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Variation of tropospheric NO_2 over Indo-Gangetic plain during COVID-19 outbreak in India

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Abstract Nitrogen dioxide (NO_2) is a gaseous air pollutant which primarily gets in the air when fossil fuels such as coal, oil, gas or diesel are burned at high temperatures through industries, power plant, automobiles and locomotive. Continuous exposure to elevated concentration of NO_2 may impose development of asthma and potentially increase in susceptibility to respiratory infections in humans. The present study examined impact of lockdown due to COVID-19 in terms of spatial and temporal variation of tropospheric NO_2 in Indo-Gangetic plain. The results showed steep reduction in tropospheric NO_2 as a result of ceased industrial and economic activities. Analysis of Sentinel-5P satellite data was carried out for specific period during 2019–2020 at a regional scale and for major industrial cities. Tremendous positive impact of lockdown in atmospheric condition is observed, wherein NO_2 concentration has gone down by 20–40% in all major cities except few exceptions were noticed. The concomitant impact of Covid-19 has ensued pragmatic constructive impact on environment and climate, due to drop in NO_2 emissions.

Keywords Nitrogen dioxide · Covid-19 · Sentinel-5P · Indo-Gangetic plain

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1 Introduction

COVID-19 was initially identified as a novel virus which spreads by human to human transmission in Wuhan, China since December 2019 [1]. The size of the COVID-19 virus is speculated to be about 70–90 nm, smaller than the size of smoke and dust aerosols [2], COVID-19 infection causes severe acute respiratory syndrome in human beings and in worst cases causes' kidney failure, pneumonia, and even death [3]. On 30th January, 2020 the World Health Organization (WHO) declared international public health emergency due to novel corona virus spread (Euro surveillance Editorial Team., 2020). In February, 2020 several community outbreaks occurred in countries other than China, such as Iran, South Korea, Italy, Germany and Spain [4]. Over time COVID 19 spread vigorously across the boarders turning this epidemic into pandemic by the end of March, collapsing half of the world population under lockdown situations [5].

In the beginning of March 2020, India reported 3 cases from capital city of Delhi [6] the number swallowed exponentially in a quick time. The outbreak forced the Union Government of India to impose lockdown from March 25 to April 14, 2020 [7]. It is pertinent to mention that COVID-19 came as blessing in disguise for environment and human health because over the years due to constant emissions from fossil fuel combustion and biomass burning, local air quality was highly reduced and global troposphere column was affected over the years [8]. In fact Nitrogen Dioxide (NO_2) generated from fossil fuel combustion is also responsible for generating some harmful secondary pollutants such as Nitric Acid (HNO_3) and Ozone (O_3) [9] but Covid-19 brought a clear cut relief in the entire situation.

Nitrogen dioxide (NO_2) is one of the most important emissions in the troposphere by man-made activities it plays important role in the troposphere and in the photochemical production of O_3 [10]. Its release in atmosphere influences directly meteorological parameters of the troposphere which consecutively triggers asthma, bronchitis, pneumonia like diseases where bacteria and viruses are the most accepted causative factors that harm airway stability, driving to infection exacerbation like Covid-19 [11, 12]. In addition, since India reported as the fourth highest emitter's of NO_2 after USA, China and Brazil, NO_2 stands as a critical component of Indian atmospheric condition [13]. Positive associations between NO_2 and COVID-19 have been reported over some cities of China [14] thus, monitoring the spatial and temporal behavior of NO_2 during the lockdown phase of India over Indo Gangetic Plain was carried out to facilitate understanding of mitigation strategies during post COVID-19 normalization period.

2 Material and methods

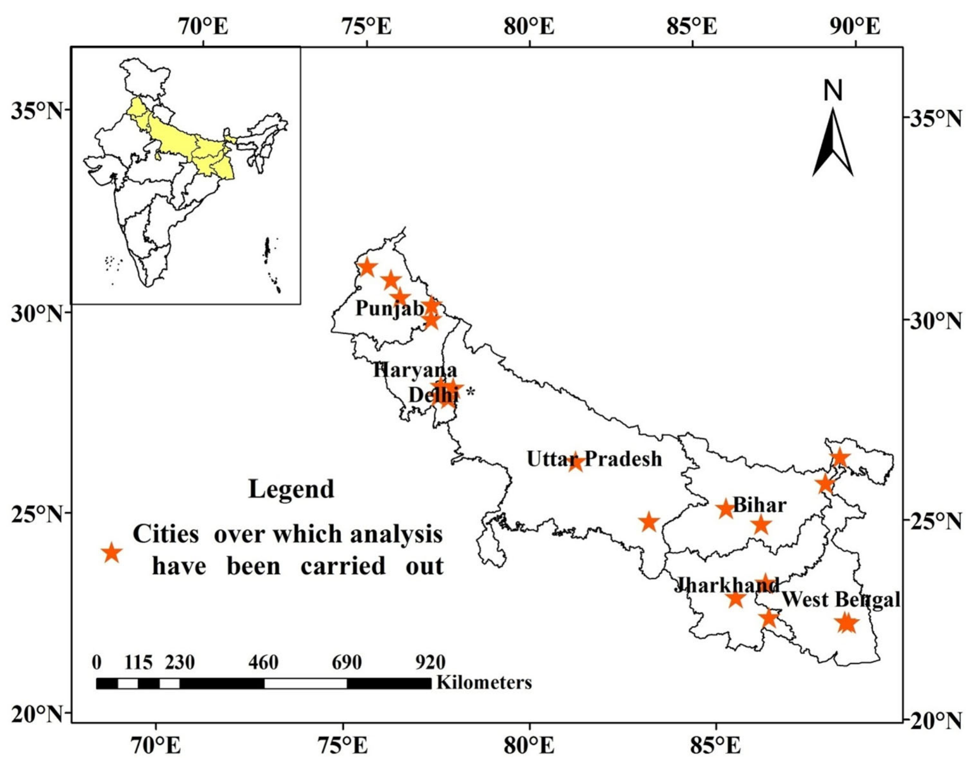
2.1 Study area

Indo-Gangetic Plain (IGP) is hub of industrial and economic activities, stretching vast from east to west in Northern part of India, this region includes seven major states and one Union Territory (Fig. 1). IGP is most productive area and supports almost half of 1.3 billion core population. This region is also climatically fragile due to decreasing trend of Ozone and relatively poor air quality was reported [15–17]. In conjunction to this, most of the blooming secondary and tertiary industrial sectors are situated in and around this region. Thus spatial and temporal spread of NO_2 was analyzed over IGP region with special emphasis on major cities in each state within the boundary of IGP during Pre-Covid 19 and during lockdown phase.

2.2 Data used

The data collected by Tropospheric Monitoring Instrument (TROPOMI) onboard Sentinel 5P of European Space Agency (ESA) was utilized for analysis and monitoring of NO_2. TROPOMI is a single payload on Sentinel 5P satellite in Sun-synchronous orbit covering the entire globe on daily basis. TROPOMI scans earth's surface with three spectrometers that covers ultraviolet-near infrared (UVN) with two spectral bands at 270–500 nm and 675–775 nm, and one spectrometer that covers the shortwave infrared. These datasets are acquired with spatial resolution of 7.5 × 7.5 km varying in across-track position and having swath of 2760 km [18].

Fig. 1 Study area



2.3 Data processing

The data set was retrieved and analyzed using Google Earth Engine (GEE) powered by Python API. Time series analysis was carried out in GEE environment in four phases:

(a) Pre-Covid Situation (01 March, 2020–24 March, 2020)
(b) Lockdown 0.1 phase (25 March, 2020–15 April, 2020)
(c) Lockdown 0.2 phase (16 April, 2020–30 April, 2020)
(d) Images for these dates were also compared with respective images of Pre-Covid-19 vintage for 2019.

Spatial and Temporal trend of NO_2 were extracted in GEE by computing mean values of each day. In addition, major industrial cities located within this area were separately compared to understand the deviation from normal standards with that of lockdown period due to ceased industrial, economic and social activities.

3 Results and discussion

3.1 NO_2 retrograde during Covid-19

Several researchers around the world have reported reduction in pollution due to Covid-19 lockdown in Italy, USA, China and Spain [19–21]. The interest around monitoring IGP region of India grew because this region has vast transport network including rail, road and airways. Additional to this it is also hot spot of some of the major Indian industrial zone (steel, coal and iron) in India. Cities within IGP makes most of the economy of the country, therefore it is one of the most busy regions consequently air pollution has been identified over this region as a critical issue impacting on public health and mortality rates over years [22]. Long-term studies have been, carried out across different Indian cities which reported persistently high values of Aerosol, PM 2.5, PM10 and NO_2 due to increase in vehicles, increase in the demand of coal-based power plants, ill monitored industrial zones, emissions from biomass burning sources and various household fuel consumption [23]. Monitoring lockdown response to COVID-19 in terms of air pollution was important as it caused an unprecedented reduction in industrial and economic activity in the region reducing tropospheric and ground-level air pollution to a considerable amount as compared to 2019 of the same period.

Satellite based image analysis indicated around 40% drop in tropospheric nitrogen dioxide (NO_2) during the lockdown period over the study area when two time frame datasets of each pixel were compared. The range of NO_2 concentration varied between >0 to 50 μmol/m^2 over this region in both the years but higher spatial variation differed in both the cases. Typical red hotspots marked high NO_2 concentration of around 50 μmol/m^2 in both 2019 and 2020 which is pre Covid-19 year and concurrent Covid-19 year over major thermal power plants located in the country. Therefore one fact is clear that air in and around thermal power plants is polluted due to rise in NO_2 level. A clear drop in NO_2 level is seen during Lock down 0.1 phase from 25 March, 2020 to 15 April, 2020 over this region. Fig.2e records reduced NO_2 concentration in the troposphere even in metropolitan cities like New Delhi and Kolkata due to complete shutdown of activities. NO_2 levels showed clear drop when compared to Fig. 2b which showed higher records of NO_2 during the same months in the previous year 2019. Fig. 2e depicts only two major bright spots in the eastern side due to the existence of the thermal power plant which were operational as essential services in the country to provide power in some of the major cities. Apart from the power plants there were some forest fires also reported in Jharkhand (17).

The lockdown 0.2 phase showed slightly higher levels of NO_2 in entire IGP region due to crop residue burning practice prevalent in the area. In conjunction to this, it was observed that the areas devoid of agricultural field activities still recorded low NO_2 emission due to shut down of industries. Fig. 2a, b, c are clear contrasting images from pre COVID-19 era where pollution is very high due to NO_2 emission. Fig 2d shows a scenario of COVID-19 in 2020 during 1st to 22nd March when it was spreading worldwide but India didn't yet announce lockdown for the entire nation, thus hotspots were still bright and prominent due to active transport and industrial activities.

Thus in totality Fig.2 gives a clear birds view of spatial and temporal variability of NO_2 in troposphere over IGP for Pre lockdown and during lockdown phases which actually proved to be a blessing in disguise. Lockdown due to COVID-19 brought much needed breakthrough in this respect, with air quality showing marked improvement in the Indo-Gangetic-Plains of India.

3.2 Temporal NO_2 emissions during Covid-19 free 2019 and infected 2020 over selected cities at local scale

3.2.1 New Delhi

New Delhi is clearly identified as a hot spot zone from Fig. 2. In Fig. 3, concentration of NO_2 over New Delhi exhibits very high with clear bright red spot stretching in most parts in pre Covid-19 era, but after 25 March, 2020 till 15 April, 2020 complete shutdown was observed under

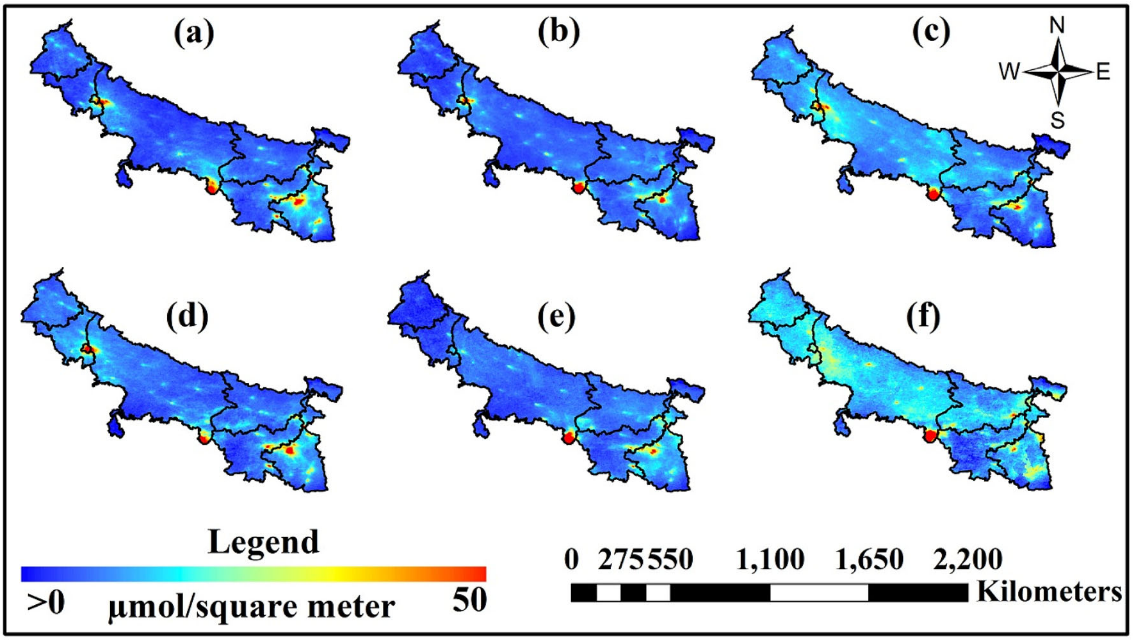


Fig. 2 Spatial and Temporal variability of NO_2 in troposphere over Indogangetic plain in Pre-COVID scenario: **a** 1st-24th March, 2019; **b** 25th March-15 April, 2019; **c** 16th April-30th April, 2019 and Concurrent COVID scenario **d** 1st-24th March, 2020; **e** 25th March-15 April, 2020; **f** 16th April-30th April, 2020

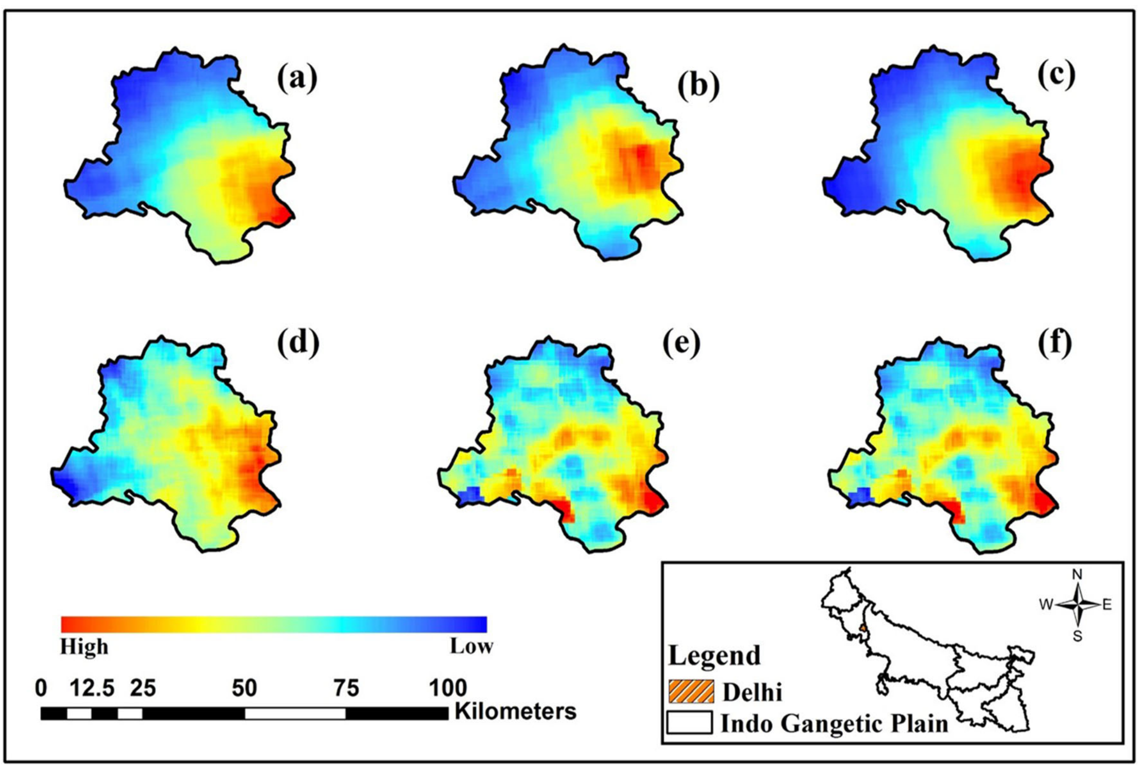


Fig. 3 Spatial and Temporal variability of NO_2 in troposphere over capital city of Delhi in Pre-COVID scenario: **a** 1st-24th March, 2019; **b** 25th March-15 April, 2019; **c** 16th April-30th April, 2019 and Concurrent COVID scenario **d** 1st-24th March, 2020; **e** 25th March-15 April, 2020; **f** 16th April-30th April, 2020

strict regulation, bringing down NO_2 levels to least and even the same pattern continued for the phase 2 lock down between 16th April to 30th April, 2020. Therefore the pattern of NO_2 emission seems to deviate from the normal pattern before covid-19.

3.2.2 Ludhiana

Ludhiana, located in the far western part of IGP, the major industrial town of Punjab state, showed downfall of NO_2 almost to a negligible level from the past year (Fig. 4) but the high concentration of NO_2 in the central part gets scattered during the lock down phases.

3.2.3 Bokaro steel city

Bokaro steel city, located in Bokaro district of Jharkhand State, has most number of thermal power plants of India (Fig. 5). The Thermal Plants in the city were operational during the lockdown to provide power supply. The city showed very high concentration of NO_2 in two patches in the central part of the city. In 2020 before lockdown also, the situation remained same but after lock down the condition comparatively improved to a great extent. In first phase of lockdown the concentration of NO_2 diminished to some extent and over time in phase two, it further improved except over the region where the Thermal Power plants are located, showing moderate NO_2 levels (Fig. 5).

3.3 State wise comparison of NO_2 emissions in major cities for Pre-COVID 2019 and concurrent COVID 2020

Long term analysis of columnar NO_2 clearly shows that urban area and areas with Thermal power plants are more affected by NO_2 emission. Three important cities in Punjab namely Amritsar, Ludhiana and Jalandhar were studied exclusively due to its population size and industrial activities. Maximum NO_2 level ranged till 20 μmol/m^2 in Pre COVID-19 era which goes remarkably down to almost an average of 13 μmol/m^2. Among these three, Ludhiana displayed maximum reduction in pollution rate. Being an industrial zone as compared to rest two cities clear atmospheric conditions were observed over it due to shut down (Fig. 6). It is to be noticed that over three cities in Punjab the NO_2 level has gradually stabilized during lockdown period from 25 March, 2020.

Haryana state is essentially an agricultural based state with some exceptionally small scale industries like automobile and textile industries. However eastern Haryana is continuously expanding with urbanization of Gurugram and Faridabad cities. Pattern in Gurugram showed

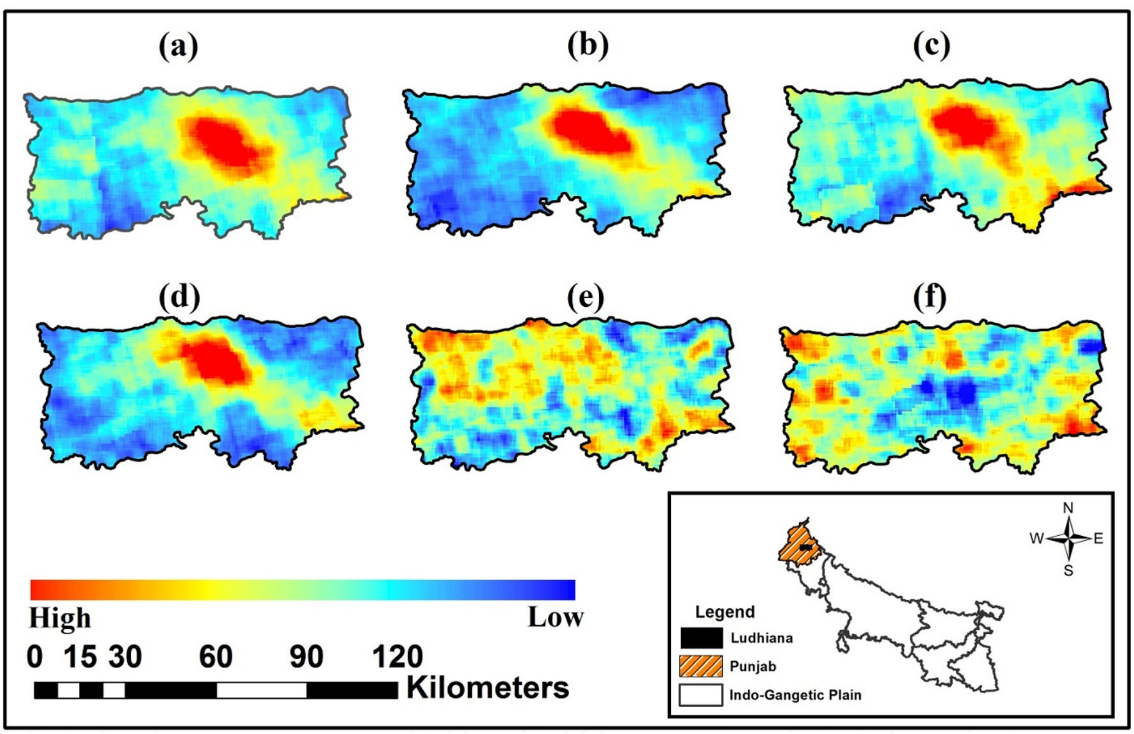


Fig. 4 Spatial and Temporal variability of NO_2 in troposphere over Ludhiana district in Pre-COVID scenario: **a** 1st-24th March, 2019; **b** 25th March-15 April, 2019; **c** 16th April-30th April, 2019 and Concurrent COVID scenario **d** 1st-24th March, 2020; **e** 25th March-15 April, 2020; **f** 16th April-30th April, 2020

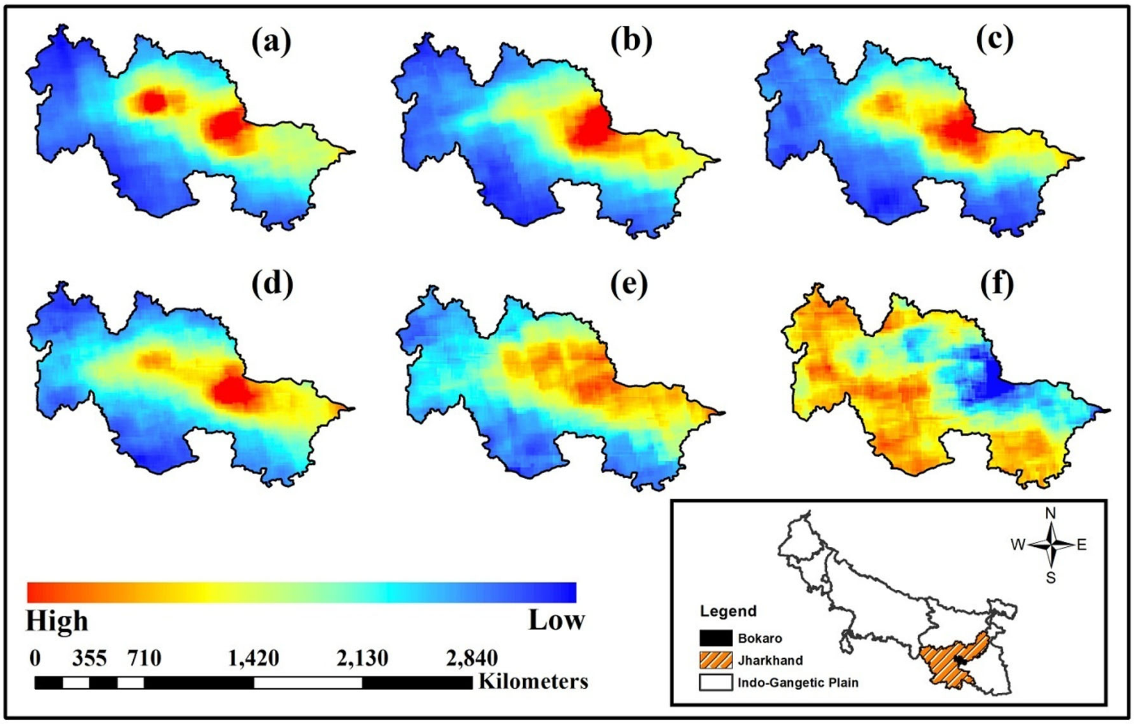


Fig. 5 Spatial and Temporal variability of NO_2 in troposphere over Bokaro district in Pre-COVID scenario: **a**1st-24th March, 2019; **b** 25th March-15 April, 2019; **c** 16th April-30th April, 2019 and Concurrent COVID scenario **d** 1st-24th March, 2020; **e** 25th March-15 April, 2020; **f** 16th April-30th April, 2020

remarkable changes due to shutdown of the three major power plants like the NBRC, RGTPS, IGSTPP power plant. In Haryana, the average temporal spread of NO_2 in the lockdown phase was around 12 µmol/m^2 in almost all the three cities (Fig. 7). However Ambala city showed large changes but much variation was not observed from 2019. In Faridabad city, again the pattern showed that NO_2 density was much more stabilized in the troposphere during the lockdown phase apart from lowering of NO_2 levels above this city.

New Delhi being the capital city of India, records higher industrial units and traffic, it displayed very high density of NO_2 in the troposphere for the pre COVID-19 period but it recorded as high as 26 µmol/m^2 in average but during lockdown phase 0.1 and 0.2, the emission curve was totally flattened and became stable (Fig. 8). On the other hand, Chandigarh, a planned city which has mainly government buildings and residential area, does not show much variation in pattern from pre COVID-19 phase to concurrent COVID-19 phase as it is so called non-polluted city because it is well planned and maintained with proper greenery.

Benaras, Lucknow and Ghaziabad from Uttar Pradesh State were chosen to study the NO_2 distribution. Benaras in eastern Uttar Pradesh is a popular place of tourist attraction in India, with not much of industrial resources therefore fluctuation in pollution was not observed during entire lockdown period. On the other hand Lucknow the capital city of Uttar Pradesh depicted a different pattern because it has more of industrialization around its periphery and it's a capital city. The pattern clearly showed reduction in NO_2 concentration as well as stabilization over the period (Fig. 9). The average NO_2 concentration over this period remained less than 10 µmol/m^2 where as in pre COVID phase the average was higher than 10 µmol/m^2. On contrary, Ghaziabad showed a complete difference in NO_2 concentration pattern being a highly industrial city and influenced by Delhi due to its close proximity. In this region, average NO_2 was greater than 20 µmol/m^2 where as during lockdown period the level of NO_2 concentration reduced to an average of 14 µmol/m^2.

Patna being capital of Bihar State is comparatively a bigger city and has some major industrial units like leather industry, manufacturing of transport equipment, chemical and tobacco. Therefore lockdown showed a still in the pattern of NO_2 release. Some peaks of NO_2 release have been observed in the graph of Patna in 2019 but during lockdown phase it stabilized and average NO_2 release was less than 10 µmol/m^2. Further estimations were observed over Lakhisharai which is very scantly industrialized area with some iron rod and rice mill industries (Fig. 10). This region showed no such difference during pre and post lockdown periods.

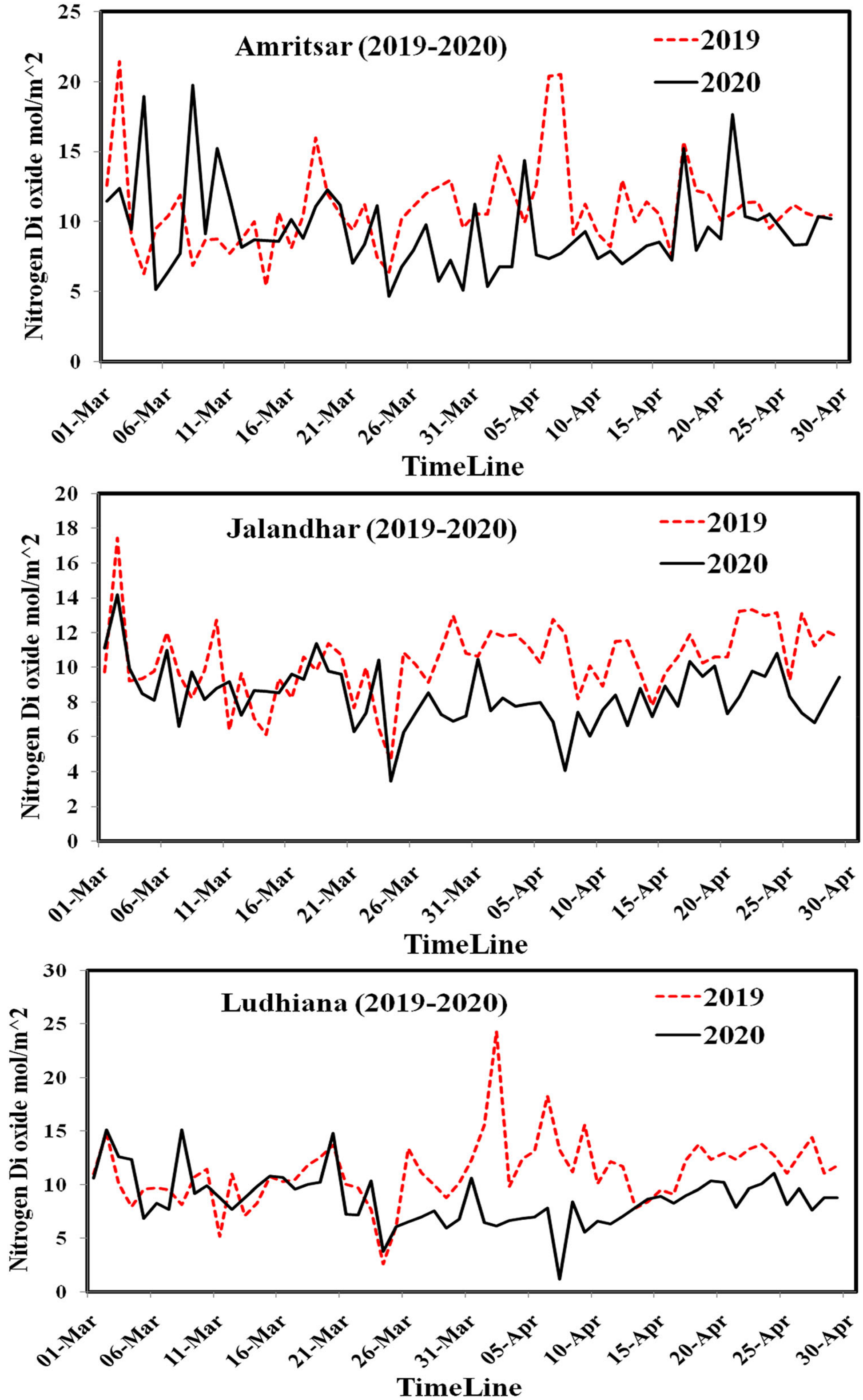


Fig. 6 Temporal distribution of NO_2 over major cities of Punjab

The distribution of NO_2 remained same during both the periods. Kishanganj a city in the northern part of Bihar also showed no such difference in the pattern of NO_2 distribution. The city is pollution free and is situated in the foothills of Himalayas.

Jharkhand state has a complete industrial driven economy; it is power house of most of the mineral resources and

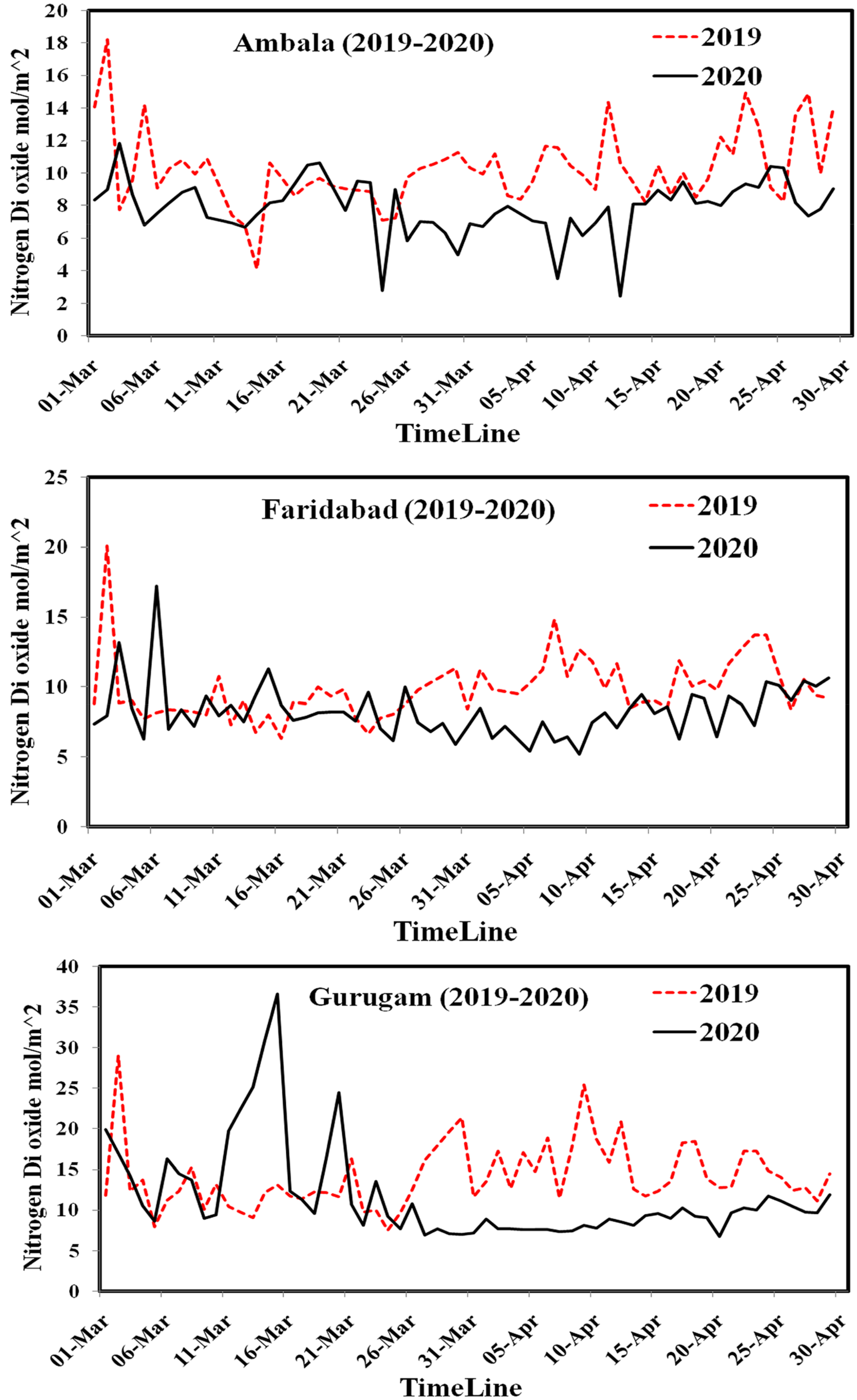


Fig. 7 Temporal distribution of NO_2 over major cities of Haryana

famous for mining activities. Jamshedpur, Ranchi and Bokaro steel city were selected. All these three cities have thermal power plants in conjunction to iron and steel plants which form the major industrial backbone of India. Therefore NO_2 concentration was comparatively high in these regions in post lock down phase. But in contrast

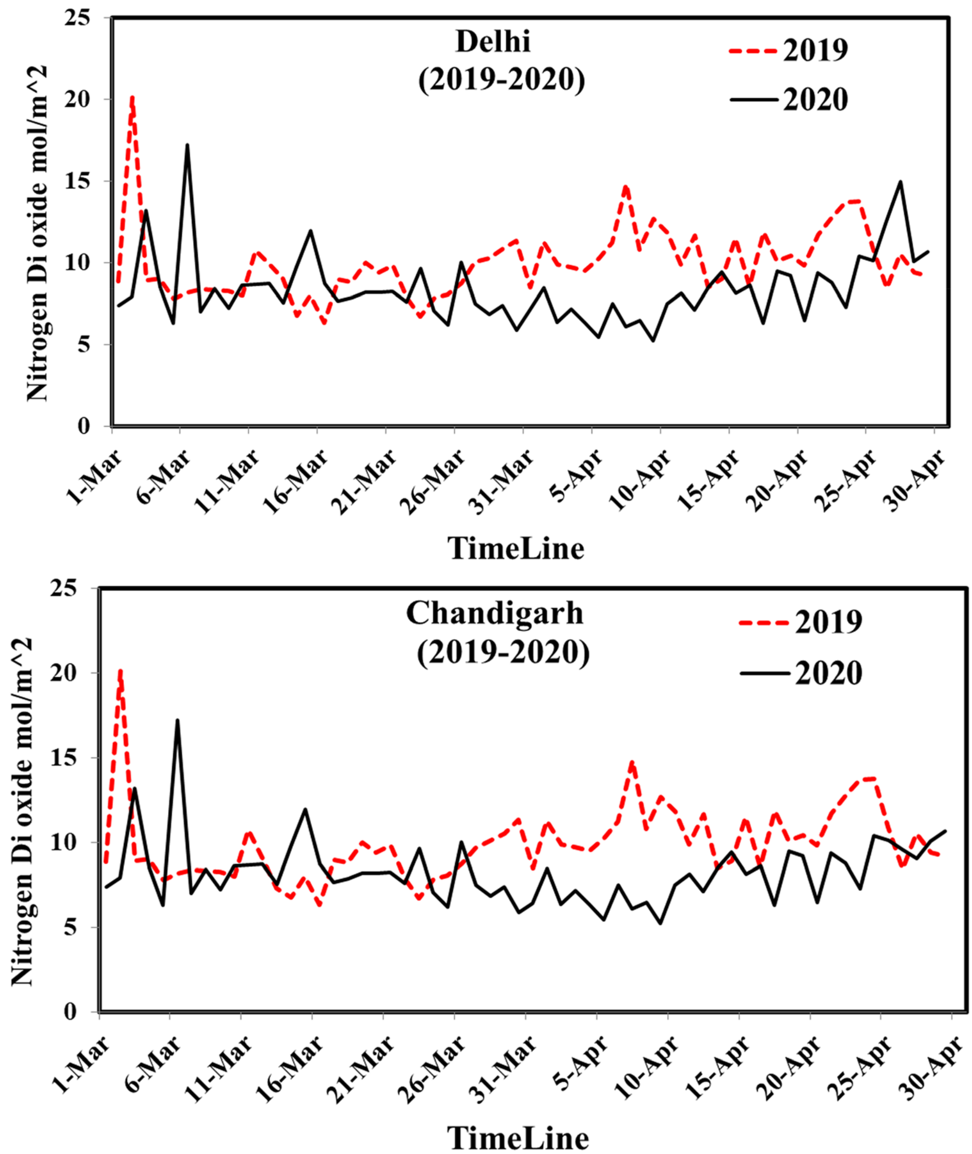


Fig. 8 Temporal distribution of NO_2 over Delhi and Chandigarh

Jamshedpur and Ranchi in the lockdown period showed some stabilization level and an average of 2 μmol/m^2 was observed Bokaro steel city showed no change in pattern in pre and concurrent lockdown phase because Thermal Plants in this city were operational for power supply (Fig. 11).

Kolkata being the gateway of North East and capital city of West Bengal is highly polluted. NO_2 concentration over pre COVID and concurrent COVID phase in 2020 remained almost same around an average of 13 μmol/m^2, thus indicating proper lockdown was perhaps not followed. Howrah which is a small industrial town, showed change in NO_2 concentration levels. The average in 2019 was around 12 μmol/m^2 and in 2020 this came down to below 10 μmol/m^^{2} (Fig. 12). Siliguri, a small city in foothills of Himalaya has showed a major drop of NO_2 concentration in comparison to 2019 average of 10 μmol/m^2 was observed during lockdown period in the year 2020, the average NO_2 concentration was stabilized to an average of 8 μmol/m^2 are observed.

4 Conclusion

The concentration of the tropospheric NO_2 were explored over IGP in India using the Sentinel-5P satellite data in order to understand its spatial and temporal variation due to lockdown as a result of COVID-19, which out of all disguise proved to be a blessing for the environment and human health. Concurrent lockdown and pre lockdown situation clearly showed improvement (fall) in NO_2 concentration in majority of cites in IGP of India. Lockdown

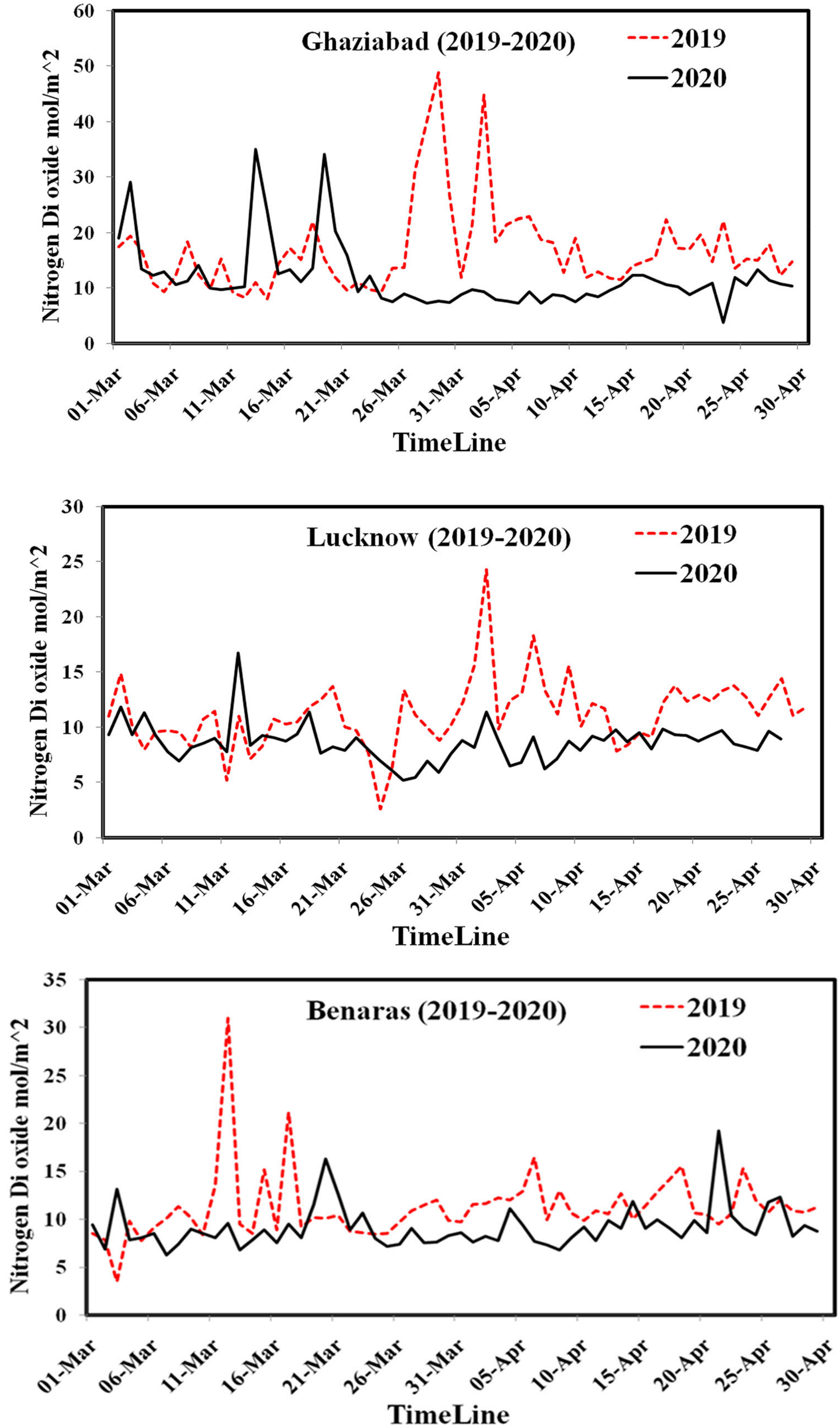
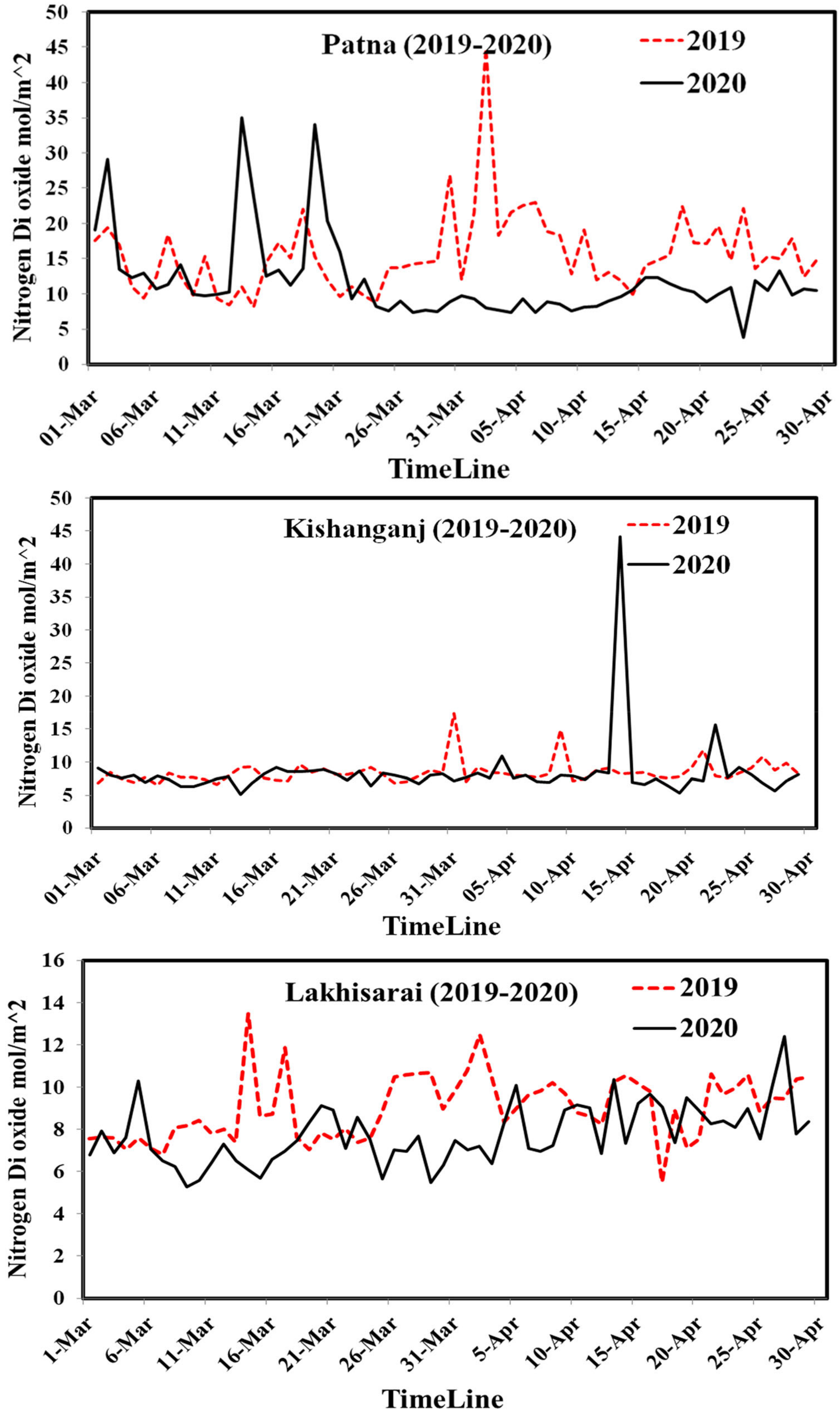


Fig. 9 Temporal distribution of NO_2 over major cities of Uttar Pradesh

Fig. 10 Temporal distribution of NO_2 over major cities of Bihar



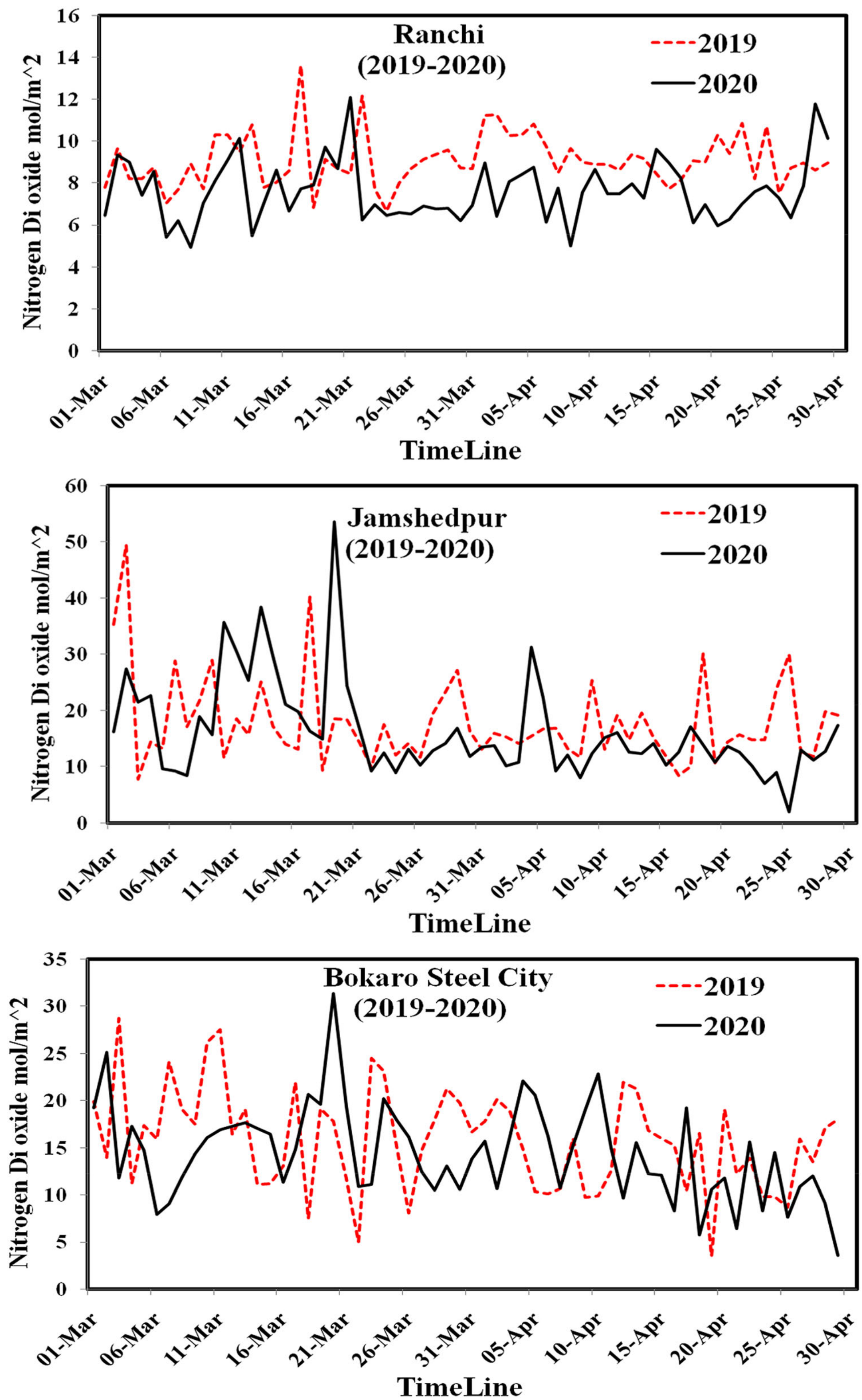


Fig. 11 Temporal distribution of NO_2 over major cities of Jharkhand

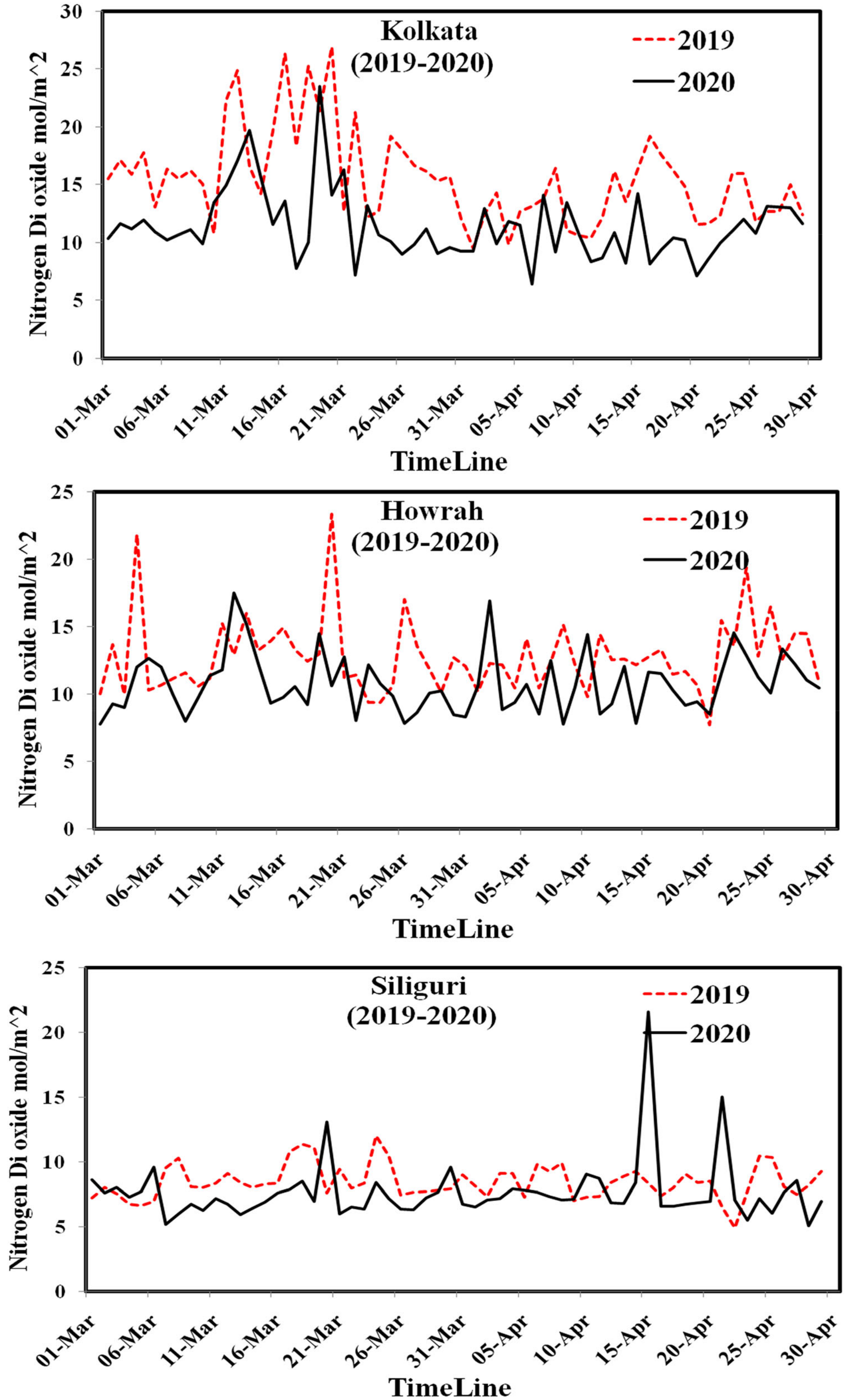


Fig. 12 Temporal distribution of NO_2 over major cities of West Bengal

of major industrial, economic and transport activities has brought Indian economy to a great shock, but environment in most of the spaces displayed a big revival over this period because pollution level were brought down to least possible level. The major take away from this study is that the fight against Covid-19 in form of lockdowns has brought back our own space in terms of vastly improved climate and environment. Once the country takes grip of Covid-19, better implementation of regulations in terms of environment will be required to continue with the same.

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Data availability All datasets used in this study are freely available in the ESA data hub.

Code availability Code composed in GEE environment will be available on request to the corresponding author.

Declarations

Conflict of interest There is no conflict of interest regarding the paper submitted. Freely available datasets have been used for computation of the results therefore there is no conflict with other parties.

Consent to participate The authors (Koyel Sur, Vipan Kumar Verma and Brijendra Pateriya) of this article have verified that this article is original and that it does not violate any other publisher's rights nor does it contain matters that may disgrace or invade privacy.

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