattisgarh, Jharkhand, Madhya Pradesh, and Orissa (Asfa Siddiqui

et al. 2020). In India, lockdown has adversely impacted the economy that the working people were critically affected by the termination in the economic activities by the regulations. Drastic actions followed to slow down the anthropogenic activities were not effective solutions as a way to save the environment from pollutions. Likewise, the decreases in pollutant's emissions in the country and around the world were transient just because of lockdown policies were varying in degrees. In the meantime, researchers and environmental activists got a chance from the lockdown outcomes to measure the effects of anthropogenic activities on the environment and also it helped them to re-make the plans and strategies over a place about air pollution. There are time-tested approaches to reach an acceptable air quality without restrictions to mitigate emissions rate coming back to normal condition as economies are turning a corner and coronavirus crisis became familiar. The outcome of this research is to analyze the variation of NO₂ in South Asia before and during the COVID-19 epidemic lockdown. Also, to determine the NO₂ data sets of sentinel and ground-based monitoring and their effects of pollution reductions by the decreased anthropogenic activities in South Asia.

Materials and methods

Study area

India (20.5937°N , 78.9629°E) is the second-highest populated country at worldwide located in the southern part of the Asian continent. India has four major climatic zones with the mean annual temperature of $> 24^\circ \text{C}$ in tropical, $17\text{--}24^\circ \text{C}$ in the subtropical zone, 7 to 17°C in the temperate zone and $< 7^\circ \text{C}$ in the alpine zone. Representing 17.5% of the world's population and the seventh-highest land region of 32,87,263 km. The megacity is quantitatively defined as cities having the population more than 10 million; currently, Mumbai, Delhi, Kolkata, Bangalore, Chennai, and Hyderabad are the megacities in India.

Sampling methods

Central Pollution Control Board is carrying a nationwide programme of National Air Quality Monitoring Programme (NAMP) that continuously measures the air quality by the defined time of intervals. This programme includes 793 operating stations that covers 344 cities of 29 states and 6 Union Territories of the nation. For continuous measuring at all locations, the sulphur dioxide (SO₂), nitrogen dioxide (NO₂), respirable suspended particulate matter (RSPM/PM 10) and particulate matter (PM 2.5) have been recorded. Meteorological parameter such as pressure, relative humidity, temperature, wind speed, and

wind direction were also recorded along with the pollution factors. The NO₂ data taken from CPCB site as a numeric data table which has the units of µg/m³. The numeric data were recorded consequently with the 24 h interval to get the diurnal data. We selected basic gaseous pollutants such as NO₂ concentrations at 231 CAAQM station in India as it shows in Fig. 1.

The first mission to monitor the atmosphere is executed by Copernicus Sentinel-5P with the joint collaboration between European Space Agency and Netherland Space Office. In this mission, the Tropospheric Monitoring Instrument (TROPOMI) satellite is used to derive the atmospheric conditions. This Copernicus Sentinel-5 Precursor satellite aims to carry out atmospheric evaluations with high spatiotemporal resolution to get the air quality, climate monitoring and forecasting, ozone and UV radiation. From the various bands, the Tropospheric NO₂ Column Number Density band has used in offline type. This process to get the NO₂ emission of entire nation is performed in Google Earth Engine by java scripts. The short and long-term periods ground-based data sets are collected from the regular air monitoring stations of Central Pollution Control Board in India and satellite-based observation data set of Copernicus Sentinel-5P TROPOMI data at the European Space Agency’s data hub.

The short- and long-term periods ground-based data sets are collected from continuous ambient air quality monitoring stations at the Central Pollution Control Board in India and satellite-based observation data set of Copernicus Sentinel-5P TROPOMI data at the European Space Agency’s data hub. Real-time air quality data generated and gathered via Continuous Ambient Air Quality Monitoring (CAAQM) network in India have been analyzed in the Geo Da software. In the course of the lockdown durations, there were very restricted transportation services, manufacturing and financial activities apart from some indispensable services. Hence, the air quality improvements and environmental outcomes as a consequence of COVID-19 pandemic was analyzed.

Results and discussions

Assessment of satellite perspectives of airborne NO₂ variation in India

Satellite-based monitoring is widely used to generate data on air quality. This remote-sensing techniques have the advantage that they can provide country-wide coverage of all locations. The National Lockdown, which has been successfully

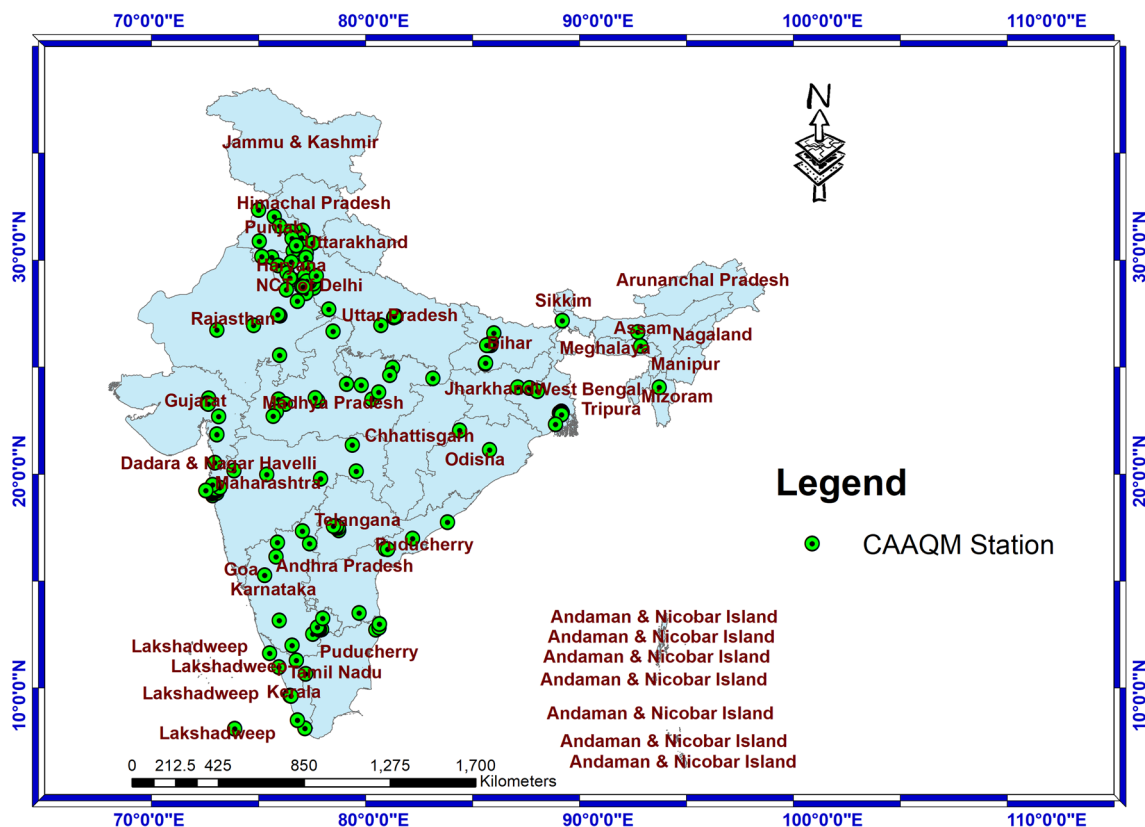


Fig. 1 Continuous ambient air quality monitoring (CAAQM) stations in India

amended since midnight on March 24th in the light of the COVID-19 pandemic, has led to remarkable improvements in the nation's air quality, as demonstrated by data analysis and time data measurement before the implementation of restrictions. The emission of nitrogen dioxide (NO_2) during the COVID-19 before locking (January 01–March 24, 2020) and after locking (March 25–April 20, 2020) and long-term variations in pollution levels are shown in Fig. 2. During the national lockdown time, which is a situation of controlled and reduced industrial activity, fuel utilization in the transport, and energy sector, the study showed us notable depletion in NO_2 levels. The notable parts of India where hot spots of air pollution were higher than normal like

industrial/coal burning areas remarkably reduced NO_2 levels by 40–50%, as represented in spatial maps shows reduced pollution levels (Fig. 2).

Before the national lockdown period, major megacities such as Mumbai, Jharkhand, Gandhinagar, Lucknow, Delhi, Kolkata, and Hyderabad had maximum concentrations of tropospheric nitrogen dioxide (NO_2) ranged from 100 to 350 $\mu\text{mol}/\text{m}^2$. But the time of the national lockdown periods from March to April, the concentration of NO_2 ranges falls in 75–150 $\mu\text{mol}/\text{m}^2$ mostly Northeast India over the cities of Madhya Pradesh, Odisha, Jharkhand, Bihar, and West Bengal because of this region having more coal power plants in India. Ogen et al. (2020) reported that while

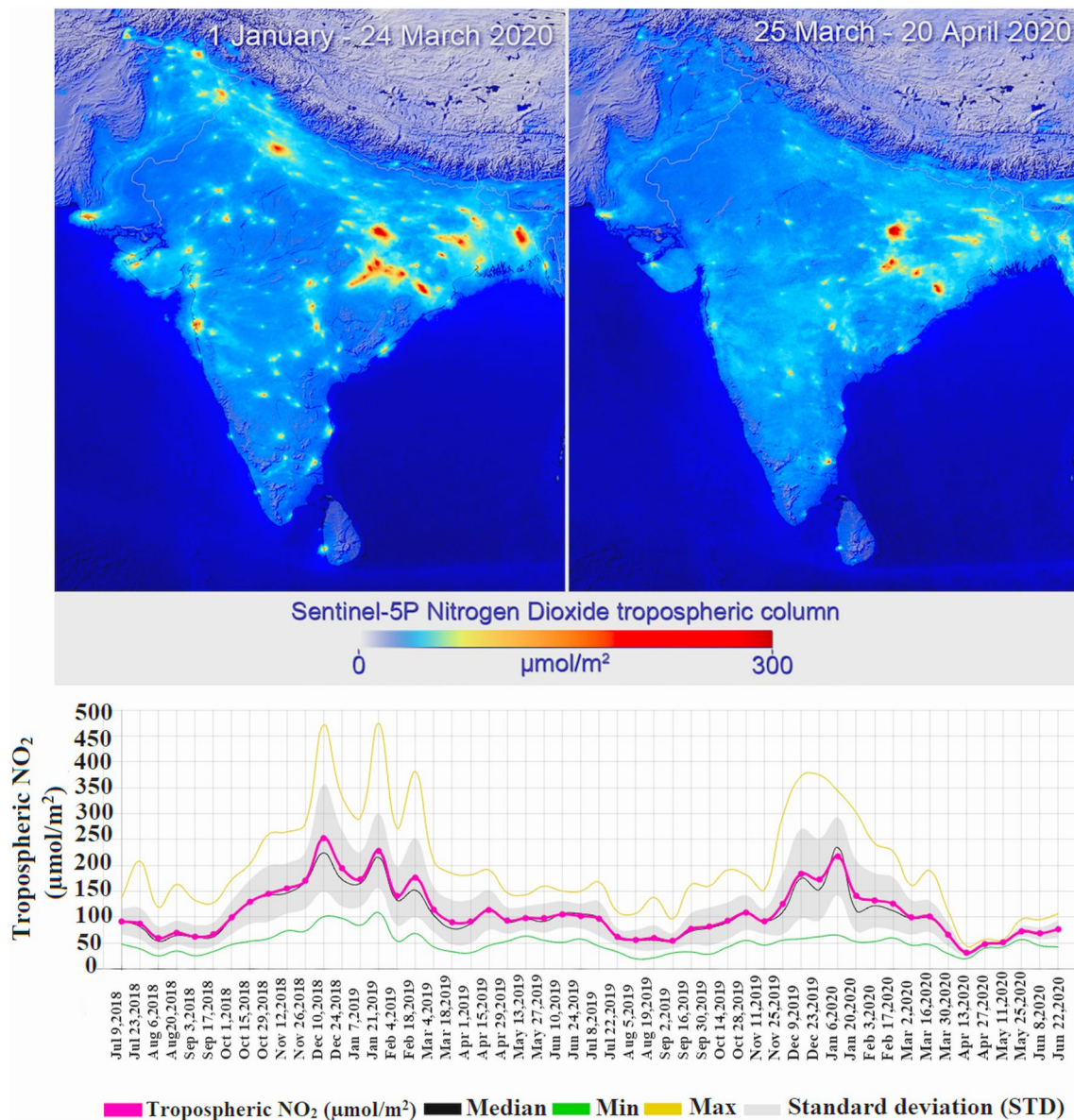


Fig. 2 Spatial average across India of bi-weekly tropospheric nitrogen dioxide (NO_2) concentrations (Sentinal-5P satellite data)

long-distance air pollutant transmission resulted in heterogeneous improvements over NO₂ concentrations, satellite observations generally matched the troposphere. The frequent output of nitrogen dioxide into the atmosphere as a result of power plants, manufacturing processes, automotive industries, and trafficking its impacts on the likelihood of respiratory infections (Bharath et al. 2020). Annual death rate by air pollution is nearly 7 million people worldwide (WHO). Nowadays, NO₂ exposure is a major threat to the health of people in developed and developing countries alike (Mansouri Daneshvar et al (2021)). The IQAir Global Air Quality's report says six of the world's 10 severely polluted cities are Indian cities. Also one report revealed that the country capital's air quality is most polluted region, mostly affected by sclerotic traffic pollution, fossil fuel burning, and industrialization (IQAir 2019). The long-term, cumulative geographic variance in bi-weekly concentrations in tropospheric nitrogen dioxide (NO₂) is shown in Fig. 2. The basic statistical patterns of the NO₂ concentration spectrum seen the peak during October to March in each year. Likewise, tropospheric NO₂ decreasing levels were dropping in the shown in Fig. 2 from April to June. The metropolitan area of Northern Italy and Madrid was noted as the hotspot with a high concentration of NO₂ accompanied by downward airflows that make it stay close to the surface (Ogen 2020). These results shows that the high concentration of NO₂ level is closely linked with the ongoing operation sites of coal-based power plants in northeast India. Around 3.5 lakhs new cases of pediatric asthma and 16,000 early deaths annually occurred due to NO₂, a poisonous agent in India (Farrow et al. 2020). The airborne concentrations of nitrogen dioxide in India from 2018 to 2020 are the minimum, mean, maximum and standard deviation ranges in 50–120 µmol/m², 90–250 µmol/m², 80–460 µmol/m² and 60–300 µmol/m² (Fig. 2). The NO₂ concentration derived from the Sentinel-5P with the airflow vertical movement and the number of mortality rates corresponding to the concentration of NO₂ was studied in Italy, Spain, France, Germany (Asheshwor Shrestha et al. 2020).

Satellite-based observation of tropospheric NO₂ variation

Figure 3a, b shows the dramatic decrease in NO₂ levels in South Asia and East Asia during the COVID-19 pandemic quarantine period. The quarantine period by the COVID-19 situation made the significant reduction of NO₂ in major cities of India. Mumbai and Delhi reported declines of about 50–60% compared to their the same time last year that displayed in Fig. 3. Vindhyachal Super Thermal Power Station, one of the biggest power plants of India, indicates a decline of just about 15% relative to last year's same time (ESP survey in India-COVID19; <https://www.esa.int/Appli>

[cations/Observing_the_Earth/Copernicus/Sentinel5P/Air_pollution_drops_in_India_following_lockdown](#)). Another source of NO₂ levels decreased in the maritime transport region across the Indian Ocean during the quarantine time (Bhadra et al. 2021). Reduction in population mobility and shutting down of factories during the lockdown have helped in the improvement of air quality (Tobías et al. 2020). Thus, these findings demonstrate that the low trail of the NO₂ emissions remaining in the atmosphere is almost the same as last year as the International Marine activity (Liu et al. 2020). Thus the level of decreases in the environmental pollution in India and around the globe are short-term and although measures are challenged to changing degrees, as well as the dramatic steps are taken to shut down the various sector are not feasible process of cleaning up the atmosphere (Wang et al. 2020; Filonchik et al. 2020). There are demonstrable approaches to ensure improved air quality without restrictions to avoid recovering pollution as factories about to be in action and the outbreak of coronavirus disappears.

Ground-based continuous ambient NO₂ plummet in India

The regional air quality was investigated throughout India and at major megacities. The data sets obtained from 30-12-2019 to 28-04-2020 in real-time and also correlate with the Center for Pollution Control's historical data sets in India. Figure 4a, b. displays the NO₂ data obtained from 231 continuous monitoring stations during (COVID-19) quarantine from 30-12-2019 to 28-04-2020, with minimum, maximum, and mean varies from 3.24 to 20, 20–160 and 10–90 (µg/m³). Figure 4a, b indicates the emission levels of nitrogen dioxide (NO₂) during the COVID-19 quarantine time of (30-12-2019 to 28-04-2020) before lockdown and after lockdown and time series of diurnal variability in the NO₂ pollution levels. In India, the pollution level of NO₂ was in suddenly decreased around 50% at 23-03-2020 to 28-04-2020 during the full national lockdown of India. The diurnal NO₂ concentration variance decreases dramatically during the lockdown time and is shown in Fig. 4. Globally, 4.6 million people affected annually by air pollution (Sulaman Muhammad et al. 2020). The ambient NO₂ is a highly sensitive pollutant produced by the combustion of fossil fuels (He et al. 2020; Bhadra et al. 2021). Last year, 83,000 deaths were reported due to pollution (IQAR 2020). Hence, this finding suggests that due to the COVID-19 outbreak followed by controlled lockdown has made an improvement in air quality and major benefits for public health.

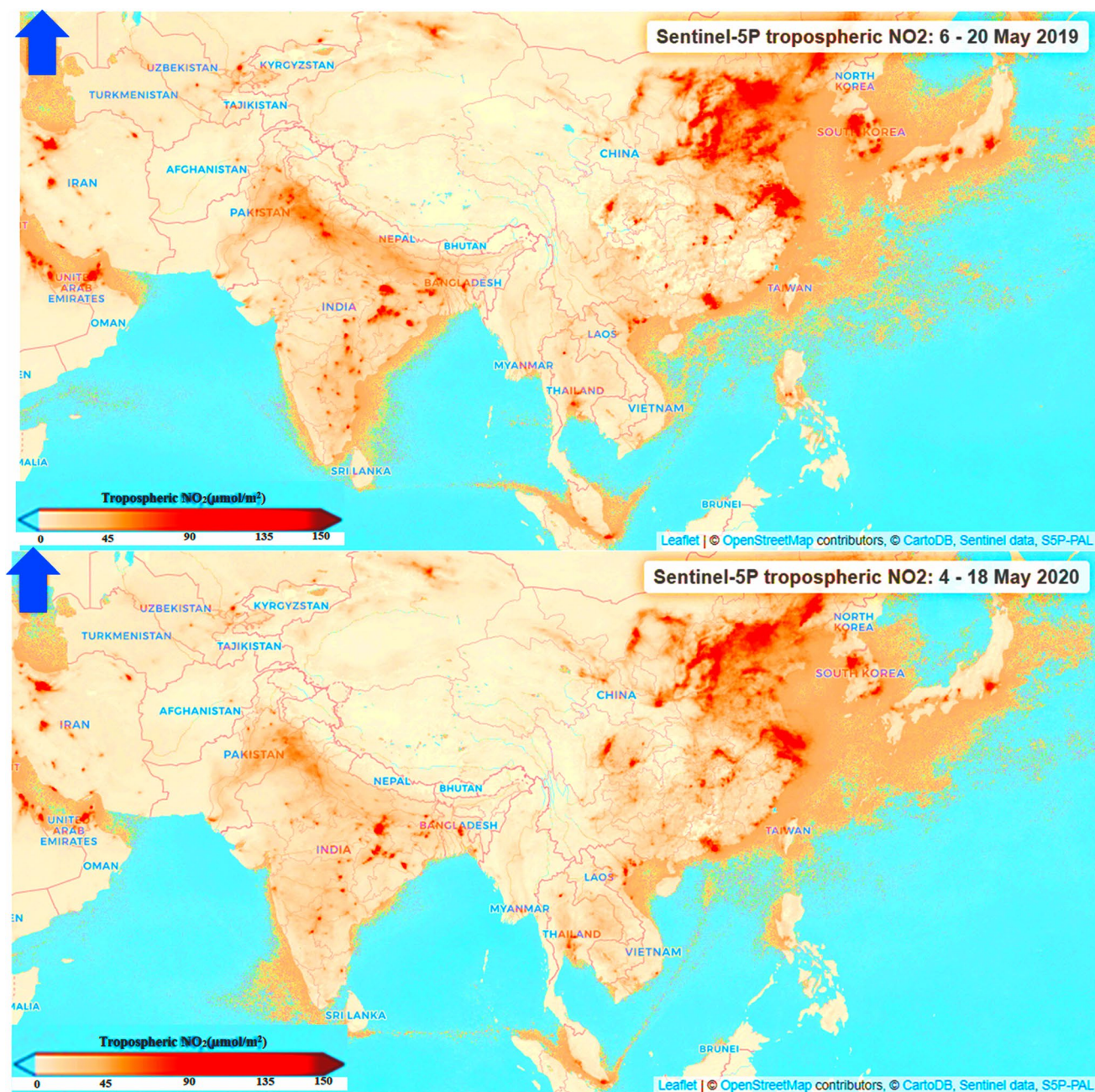


Fig. 3 Airborne NO₂ levels in South Asia and East Asia before and during lockdown (Sentinel-5P satellite data)

Ambient NO₂ variation of Indian megacities

As a result, a change in air quality observed in several cities and towns across the country. Figure 5 shows the extent of NO₂ pollution reduction over major cities in India, before and after the lockdown periods. The NO_x has a remarkable direct proportion with the PM 2.5 concentration because the secondary conversion of NO_x has a notable effect on PM 2.5 (Lijun Wang et al. 2019).

Pre-lockdown period has the highest average of diurnal variation of NO₂ than the multiple peak values seen during the lockdown period. The automobile activities reduction over the restrictions of transportation made the crest of NO₂ pollution reduced during night times (Halder et al. 2021). Figure 5a, b shows that the concentration of NO₂ and statistics details of the ambient level of NO₂ in major cities across India. Box plots shows average concentrations of NO₂ in major hotspots between 30-12-2019 and

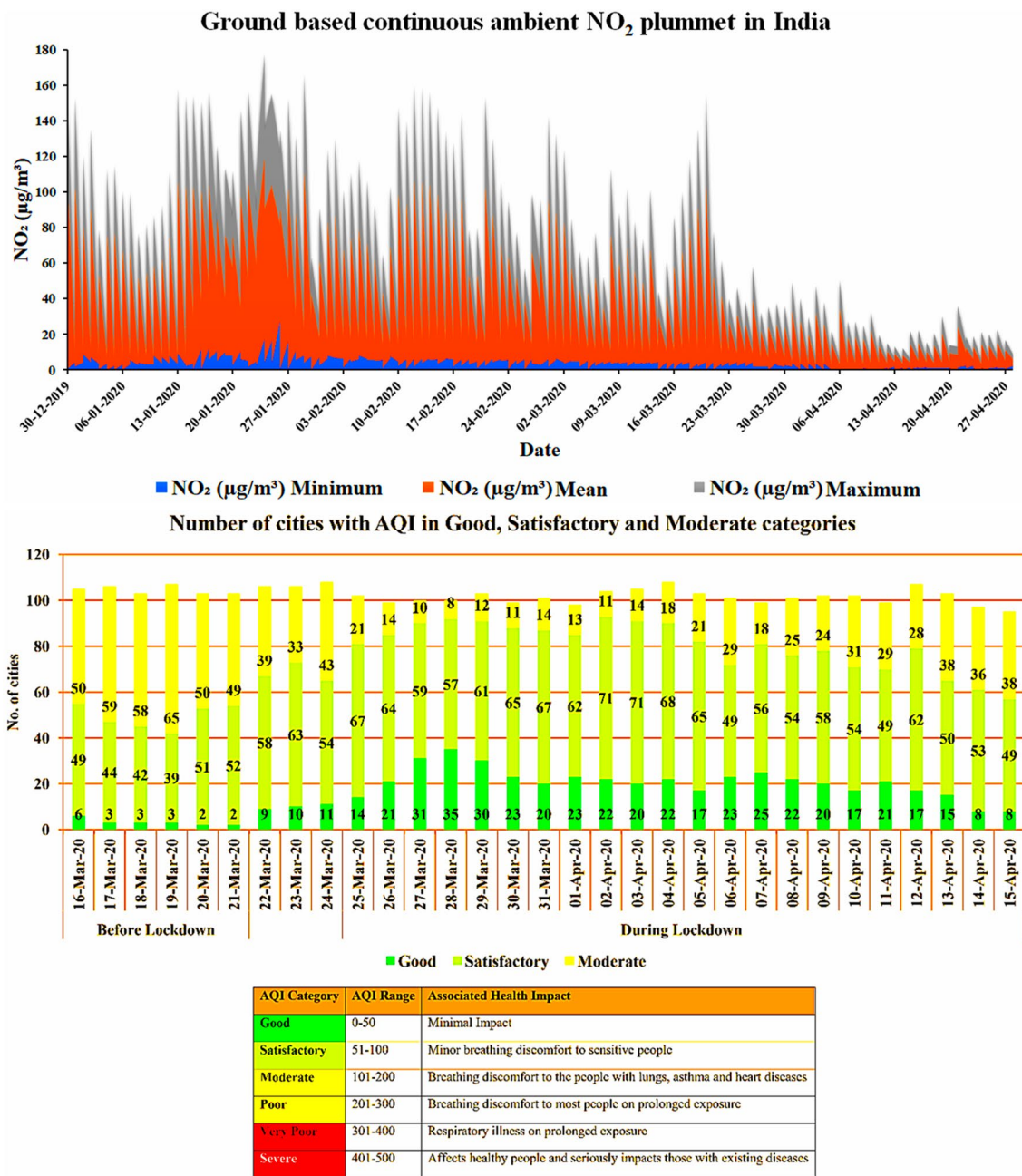


Fig. 4 Diurnal variation of ground-based ambient NO₂ across India

28-04-2020. The study entry period statistical summary of the NO₂ concentration falls in the ranges 1–256 with a mean of 21 µg/m³ and the Interquartile range is 18 µg/m³ and a standard deviation of 20 µg/m³. Similarly, the frequency distribution of the NO₂ range is between 1 and 250.8 µg/m³, with a maximum of 96 per cent of the frequency falling within the range of 1–25.98 µg/m³ shown in Fig. 5. In India National Ambient Air Quality Standards in industrial, residential, rural, and Other Areas ranges for Annual and 24 h as nitrogen dioxide was in (NO₂) (40;

80 µg/m³). Our results shows, during the national lockdown NO₂ fell in 21 µg/m³, it is decreased 50 times of monthly mean of NAAQS related with National Ambient Air Quality Standards of mean of NO₂ in India. The plots show a significant decrease in the value distribution or standard deviation for all hotspots, suggesting the absence of major sources of pollution that led to variability in pollutant levels (Behnam and Jahanmahin (2021)). This may be evident due to increased activities in local combustion and the use of solid fuels in household and industrial

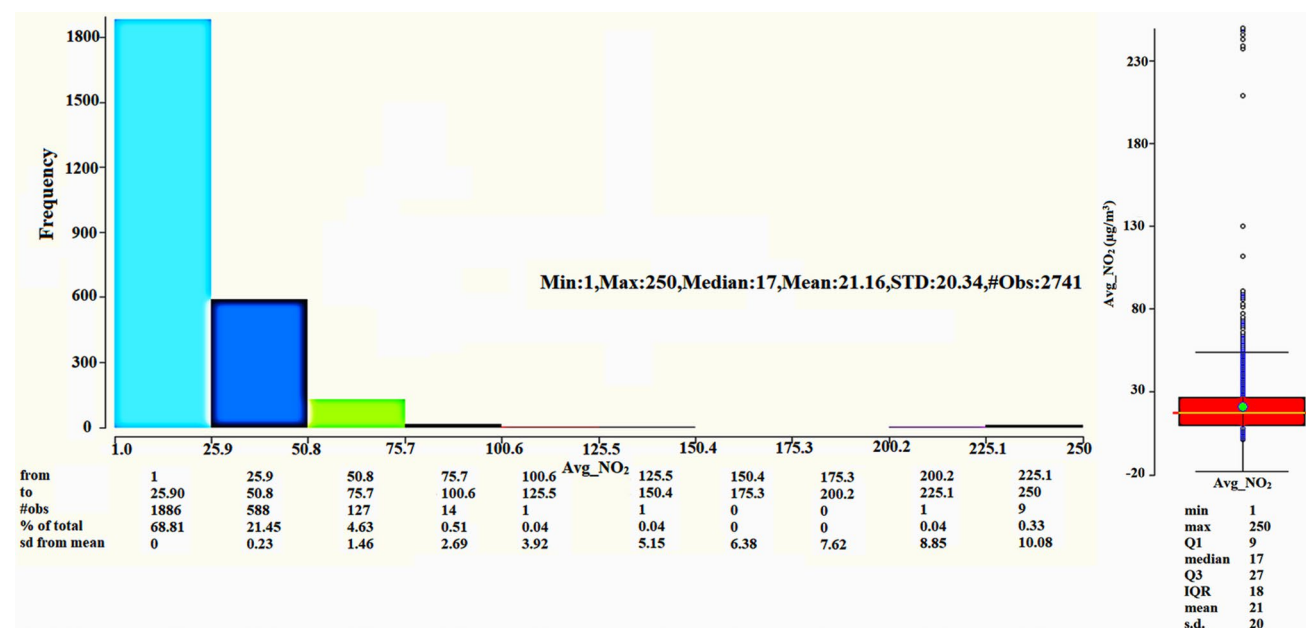


Fig. 5 Overall NO₂ variation of the major cities of South Asia

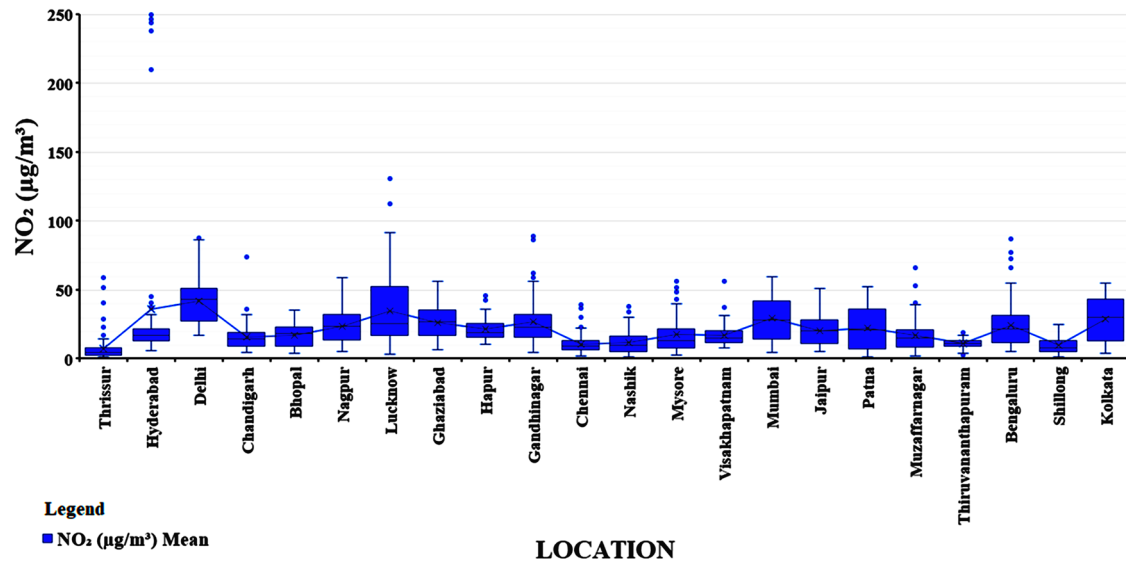
units. Long-term NO₂ declines over the major Indian quotations and NO₂ concentration reduction trends from 2017 to 2020 are shown in Fig. 6. Where NO₂ emissions in the lockdown period were found to be higher over few days, possibly because of coal-based power plants in and around nearby areas were not shut down due to the power demands of the nation (Bhadra et al. 2021). Besides, in the absence of complete data on the scale of industrial activity in different categories except for power plants and critical activities. At this point, it may be difficult to evaluate the effects of those sources on air quality (Ganiny and Nisar (2021)). The NO₂ levels remained within National Ambient Air Quality Standards (NAAQS), with the peak hourly NO₂ value decreasing from 76 µg/m³ during the pre-lockdown time to 20 µg/m³ during the lockdown period (Fig. 6). Only the Patna region showed a concentration of NO₂ in 2020 with increasing trends, probably due to local combustion activities such as biomass burning and Agri-waste burning in surrounding areas (Fig. 6). The effect of lockdown among five India’s big cities such as Delhi, Mumbai, Chennai, Kolkata, and Bangalore investigated and recorded a decrease in NO₂ rates of ~ 51 per cent (39–19 µg/m³), respectively (Jain et al. 2020). The air quality indices are determined using data from CAAQM stations for cities all over India. All major cities, evaluated in this study, based on the Indian NAAQS their air quality, mainly in the Good-Moderate categories, with Bengaluru, Chennai, and Mumbai reporting all 22 days of the lockdown duration in Good Satisfactory categories, while Patna had a moderate fall in South Asia for the majority

of days (Fig. 6). Air quality has been slightly improved in the country during the lockdown period as outcomes of regulations amended over the various anthropogenic activities by lockdown policies, which is corroborated by both ground-based CAAQM station data and satellite-based sentinel 5P data sets.

Conclusions

Our present study reveals that India’s NO₂ levels decreased within two weeks under the national lockdown compared to two weeks before lockdown in major cities and geographic regions by analyzing with satellite-based observation data as well as ground-level monitoring data. In the course of the national lockdown period, the tropospheric nitrogen dioxide (NO₂) concentrations have been reduced in 40–50% from the air pollutants hotspots and industrial zones of India. Likewise, it dramatically decreased in South Asia and East Asia during the COVID-19 pandemic quarantine period. These are the radical measures to shut down the industry as an attempt to clean up the air is not feasible. The statistical patterns of the tropospheric nitrogen dioxide (NO₂) concentration spectrum of historical data sets (2018–2020) bi-weekly showed during October to March were seen higher in each year. Also, decreasing level of tropospheric NO₂ seen in April to June every year in India. In India, the pollution level of NO₂ was in suddenly decreased around 50% at 23-03-2020 to 28-04-2020 during the full national lockdown of India. Correlated with

NO₂ (µg/m³) variation across the India



NO₂ levels in India by city

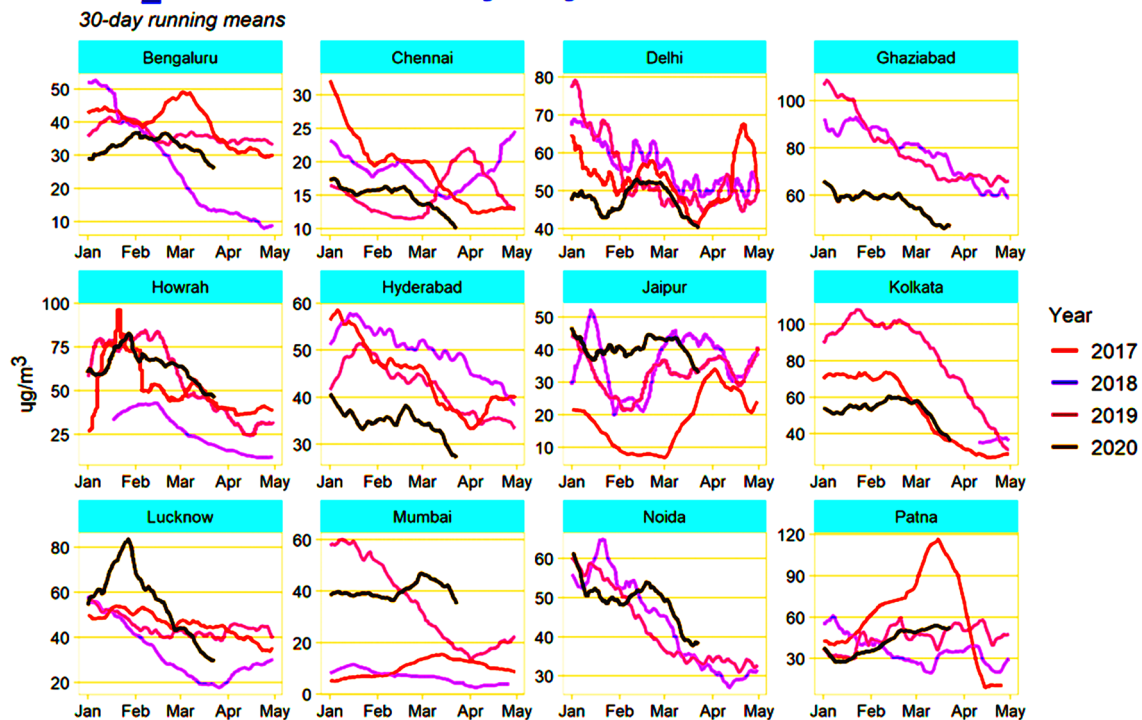


Fig. 6 Long-term NO₂ plummet and Air Quality Indices over the major cites of Indian cites

National Ambient Air Quality Standards (NAAQS) of India, the average level of NO₂ was in 80 µg/m³ for hourly ranges but our result shown in 21 µg/m³ at during the national lockdown, it is decreased around more than 50% of the hourly mean of standards of air quality in Central Pollution Control Board in India. All major cities, evaluated in the NO₂ levels, based on the Indian NAAQS their

air quality, mainly in the Good-Moderate categories, with Bengaluru, Chennai, and Mumbai reporting all 22 days of the lockdown duration in Good Satisfactory categories, while Patna and northeast region of India had a moderate fall in India for the majority of days. The pandemic situation has taught us that clean sky and good air conditions can be attained very easily if strong processes is taken to

slow down fossil fuel consumption, and we believe that this outcomes and changes in environmental condition is a key to make new plans for maintaining a good air quality to the health of the nations.

To control the pollution from rising as the environment is turning a corner and the COVID-19 outbreak condition is coming to an end, temporally checked decisions are availed to ensure improved air quality standards without putting people in trouble. However, the improved air quality standards across the nation may turn back to the normal condition that was happened before the lockdown period as the nation was planned to gradually eradicate the lockdown policies that will involve the industrial, power plants and anthropogenic activities without any restrictions.

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Data availability The data sets and source of the data files will be given by the requesting to the author krmanibharath93@gmail.com.

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