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Geospatial Technology-Based Analysis of Air Quality in India during the COVID-19 Pandemic

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Abstract: The study evaluates the impacts of India's COVID-19 lockdown and unlocking periods on the country's ambient air quality. India experienced three strictly enforced lockdowns followed by unlocking periods where economic and social restrictions were gradually lifted. We have examined the in situ and satellite data of NO_2 emissions for several Indian cities to assess the impacts of the lockdowns in India. Additionally, we analyzed NO_2 data acquired from the Sentinel-5P TROPOMI sensor over a few districts of the Punjab state, as well as the National Capital Region. The comparisons between the in situ and satellite NO_2 emissions were performed for the years 2019, 2020 and up to July 2021. Further analysis was conducted on the satellite data to map the NO_2 emissions over India during March to July for the years of 2019, 2020 and 2021. Based on the in situ and satellite observations, we observed that the NO_2 emissions significantly decreased by 45–55% in the first wave and 30% in the second wave, especially over the Northern Indian cities during the lockdown periods. The improved air quality over India is indicative of reduced pollution in the atmosphere due to the lockdown process, which slowed down the industrial and commercial activities, including the migration of humans from one place to another. Overall, the present study contributes to the understanding of the trends of the ambient air quality over large geographical areas using the Sentinel-5P satellite data and provides valuable information for regulatory bodies to design a better decision support system to improve air quality.

Keywords: COVID-19; Sentinel-5P; TROPOMI; air quality; North India

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1. Introduction

In the last week of December 2019, an unusual type of pneumonia spreading quickly was reported in Wuhan city in the People's Republic of China [1]. During the early period, it was treated as a new form of pneumonia. After a group of infections was reported by Wuhan Municipal Health Commission to the World Health Organization (WHO) on 31 December 2019, the WHO published the first news of the outbreak of this virus on 5 January 2020 by identifying it as Coronavirus Disease 2019 (COVID-19), a sequel of pneumonia [2]. The patients with this disease showed similar symptoms as of Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome

(MERS) [3]. Following this, several studies suggested that COVID-19 patients suffered from coughs, severe body pain, unusually high fever, fatigue, loss of smell and taste, infection in the lungs and shortness of breath or breathing difficulties, resulting in unpreventable casualties [4,5]. On 13 January 2020, the first international case of COVID-19 was reported in Thailand (https://www.who.int/news-room/detail/29-06-2020-covidtimeline, accessed on 21 August 2020). In response to the increased cases of COVID-19 in Wuhan, the first lockdown was implemented by the Chinese authorities on 23 January 2020, which resulted in the prohibition of gatherings and the movement of individuals. With the sharp and continuous amplification of COVID-19-positive cases around the world, the WHO declared the novel coronavirus outbreak a Public Health Emergency of International Concern (PHEIC) on 30 January 2020, and on the same day, the first COVID-19-positive case was registered in India (https://www.mohfw.gov.in/, accessed on 21 August 2020). Subsequently, the WHO declared the COVID-19 outbreak as a pandemic on 11 March 2020 (by this time, a total of 71 confirmed cases of COVID-19 had been reported in India). It was observed that the known modes of transmission of COVID-19 were in the form of coughs/sneezes, personal contact, contaminated objects and mass gatherings, and, so far, the identified methods of prevention against COVID-19 are physical distancing, quarantine, maintaining hand hygiene, wearing face masks and avoiding contact with virus-infected persons [6,7]. Moreover, several studies have also reported that the rate of spread of COVID-19 may vary with varying atmospheric conditions, such as temperature, pressure, rainfall etc. [2,3,8–10].

According to the Worldometer elaboration of the latest United Nations data, the population of India totals 1,380,004,385 (as of 2020), representing approximately 17.7% of the world's population, and the average population density is 464 per km^2 and ranks 31st in the world (https://www.worldometers.info/world-population/india-population, accessed on 21 August 2020). Considering the potential explosion of COVID-19-positive cases in such a hugely and densely populated country, from 25 March 2020 to 14 April 2020, the Indian government announced and implemented a nationwide complete lockdown for 21 days (Table 1). This was followed by less restrictive lockdowns and unlocking in phases (see Table 2 for more details on these lockdown/unlocking phases). During the lockdown periods, most of the economic activities, trade, industry, employment for daily wage workers, school, colleges, universities and public and private companies' offices were either halted or completely shut down, resulting in reduced power consumption (e.g., Aruga et al. [11]) and a massive loss in GDP (e.g., Kanitkar [12]). By August 2020, most social distancing restrictions were lifted due to the severe impacts of the lockdowns on people's livelihoods and social relationships [13–18].

Table 1. Lockdown and unlocking phases in India, duration and areas closed/opened (excluding the unlocking phase 4 from 1 September to 30 September 2020).

Lockdown Phase	Period	Duration (Days)	Major Areas of Restriction
Phase 1	24 March–14 April 2020	21	All activities except essential services; leaving homes
Phase 2	15 April–3 May 2020	19	Air, rail and metro activities; all educational and related institutions (only online education allowed); hospitality services including hotels and restaurants; large public gatherings such as cinema halls, malls, gymnasiums, sports complexes, etc.; social, political and cultural gatherings in all places
Phase 3	4 May–17 May 2020	14	Same as phase 2
Phase 4	18 May–31May 2020	14	Same as phase 2

Table 1. *Cont.*

Unlocking Phase	Period	Duration (days)	Major Areas of Reopening
Phase 1	1 June–30 June 2020	30	Economic activities with strict conditions; vehicular traffic under certain circumstances; relaxation in day-to-day activities, religious places and other establishments but with conditions
Phase 2	1 July–31 July 2020	31	In addition to the above, relaxations in night curfew; the opening of vehicular traffic with conditions; clearance for more than five people in a shop
Phase 3	1 August–31 August 2020	31	As above but with more relaxations

Table 2. Lockdown and unlocking phases in India, duration and areas closed/opened (excluding the unlocking phase in 2021 during wave 2).

Lockdown Phase	**Period**	**Duration (Days)**	**Major Areas of Restriction**
Phase 1	8 March–30 April 2021		All educational and related institutions (only online education allowed); hospitality services including hotels and restaurants; large public gatherings such as cinema halls, malls, gymnasiums, sports complexes, etc.; social, political and cultural gatherings in all places. Night curfew from 9 PM to 5 AM.
Unlocking Phase	Period	Duration (days)	Major Areas of Reopening
Phase 1	May 5 onwards		Economic activities with conditions

However, by mid-September, 2020, the death toll from COVID-19 in India had risen to around 75,000, and the disease was spreading rapidly due to the total cessation of the lockdowns and the opening of commercial and economic activities, as well as the increasing dominance of the more contagious COVID-19 "delta" variant. Although the world economy was drastically slowed due to the lockdowns imposed by various countries, the virus is thought by many to have been a boon for environmental recovery (for the atmospheric environment in particular). For the first time since the industrial revolution, all of the industrial activities in India and around the world were suspended during the lockdown period, giving the atmospheric environment time to recover due to the absence of industrial air pollution.

In the last two decades, global warming and climate change have emerged as hot topics for scientific research, which led to the study of and research on the phenomena behind global warming, climate change and pollution in the Earth's atmosphere. Over the years, pollution has largely impacted the ecology and environment, as well as human health, due to air pollutants such as ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), particulate matter (PM) in different size fractions (PM0.1 µm, PM2.5 µm and PM10 µm), volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs), which have led to oxidative stress, viral and bacterial infections, asthma, hypertension, heart disease and chronic lung disease, and may further lead to damage to the cardio-respiratory and immune systems [19–23]. Due to COVID-19 restrictions around the world, there was a significant decrease in the consumption of diesel, petrol and other petroleum fuels' combustion, which also led to a significant reduction in NO_2 emissions in the developing (India, China, etc.) and western developed world [24,25]. Several studies have been conducted to understand the impacts of lockdown periods on ambient air quality at national and global scales.

Such studies have shown that the cessation of industrial units and vehicular movement caused a great improvement in air quality [26–29]. Air pollution and air quality have become global issues, and have impacts at the local, regional and global scale. Particulate matter and pollutant gases (NOx/SOx/CO) not only affect the environment, but also affect human health and cause various types of respiratory problems. Various studies have shown the influence of aerosols on the radiation budget [30,31], human health [32] and even the intensity of monsoons [33]. Long-term exposure to particulate matter, NOx and ozone can cause an increase in cardiovascular mortality [34,35]. According to the national ambient air quality monitoring program, the particulate matter (PM2.5 and PM10) emissions are the highest in India, followed by NO_2, SO_2 and CO [36]. The primary source of NOx pollutants is anthropogenic action, industrial activities and exhausts from vehicles. The air quality index (AQI) and the corresponding NO_2 concentrations are shown in Table 3. During the lockdown periods, all industrial, manufacturing and engineering activities, as well as all types of traffic, were suspended by the government of India, and this improved the air quality to a great extent.

Table 3. AQI categories and concentration ranges for India (source: CPCB).

Air Quality Category	Air Quality Index	NO_2 Cocentration (μg/m^3)
Good	0–50	0–40
Satisfactory	51–100	41–80
Moderately Polluted	101–200	81–180
Poor	201–300	181–280
Very Poor	301–400	281–400
Severe	401–500	400+

This paper investigates the impact of the lockdown and unlocking periods on the atmospheric environment of India during 2019, 2020 and 2021, through an analysis of in-situ and Sentinel-5P satellite remote sensing data. A key point of this research is to evaluate in situ emissions of NO_2 against satellite-based NO_2, so as to better understand the accuracy of the satellite estimates. To our knowledge, this is the most comprehensive study on the spatio-temporal variation of atmospheric NO_2 during the COVID-19 era (2019–2021) in India. First, an analysis of in situ data was conducted for several northern cities in India to understand the trends in air quality and validate the satellite-based estimates. Subsequently, a national-level analysis was conducted using the satellite data to understand the overall air quality status during India's national lockdown and unlocking periods. This research effort highlights the promising applications of combining in-situ and satellite-based approaches to assess changes in the air quality over Indian cities, and can potentially be applied in other countries in future works.

2. Data and Methods

In this study, we used a combination of satellite remote sensing data (Sentinel-5P data), in situ NO_2 data and climate forecast data, as explained in more detail below.

2.1. Datasets

2.1.1. Sentinel-5P Data

TROPOMI is a passive-sensing hyperspectral nadir-viewing imager onboard the Sentinel-5 Precursor (S-5P) satellite, launched on 13 October 2017. The S-5P is a near-polar sun-synchronous orbit satellite flying at a height of 817 km, with an overpass local time at ascending node (LTAN) of 13:30 and a repeat cycle of 17 d (KNMI, 2017). The TROPOMI works in a non-filtering push broom setup, with an instantaneous field of view of 108° and an estimated time of around 1 s. The outcome is an area width of approximately 2600 km and an along-track goal of 7 km and day-by-day worldwide inclusion (KNMI, 2017). It has four separate spectrometers, measuring the ultraviolet (UV), UV–visible (UV-VIS), near-infrared (NIR) and short-wavelength infrared (SWIR) spectral bands, of which the NIR and SWIR bands are new compared to its predecessor, OMI [37]. The NO_2 sections are inferred utilizing TROPOMI's UV–vis spectrometer backscattered sunlight-based radiation estimations in the 405–465 nm frequency range [38,39]. The swath area is partitioned into 450 individual valuation pixels, which bring about a close nadir resolution of 7 × 3.5 km. The total NO_2 slant column density is retrieved from Level 1b UV–vis radiance and solar irradiance spectra utilizing the DOAS strategy [40]. The NO_2 retrieval and assimilation scheme and the data product have been described in detail [37–39,41,42].

The TROPOMI NO_2 processing system is based on the algorithm developments for the DOMINO-2 product and for the EU QA4ECV NO_2 reprocessed dataset for OMI and has been adopted for TROPOMI. The assimilation modeling system uses the 3-dimensional global TM5-MP chemistry transport model at a resolution of 1 × 1 degree as an essential element. In this research, near-real-time NO_2 concentration images were created using the Google Earth engine. These images were pre-processed and corrected and stored in the Google Earth engine database.

2.1.2. Station Data

Station data of Amritsar, Bhatinda, Ludhiana Jalandhar, Khanna, Patiala, Delhi–Anand Vihar, Gurugram, Ghaziabad and Noida were obtained from the dashboard of the Central Control Room for Air Quality Management—All India.

2.1.3. CFSR

The Climate Forecast System, NCEP version 2 (CFSv2), is an upgraded version of CFS version 1 (CFSv1). It is a reanalysis product first developed as part of the Climate Forecast System by NCEP in 2004, with quasi-global coverage, and is a fully coupled atmosphere–ocean–land model used by NCEP for seasonal prediction [43]. CFSR has a 3D variational analysis scheme of the upper-air atmospheric state, with 64 vertical levels and a horizontal resolution of 38 km, spanning the period 1 January 1979 to the present day [43].

2.2. Methodology

For our study, we utilized the in-site atmospheric NO_2 data (obtained from the Central Control Room for Air Quality Management—All India) over North Indian cities, especially of Punjab state, from January 2019 to July 2021, covering the pre-COVID-19 period as well as all lockdown and unlocking periods during the first and second COVID-19 waves. NO_2 is one of the major air pollutants in India and is highly dependent on local sources because of its short residential time in the atmosphere [44]. The in situ data were compared with remote sensing data from the Sentinel-5P/Tropospheric Monitoring Instrument (TROPOMI) acquired during the same period, to understand the utility of remote sensing data for places where actual in situ data are not available for the continuous monitoring of air pollutants.

3. Results and Discussion

During pre-monsoon season (March to May), the north-west region of India heats up due to the location of the sun over the Tropic of Cancer. A hot, low-pressure area develops over this region because of this excessive heating. During this season, the normal surface wind direction is westerly to north-westerly and wind speed is between 1 and 19 kmph. Normally, the sky remains cloud-free and this helps in radiative cooling during nighttime. The maximum day temperature ranges from 26 °C to 41 °C and the minimum temperature ranges from 11 °C to 25 °C. The normal monthly rainfall, between 16 mm and 34 mm, is received during this season. Thunderstorms and associated rainfall are caused due to the interaction of westerlies and easterlies under the influence of passing western disturbances. These interactions often lead to the formation of dust storms, locally known as Andhis. After pre-monsoon season, monsoon season prevails from June to September. It is the main rainfall season for this region. The onset of monsoonal rains happens by the last week of

June. The wind direction also reverses and the easterlies set in, which brings moisture-laden winds to the region. With the onset of monsoonal rainfall, the day and night temperatures show a significant drop.

During the morning hours, a low-level temperature inversion is formed because of radiative cooling of the ground. This inversion leads to the trapping of air pollutants near to the ground level, because of which the ambient air quality deteriorates. This low-level inversion is broken after the heating of the ground by the sun during the day. The clear skies and wind flow help in the dispersion of air pollutants. The effect of meteorological parameters over the dispersion of air pollutants was observed in all preceding and following years and during the current study period. Meteorological parameters only affect the transport media in the source–transport–receptor analysis of air pollution. The COVID-19-induced lockdowns resulted in the closure of pollution-generating sources. As a result, the ambient air quality improved drastically, as discussed below.

Figure 1 shows the concentration of NO_2 emissions over India, obtained from the Sentinel-5P, from March to July 2019. It is observed that high values of NO_2 emission clusters are recorded over the thermal power plant belts of Punjab, the National Capital Region (NCR) of Delhi, Western Uttar Pradesh, Chhattisgarh, Jharkhand, Orissa and West Bengal. An extremely high NO_2 concentration of greater than 321 mole/km^2 was observed over a few areas. Figure 2 depicts the concentrations of NO_2 emissions over India from March to July 2020. After forced lockdown 1 on 24 March 2020 by the Indian government, more than half of the country experienced low NO_2 concentrations (i.e., below 70 moles/km^2) (see Figure 2). A reduced NO_2 concentration was observed in the early stage of lockdown 1 itself, even in the high-concentration clusters in the thermal power plant belts and Northern India. This fall in the thermal power plant belt was attributed to a drop in power requirements because of the shutdown of all industrial activities due to lockdown 1. The same trend was observed in April and May 2020 during other lockdown periods. Only a few industries were permitted to operate during unlocking period 1, which started on 1 June 2020. We observed that the NO_2 emissions over India remained low in June and July 2020, compared to that in June and July 2019. Figure 3 depicts the concentrations of NO_2 emissions over India from March to July 2021. As the lockdown imposed in 2021 was not as strict as that of 2020 and industries were permitted to operate, it can be seen that the NO_2 emissions in 2021 were of the same level as in 2019. The changes in NO_2 concentration over eight cities of NW India, namely Amritsar, Jalandhar, Khanna, Patiala Delhi–Anand Vihar Terminal, Gurugram, Ghaziabad and Noida, during March–July of 2019 to 2021, are shown in Table 4. The NO_2 concentrations were reduced significantly over these eight cities in the year 2020, with respect to 2019 and 2021. An approximately 18% reduction in average NO_2 concentration was observed in 2020 with regard to concentrations in 2019, and around a 19% increase in the average NO_2 concentration was observed in 2021 with respect to concentrations in 2020 during March–July. The maximum reduction of 28% in the average monthly NO_2 concentration over all cities was observed in the month of April 2020 with respect to April 2019. Similarly, the maximum increase of 36% was observed in April 2021 with respect to April 2020.

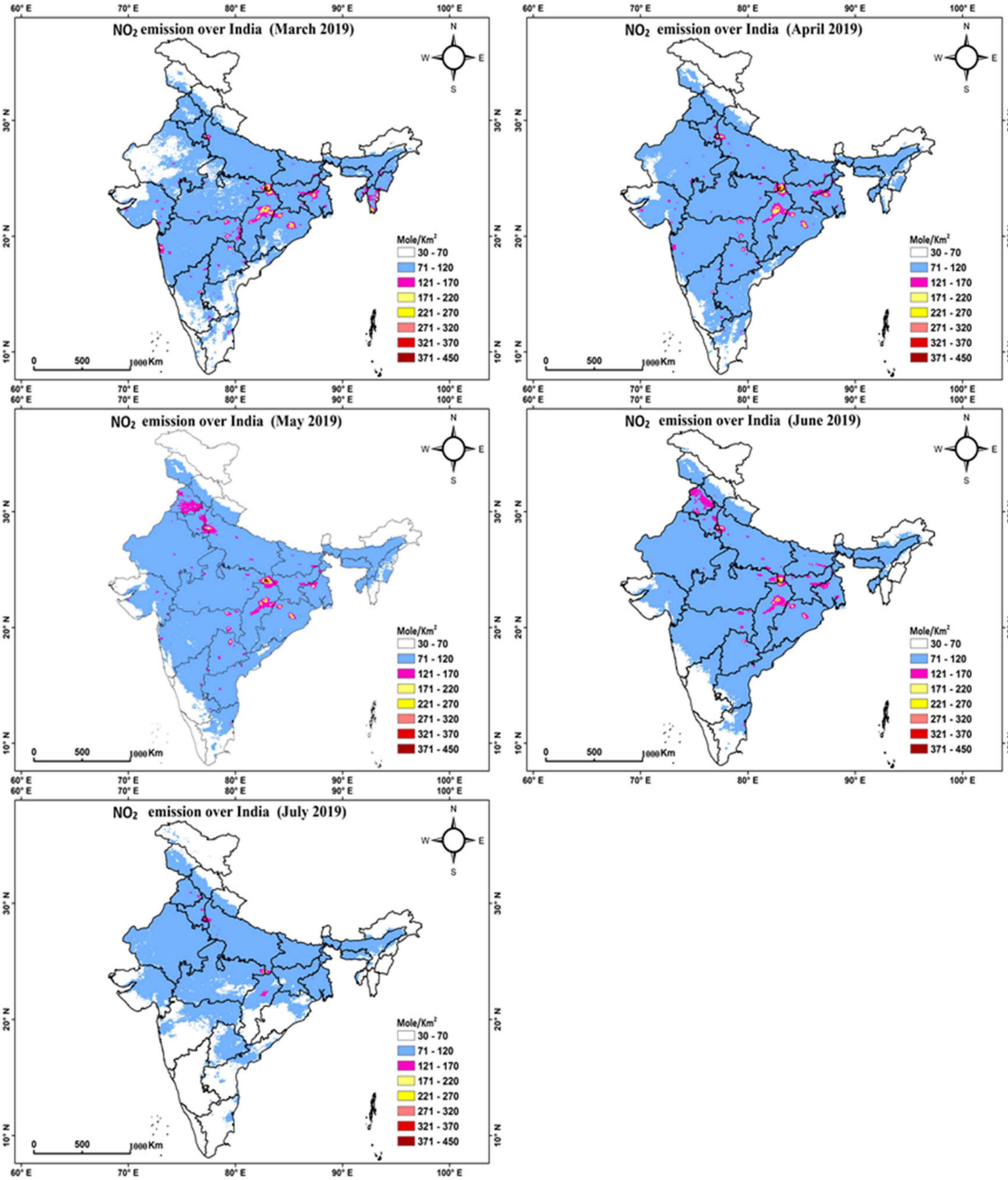

Figure 1. NO_2 emissions over India as observed by Sentinel-5P from March to July 2019.

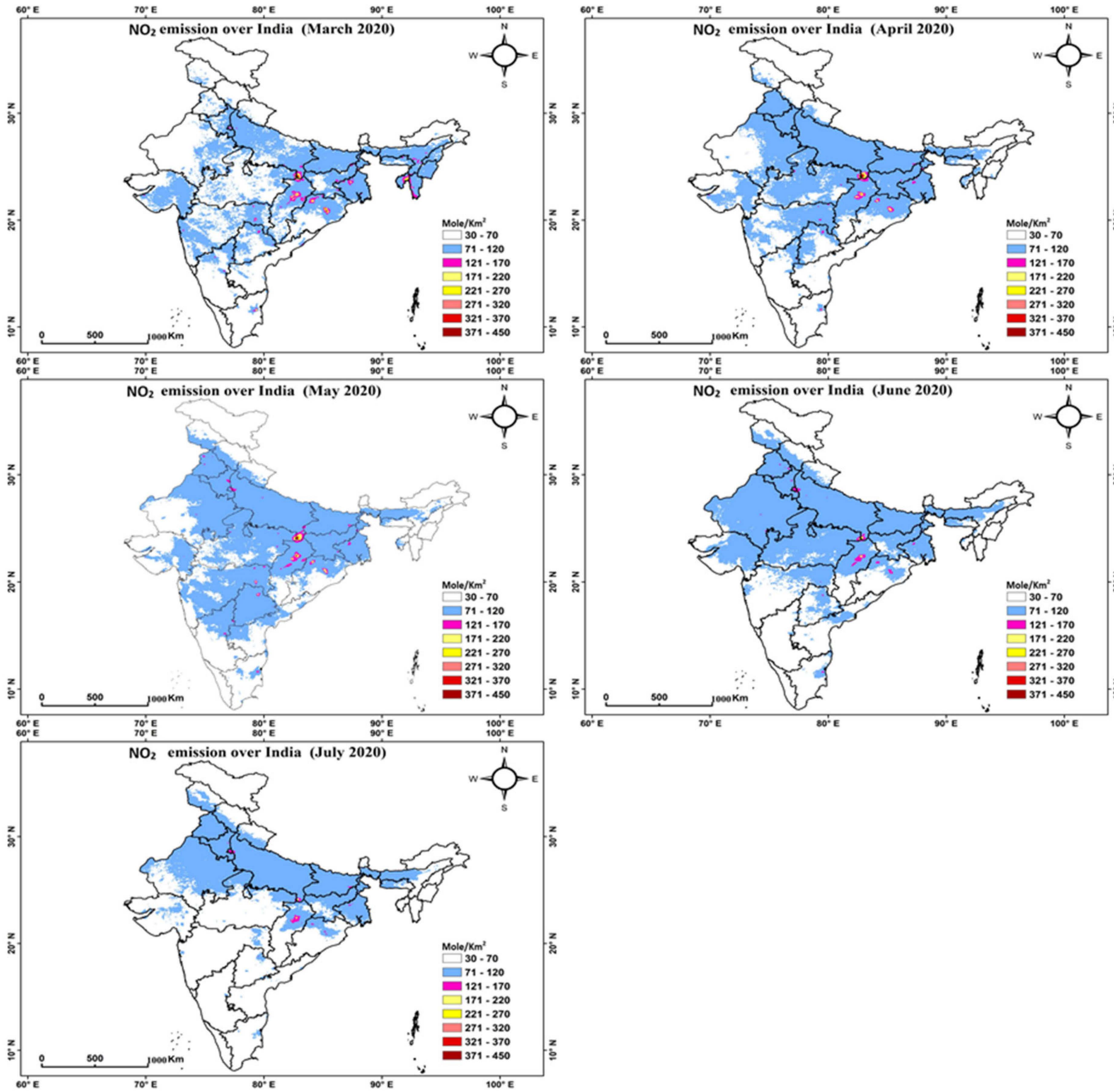

Figure 2. NO_2 emissions over India as observed by Sentinel-5P during lockdowns (phase 1–3) and unlocking periods (phase 1–2) from March to July 2020.

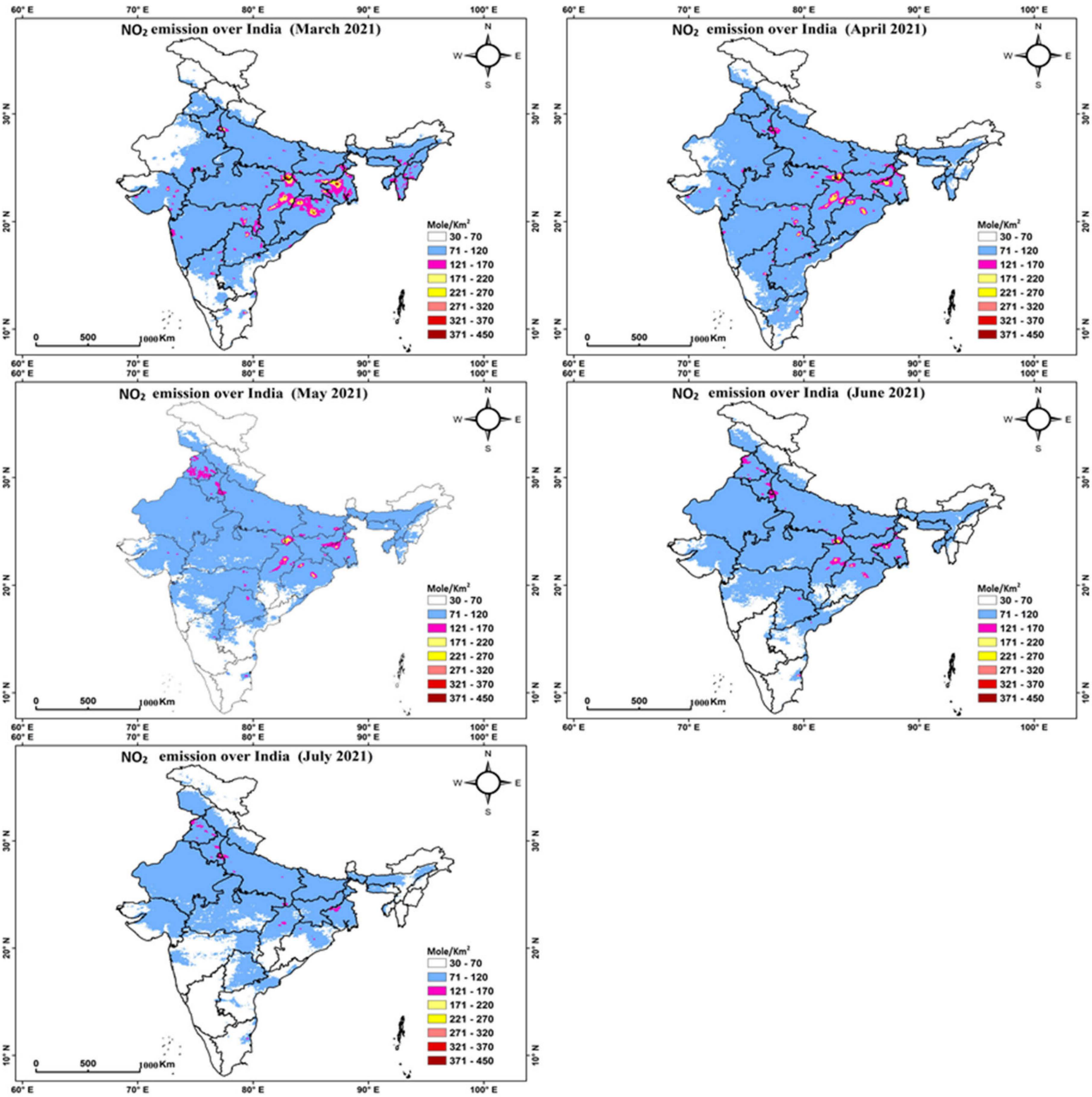

Figure 3. NO_2 emissions over India as observed by Sentinel-5P during wave 2 from March to July 2021.

Table 4. Comparison of changes in NO_2 concentration over eight North Indian cities during COVID-19-induced lockdown in 2020 (March–July) with regard to 2019 and 2021.

Place	Month	2019 (mol/km^2)	2020 (mol/km^2)	2021 (mol/km^2)	Reduction in NO_2 Concentration (%) in 2020 vs. 2019	Increase in NO_2 Concentration (%) in 2021 vs. 2020
Amritsar	March	85.63	74.44	82.31	13	11
	April	98.83	78.04	92.13	21	18
	May	121.18	112.11	118.91	7	6
	June	129.81	103.71	123.71	20	19
	July	102.16	90.37	118	12	31

Table 4. *Cont.*

Place	Month	2019 (mol/km^2)	2020 (mol/km^2)	2021 (mol/km^2)	Reduction in NO_2 Concentration (%) in 2020 vs. 2019	Increase in NO_2 Concentration (%) in 2021 vs. 2020
Patiala	March	80	75.15	80.45	6	7
	April	95.78	79.03	100.69	17	27
	May	124.11	106.46	120.39	14	13
	June	125.54	105.86	117.04	16	11
	July	105.11	91.77	106.25	13	16
Jalandhar	March	82.87	73.53	78.49	11	7
	April	96.39	80.36	97.26	17	21
	May	116.2	106.67	113.71	8	7
	June	124.78	104.58	113.03	16	8
	July	105.51	90.83	115.67	14	27
Khanna	March	84.52	74.86	82.03	11	10
	April	93.68	76.23	97.92	19	28
	May	121.63	108.19	119.72	11	11
	June	125.57	109.62	115.61	13	5
	July	109.72	95.2	114.49	13	20
Delhi	March	137.6	143.23	148.48	4	4
	April	162.19	91.25	142.75	44	56
	May	153.97	116.11	130.93	25	13
	June	160.19	127.4	146.43	20	15
	July	146.79	122.18	146.07	17	20
Gurugram	March	97.82	89.03	98.27	9	10
	April	111.86	84.7	111.37	24	31
	May	118.16	95.42	108.09	19	13
	June	116.74	100.38	116.23	14	16
	July	107.6	96.82	110.41	10	14
Ghaziabad	March	104.75	98.03	112.52	6	15
	April	125.39	89.39	118.95	29	33
	May	128.96	107.8	115.6	16	7
	June	125.19	99.78	117	20	17
	July	112.63	94.75	115.39	16	22
Noida	March	213.73	158	207.7	26	31
	April	199.87	99.69	172.6	50	73
	May	198.08	127.61	136.6	36	7
	June	180.97	128.54	164.56	29	28
	July	162.07	135.09	165.88	17	23

The concentrations of NO_2 in ambient air during the study period, i.e., March to July of 2019, 2020 and 2021, were measured and compared by using both in situ observations and satellite-based observations. The Sentinel-5P and in situ observations of NO_2 concentrations (7-day moving average) over the cities of NW India, namely Amritsar, Jalandhar, Khanna, Patiala Delhi-Anand Vihar Terminal, Gurugram, Ghaziabad and Noida, are plotted in Figures 4 and 5, respectively. It can be seen that the Sentinel-5P data follow the same trend as those of in situ observations. During the inter-year comparison, it can be seen that the concentration of NO_2 significantly decreased during the lockdown phases in 2020. It can be seen that the continuity of in situ observations is affected by the non-serviceability of sensors during the lockdown periods. This results in the creation of data gaps. This limitation can be overcome by the use of the Sentinel-5P dataset, as Sentinel-5P data exhibit a positive correlation with in situ observations. Figure 6 shows the anomalies of the monthly mean temperature for 40 years over India. A significant negative anomaly is observed during March, April and May, caused by the very active western disturbances that may have passed over the Northern Indian plains during the pre-monsoon season of 2020 (datasets are not presented for brevity). This has also played a role in the reduction in NO_2 concentrations.

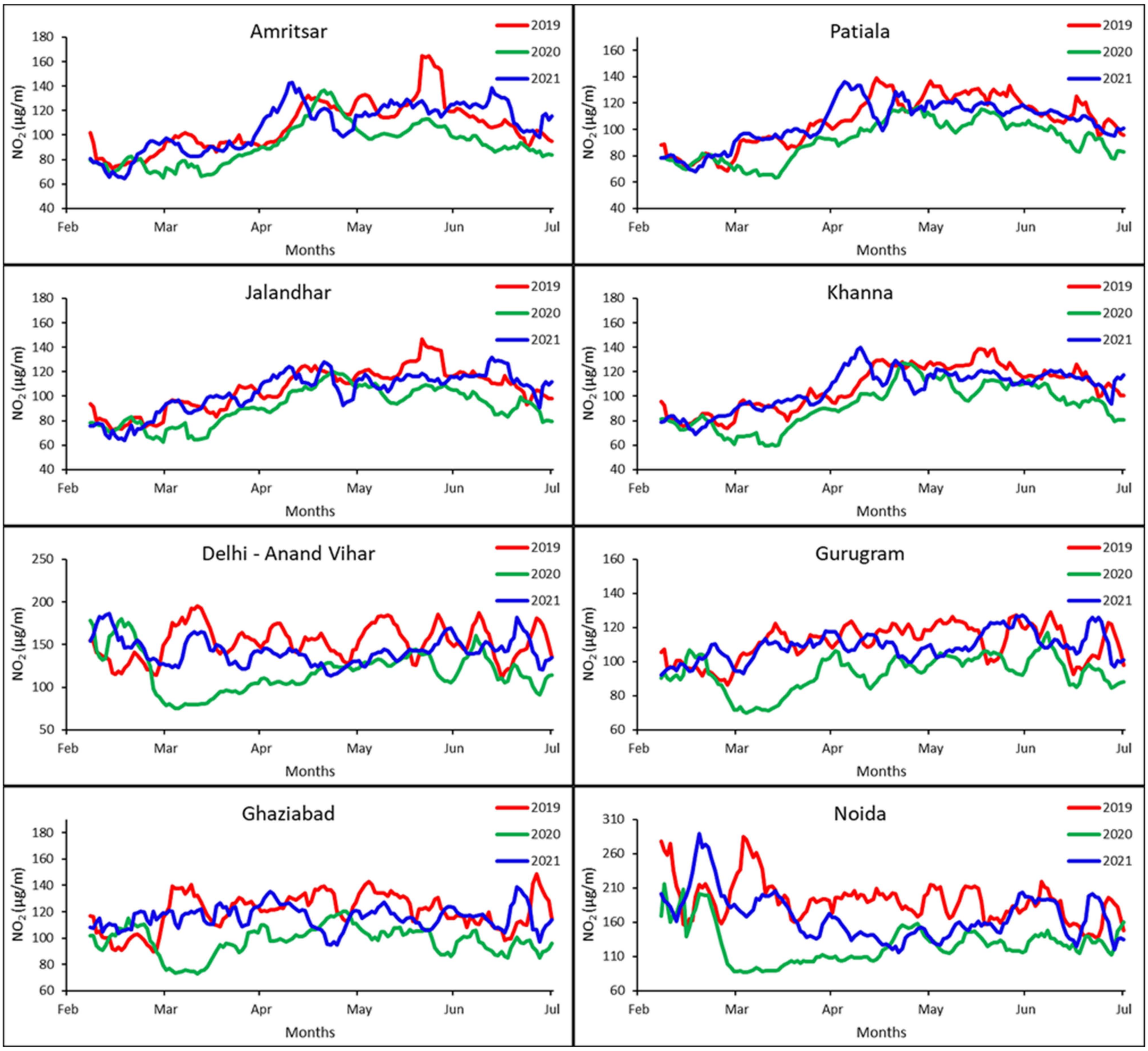

Figure 4. Sentinel-5P satellite-based NO_2 emission comparisons over Amritsar, Jalandhar, Khanna, Patiala Delhi–Anand Vihar, Gurugram, Ghaziabad and Noida during 2019, 2020 and 2021.

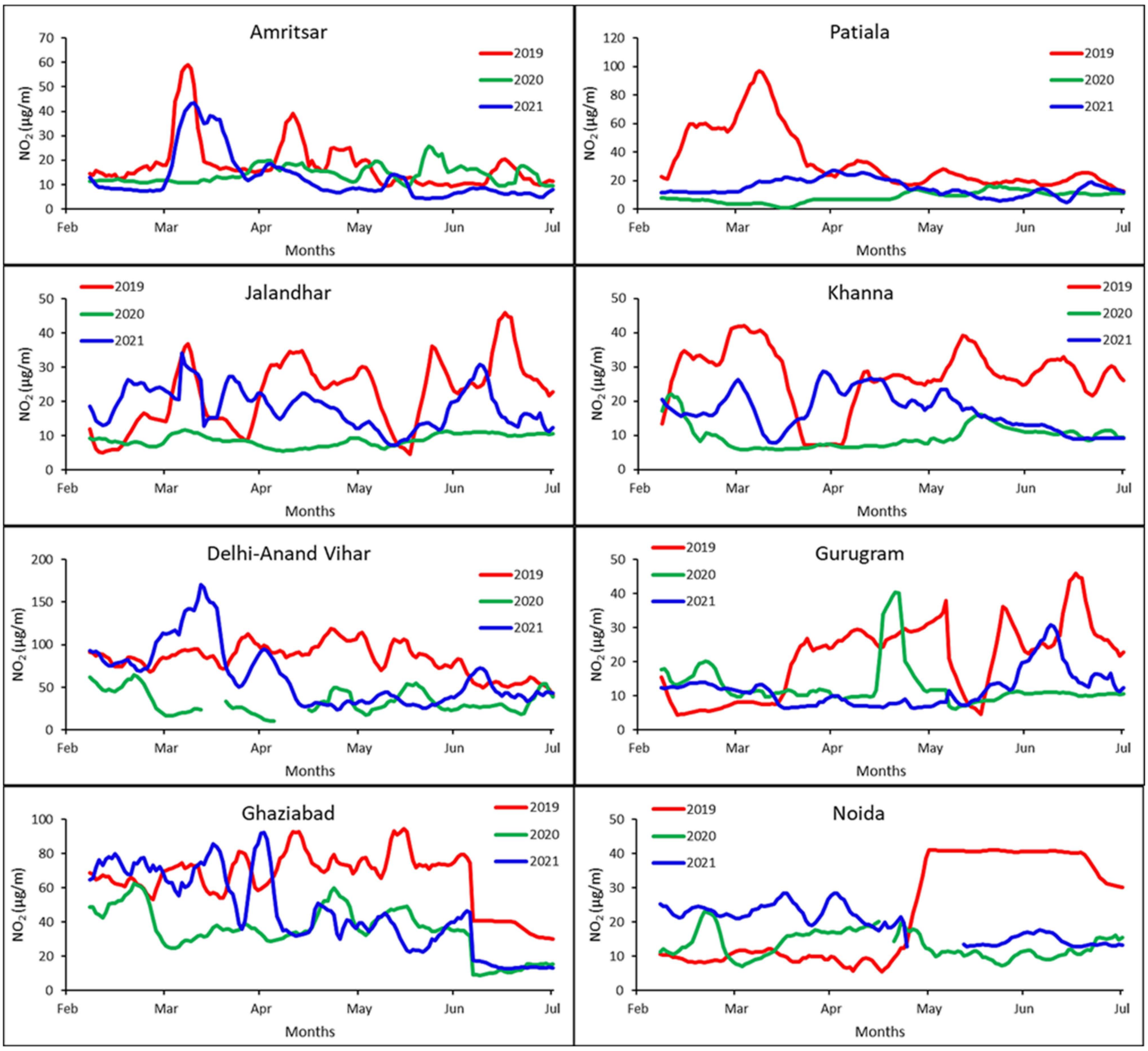

Figure 5. Ground-based NO_2 emission comparison over Amritsar, Bhatinda, Ludhiana Jalandhar, Khanna, Patiala, Delhi–Anand Vihar, Gurugram, Ghaziabad and Noida for the period of 2019 to 2021 (source: CPCB).

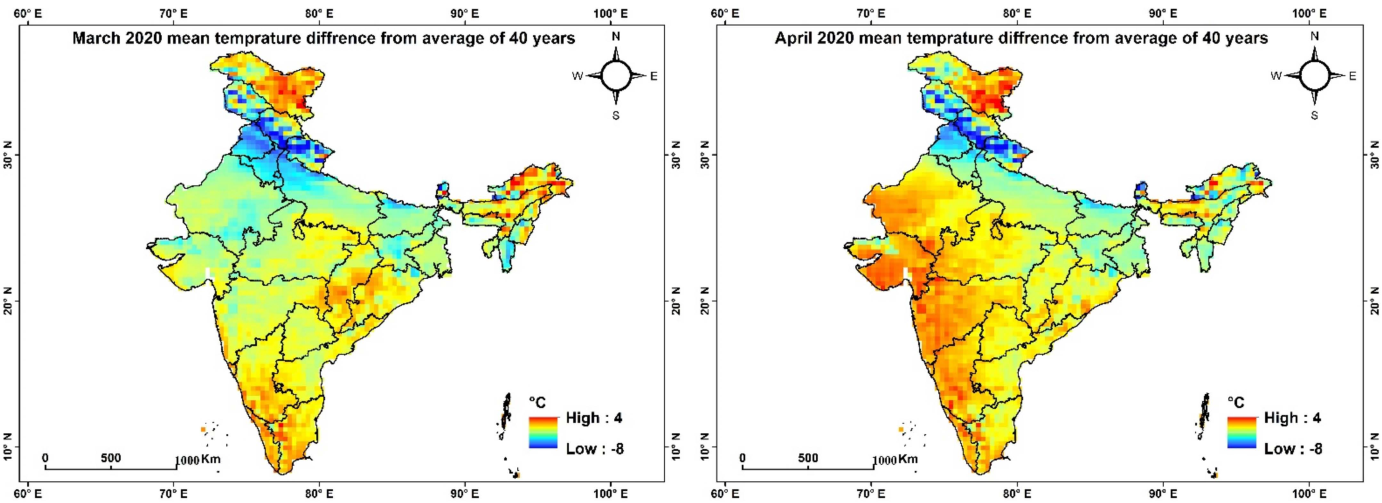

Figure 6. *Cont.*

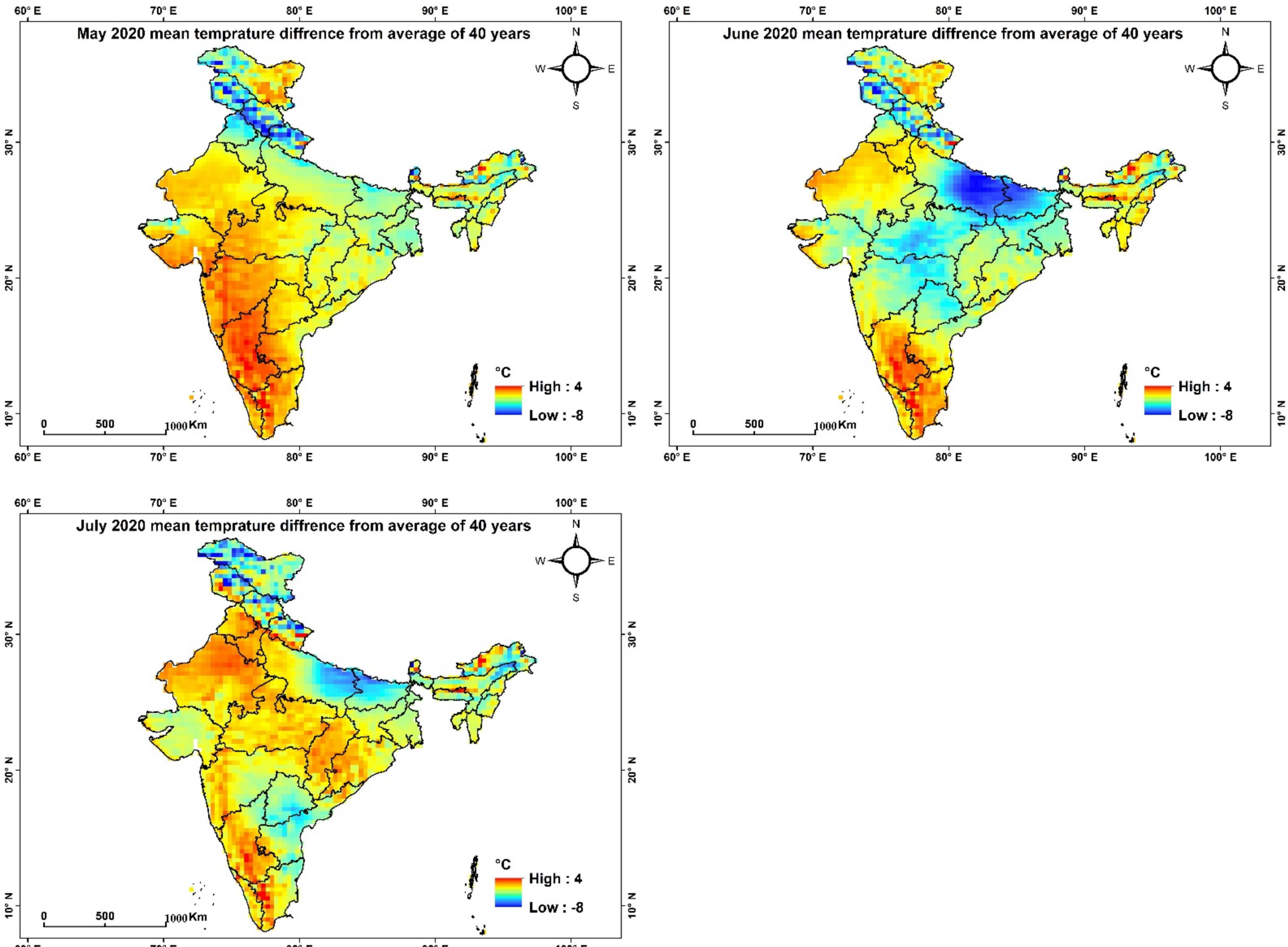

Figure 6. Mean temperature difference from the average of 40 years (1980–2020). Higher and lower values indicate increased and decreased temperatures, respectively, compared to average.

Further, during lockdowns 1–3, most of the industrial and commercial activities were suspended. Therefore, the combined effect of active western disturbances and the lockdowns may have significantly reduced the surface temperature. However, during June, the regularity of the western disturbance may have decreased—this was the time that the unlocking process had commenced, resulting in the re-starting of industrial activities. Both the reduction in the western disturbances and the re-opening of the industrial processes were probably responsible for the enhanced surface temperature. The same can be seen in Figure 6, indicating a shift towards and registering normal surface temperatures during June and July 2020.

4. Conclusions

COVID-19 has impacted normal life on the Earth's surface, with such severe impacts not seen previously in the last 100 years. Due to COVID-19 restrictions, the labor class and poor people are among the most affected due to the cessation of all economic and industrial units around the world. However, the decrease in air pollution at the cost of hunger cannot be justified. Regarding the changes in the trends of air pollution during the COVID-19 period, it is concluded that air pollution levels in the northern cities of India decreased during the forced lockdown period across the country. The lockdown appears to have caused pronounced improvements over several large, densely populated cities in the northern part of India.

Consequently, the Siwalik range of the Himalayas was clearly visible from the rooftops in Jalandhar. The improved air quality was demonstrated by in situ observations and remote sensing data as well. This study has proven the reduction in NO_2 emissions over India during the lockdown periods. A reduced surface temperature was reported during lockdown periods 1–3. It is possible that an active western disturbance and the closure of industrial and commercial activities were responsible for the reduced surface temperatures over India. Overall, the present study contributes to the understanding of the trends of the ambient air quality over large geographical areas using the Sentinel-5P satellite remote sensing data and provides important information for regulatory bodies to develop a better decision support system to improve the air quality. Monitoring of the air quality through satellite remote sensing would certainly help the local government to develop a better policy to sustain the good air quality for public health. Further, the results concluded that the NO_2 concentration was reduced during the COVID-19 pandemic significantly over the study area; we found that an 18% reduction in the average NO_2 concentration was witnessed in 2020 with respect to concentrations in 2019, and around a 19% increase in the average NO_2 concentration was observed in 2021 with respect to concentrations in 2020 during March–July, whereas a reduction of 28% in the average monthly NO_2 concentration over all cities was observed in the month of April 2020 with respect to April 2019. The study further highlights the important of Sentinel-5P satellite-based NO_2 emissions, as a path-breaking finding to determine the rate of pollution in study areas with limited physical observatories. However, in the current study, the effects of meteorological parameters on the dispersion of the NO_2 concentration were not delineated for the study periods. This limitation will be addressed in future works with an emphasis on the role of meteorological parameters in pollution dispersion over North Indian cities.

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