Unprecedented reduction in airborne aerosol particles and nitrogen dioxide level in response to COVID-19 pandemic lockdown over the Indo-Pak region

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Key Points:

- Whole of the World is under some sort of lockdown due to COVID-19.
- Controlled emissions from fossil fuels have improved the environmental pollutions.
- Huge drop in AOD ~ 45 % has foreseen over northern Indo-Pak Gangetic Plain
- NO_2 emission has also declined to 40-50 % after the national lockdown in Indo-Pak.
- Strong correlation exists between drop in AOD and NO_2 level.
- Satellites observations have strong capability to capture the environmental phenomena's over the Earth's planet.

Abstract

The present study have used space observations of NO_2 emission (OMI) and aerosol optical depth (AOD) (MODIS) from the last couple of years (2015-2019) to investigate the changes in air pollution in response to COVID-19 pandemic during the lockdown period (Mar-May, 2020) over the Indo-Pak region. Result of this study reveals a huge drop in air pollution that accounted for 40-50% reduction in NO_2 emissions and 45% in AOD over the whole Indo-Pak region. The major metropolitan areas (cities) of the region showed a remarkable decrease in NO_2 emissions, whereas the calculated rate of reduction was found highest for the city of Lahore (Pak) ranges between 29-52% followed by Ahmadabad (Chennai) as 27-52% (32-42%) respectively. The geospatial analysis revealed the existence of positive correlation (range from 0.23-0.50) between AOD and NO_2 emissions, which further implies that a decrease in AOD may be attributed to reduction in NO_2 to some extents.

Keywords: COVID-19; lockdown; NO_2 emission; aerosol optical depth; Ozone Monitoring Instrument (OMI)

Plain Language Summary

After an outbreak of novel infectious disease (COVID-19) which started at the end of 2019, later on it turned into a global pandemic and spread across 212 countries over the world. Many countries across the World went to strict lockdown measures which have been implemented by government authorities to reduce the further spread of disease infections. It has severely posed negative impacts on the social, human health and economic fronts, but on other way it also proven that strict quarantine measures and lockdown activities has resulted in recovery of environmental pollution. Huge drop in air pollution has been accounted as 40-50% in NO2 emission and 45 % in aerosol particle thickness over the whole Indo-Pak region. Moreover, all the major cities across the region also have shown substential reduction in NO2 emission duing strick lockdown measures.

1. Introduction

The observed changes in the global climate system indicate enormous threats to anthropoid, farming, nature, bionetwork, and eco-environment (Hussain et al., 2020; Hussain et al., 2019; Iqbal et al., 2018b; Malik et al., 2020; Salam et al., 2020). Moreover, human activities and daily demands are increasing continuously with fast growing world population, subsequently threating to the Earth's planet (Iqbal et al., 2018a; Iqbal et al., 2019). Indo-Pak region geographically located in South Central Asia and mainly comprises of two main countries, Pakistan and India. The two countries have ranked closely as developing countries in the last couple of years (Gul, 2009) and still these countries are using low quality fuel in transportation and in manufacturing industries due to lack of developed technologies (Dhar and Shukla, 2015; Fullerton et al., 2008; Gordon et al., 2014; Wang and Hao, 2012). Transportation and industrial activities in Manchester cities of India (i.e., Ahmedabad) and Pakistan (i.e., Faisalabad) along with other metropolitans are the major sources of anthropogenic emissions, resulting in environmental pollution (Farooqi et al., 2020; Niaz et al., 2015; Qadeer et al., 2020). According to real-time standard air quality index (US-EPA 2016 standard), Bangladesh country accounted as rank 1st in the list of most polluted countries followed by Pakistan (2nd), and India (ranked 5th). In the list of World most polluted cities, most of the top 30 polluted cities come across the South Asia especially in India, Pakistan and China (Beig et al., 2020; Conticini et al., 2020; Gao et al., 2020; Maji, 2020; Mathur et al., 2020; Yousefian and Nadafi, 2020). The reasons behind the air pollution across these countries is not limited to only low literacy rate, lack of awareness, dense population, and industrial activities, but also the use of low quality fuel, burning of waste material and less use of advance recycling technologies (Kannan et al., 2020; Patel et al., 2020). Nitrogen Dioxide (NO_2) is mainly emitted from anthropogenic emissions e.g., fuel combustion in traffic and industrial sectors are the main source of NO_2 emission. Lippmann and Leikauf, (2020) reported that, human exposure in excessive NO_2 environment for long and short term might surge the impermanence rate. Shang et al., (2020) and Yang et al., (2020) revealed that environment polluted with excess NO_2 may cause cellular inflammation, severe respiratory problem and bronchial hyper responsiveness. WHO reported that every year more than 4.62 million people died globally due to poor air quality standards. Similarly aerosol particles not only directly induced from anthropogenic and natural sources, but are also formed through various physic-chemical processes in the atmosphere (Seinfeld and Pandis, 2016). Majority of the aerosols formed in Indo-Pak regions are associated with anthropogenic emissions such as vehicles, coal-fired power plants, industrial sources, burning in agriculture farms (Guo et al., 2017). Several legislations have been implemented over the past several years to reduce the air pollution, however the current air pollution level is still exceeding the WHO Air Quality standards over most major metropolitan cities.

However, an outbreak of COVID-19 which starts in late Dec, 2019 and later on it spreads quickly to many other countries (212 countries and territories) over the world and turned into global pandemic (Ferretti et al., 2020; Givi et al., 2020; Mittal et al., 2020; Organization, 2020; Rana et al., 2020). After observing the situation about COVID-19, the World Health Organization (WHO) declared health emergency on January 30, 2020 worldwide (Sohrabi et al., 2020). Many countries started to follow the precautionary measurses, while with the implementation of lockdown situation the major human activities e.g., culture and education and industrial manufacturing sectors were constrained globally (NASA, 2020; Tosepu et al., 2020) to prevent the further spread of COVID-19 (Narayanan and Saha, 2020; Paital et al., 2020). In a lock down situation, transport, industrial and manufacturing sectors were effected badly and demand of fuel is reduced drastically, which cut down the oil prices sharply (Devi, 2020; Fernandes, 2020). No doubt, the strict lockdown measures have severely posed negative impacts on the social, human health and economic fronts globally (ESA, 2020), but on other way, positive affections were also observed in the reduction of air pollution (Wright, 2020). For example, Ozone Monitoring Instrument (OMI) and Tropospheric Monitoring Instrument (TROPOMI) were recently launched to monitor the real-time air pollution across the globe, and the observations revealed a significant reduction in airborne aerosol optical depth (AOD), nitrogen dioxide (NO_2) and PM2.5 concentrations coinciding with the strict quarantine measures (Muhammad et al., 2020; Timmermann et al., 2020). So there is an important need to quantify the effects of reduced regional anthropogenic aerosol emissions as well as NO_2 emissions over the Indo-Pak region during COVID-19 epidemic lockdown.

This study made an attempt to to investigate the changes in anthropogenic aerosol emissions as well as NO_2 emissions in response to COVID-19 pandemic lockdown across the Indo-Pak region. Tropospheric NO_2 data was taken from multi missions Ozone Monitoring Instrument (OMI)) and aerosol optical depth (AOD) from The Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra sensor from Jan-May (2020) and compared with past several years avegage (2015-2019) for same time frame. The Indo-Pak region is geographically located in South Central Asia and mainly comprises of two main countries, Pakistan and India (**Figure S1**). In total, five main cities, Karachi (Pak), Lahore, (Pak), New Delhi (IND), Ahmadabad (IND) and Chennai (IND) are chosen for this study to investigate the changes in air pollution during COVID-19 pandemic situation**.**

3. Data collecton and methodology

Satellites in space provide global observations of air pollutants, i.e. aerosol optical depth (AOD) and tropospheric NO_2 emissions for air quality monitoring over the Earth's planet. The Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra and Aqua satellites provides dataset to monitor aerosol optical depth and size distribution of the ambient aerosol. In this study latest record of daily aerosol optical depth (MOD08_D3) at 550 nm (AOD) of MODIS aboard NASA's Terra sensor was acquired at 1° × 1° (Platnick et al., 2015). Ozone Monitoring Instrument (OMI) onboard the NASA Aura satellite provides the NO_2 column density and available from Oct, 2004 to present. In this study, daily average tropospheric NO_2

(OMNO2d.003) data was used due to improved algorithms and sensitivity of OMI for NO_2 detection at lower atmosphere. The tropospheric NO_2 columns are retrieved from satellite observations based the differential optical absorption spectroscopy (DOAS) technique within 405-465 nm (Eskes et al., 2003; Van et al., 2020). Moreover, detailed description about the DOAS analysis and algorithm, data filtering, and quality control methods is available at https://earthdata.nasa.gov/.

Daily tropospheric NO_2 and AOD data over the Indo-Pak regions was processed using NASA Giovanni user interface publically available at https://giovanni.gsfc.nasa.gov/giovanni/. Giovanni is a web application that provides a simple, intuitive way to visualize, analyze, and access earth science remote sensing data, particularly from satellites. Maps of NO_2 and AOD were made from daily gridded data (Mar-May) averaged over the past years 2015-2019 and compared with 2020 (befor and after lockdown). Anomaly changes in tropospheric NO_2 and AOD were computed by mean of absolute difference (average over past years minus (-) 2020). In order to investigate the tropospheric NO_2 variations over major cities, time-series plots of tropospheric NO_2 were made by means of the 15-days average over the 1^o x 1^o grid box drawn around the cities. NO_2 data from OMI sensor, over the major cities was extracted from NASA, Goddard Space Flight Center (https://so2.gsfc.nasa.gov/no2/no2_index.html). Moreover, recent imageries of NO_2 and AOD released by NASA were also used to investigate the variations in air pollution before and after lockdown period across the Indo-Pak region. Mobility trend of different human activities was tracked from Google reports from Mar-May 2020 to understand the anthropogenic changes caused by pandemic lockdown. **Table S1** describes the detail of datasets used in this study. Geospatial statistical correlation between AOD and NO_2 was also analyzed in ArcGIS to highlight the impacts of air pollution on aerosol optical depth.

4. Results and Discussion

4.1 COVID-19 and lockdown scenarios in Indo-Pak

Outbreak of COVID-19 started in India and Pakistan after 15 March and few cases were detected but after 1st April, 2020, COVID-19 spread with faster rate over the Indo-Pak (Pakistan and India). Daily time series of COVID-19 cases, number of death and recovered since the epidemic began, as well as the mobility index of different human activities over the Indo-Pak region is being explained in **Figure 1.** (WHO, 2020). Until now, the number of case has reached to > 85,000 (Pakistan) and > 212,999 (India) until 4th June, 2020 (WHO) (**Figure 1a**). All activities including transport, industries, social places and educational sectors were running normally until 27 Mar 2020, but after situation getting worse Government authorities in both countries declared stick lockdown for citizens and stopped all human activities to minimize the fast transmission of the COVID-19. The mobility index data of different human activities (Retail/recreations, grocery/ pharmacy, work places, transit stations and residential) clearly indicated that after stick lockdown measures the mobility trends of human activates e.g., retail and recreations trend has reduced to 80-90 % over India and 60-70 % over Pakistan, while the trend in residential has gradually increased by 30-35 % over India and 25-28 % over Pakistan (**Figure 1b**). Mobility trend at work places (industries, colleges and social places) as well as public transport has also reduced with a great magnitude since the epidemic began.

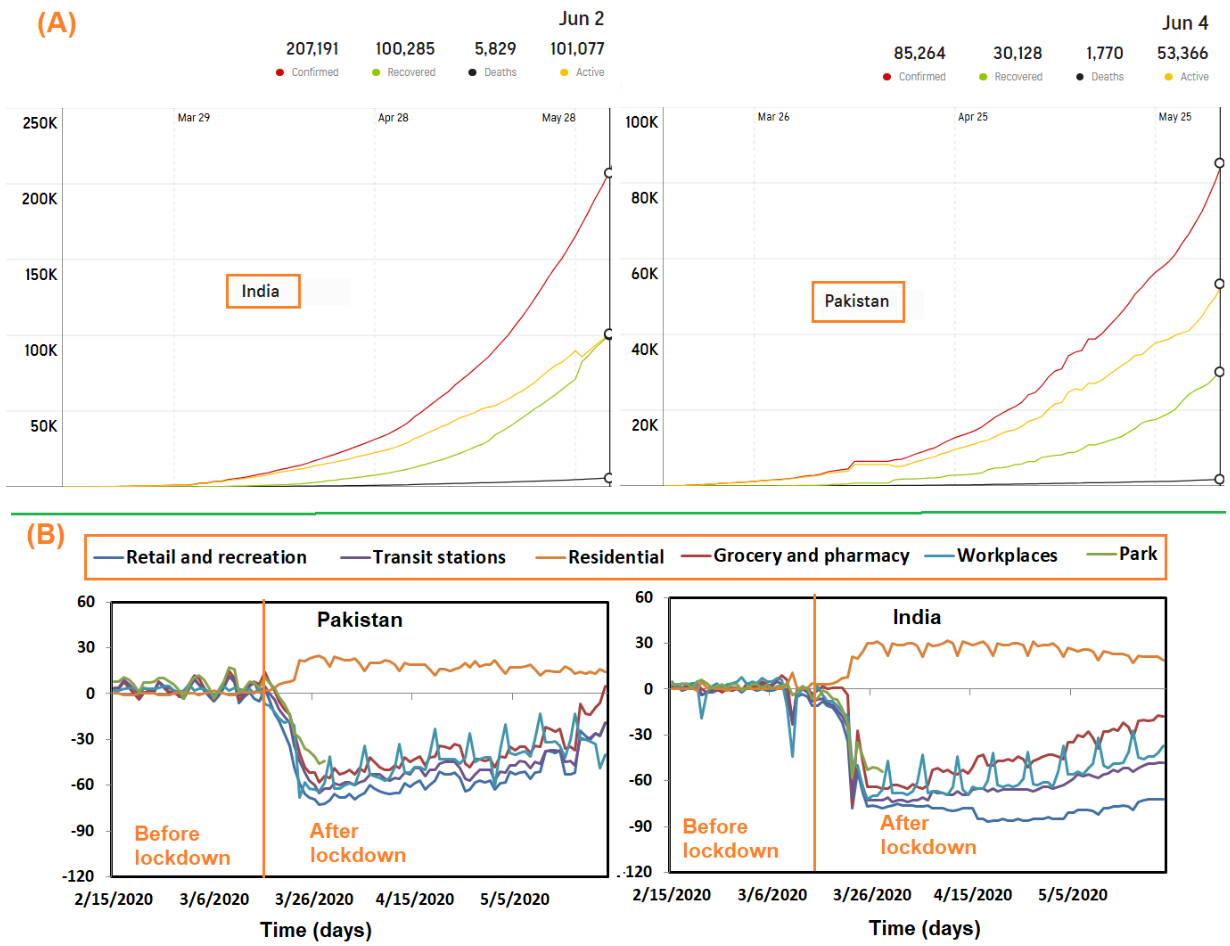


Figure 1. Daily time series of (a) COVID-19 cases, number of death and recovered, and (b) Mobility index of different human activities over the Indo-Pak region since the epidemic began.

4.2 Tropospheric NO_2 changes over Indo-Pak

Strict lockdown measures adapted during the COVID-19 epidemic have decreased the power generation, energy consumption and lower the oil demand and consequently have posed significant positive implications on ecosystem (Sulaman et al., 2020). **Figure 2a** illustrated the variations in monthly NO_2 emissions during 2020 lockdown compared to past years' average (2015-2019) over Indo-Pak region. The images in the 1st column show the NO_2 emission (Mar-May) averaged over baseline 2015-2019; images in 2^{nd} column show the NO_2 emission (Mar-May) during 2020 lockdown while images in 3^{rd} column show anomaly changes in 2020 with respect to baseline period 2015-2019. It was seen that value NO_2 emissions were much higher in Mar, 2020 over the East Indian region as ~ 15×10^{15} molecules/cm^2 comperative to baseline period. However NO_2 level has reduced to greater extend in 2020 lockdown especially from Apr-May compared to baseline 2015-2019 (Apr-May). Moreover, **Figure 2b** shown the time series of daily NO_2 emissions extracted during 2020 (before and after lockdown) and compared with baseline period (2015-2019) over Indo-Pak. It was observed that running mean of NO_2 value during 1Jan-20Mar, 2020 (before lockdown) is coinciding in fluctuation trend with average time series of 2015-2019. While during lockdown (20 Mar – 30 Apr, 2020), time series of mean

NO_2 emission over the Indo-Pak is moving with lower running mean value compared to 2015-2019.

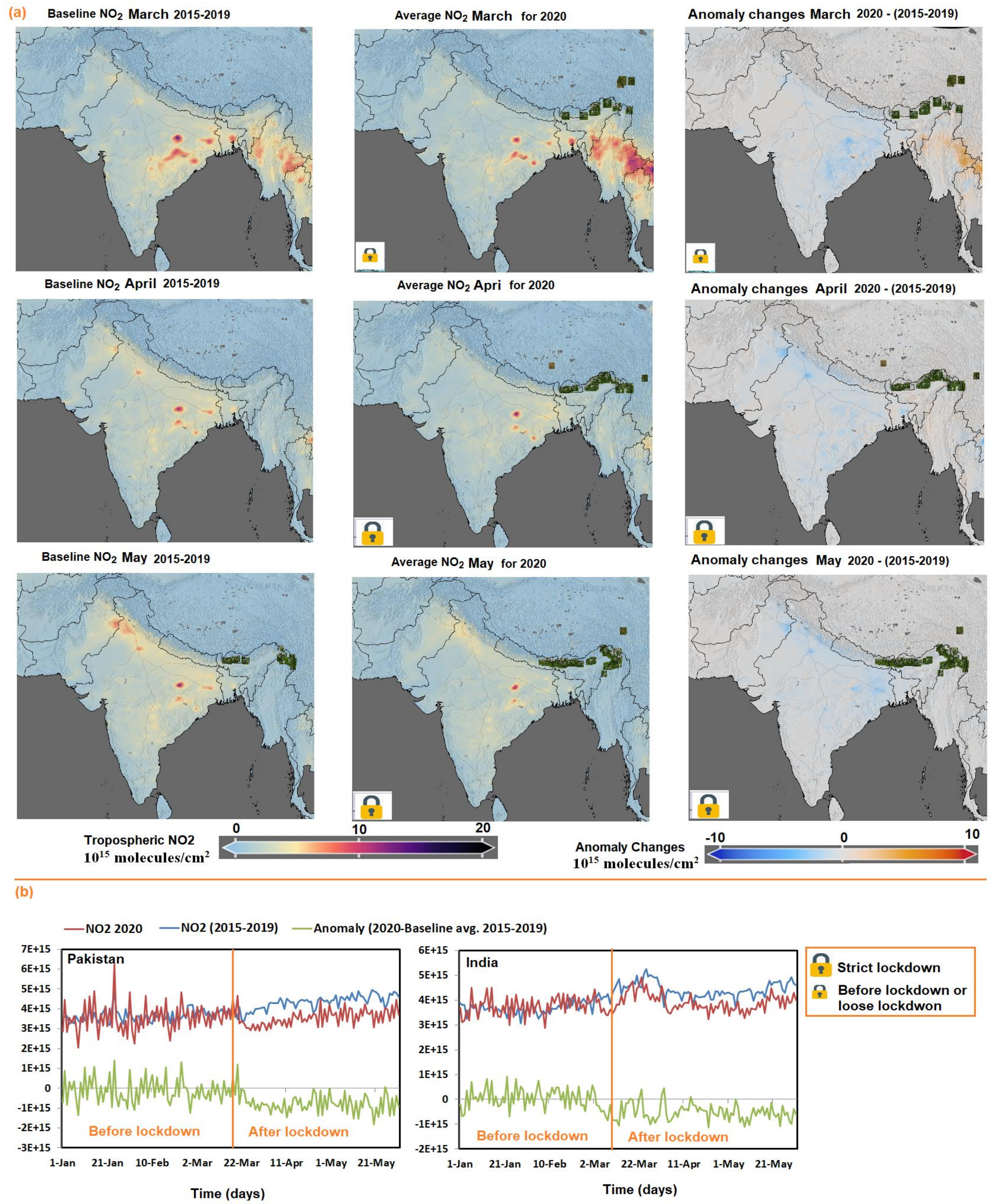
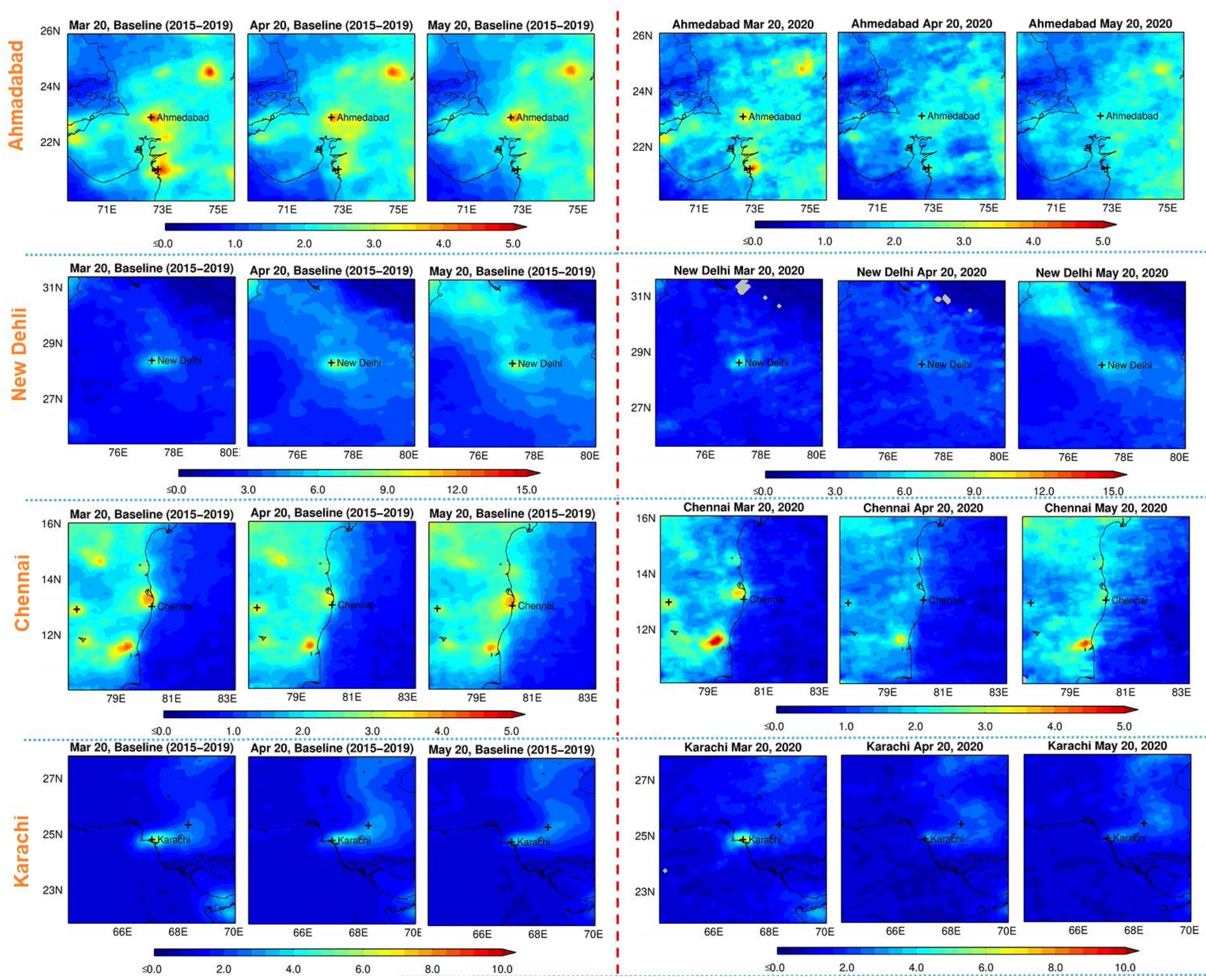


Figure 2. Variations in troposphere NO2 level (a) monthly tropospheric NO2 in 2020 compared to past years' average (2015-2019), and (b) daily time series of NO2 in 2020 compared to past

years' average (2015-2019) over India and Pakistan in 2020 : (NO_2 level represents in **10^{15} molecules/cm^2**).

From **Figure 2b**, it was also seen that anomaly changes in NO_2 emission during Jan-Mar 2020 (before lockdown) showing positive trend indicating the high emissions from industrial and transport activities compared to past years. While anomaly changes in NO_2 emission during Mar-May 2020 (after lockdown) showing negative trend after strict lockdown measures due to reduction in industrial and transport emissions. New satellite images released by the European Union Copernicus programme from the Copernicus Sentinel-5P satellite, also revealed that NO_2 emission has dropped ~40–50% in Mar- Apr 2020 compared to same time-frame in last year over the Indo-Pak (ESA, 2020). Recent improvements in air quality are associated with less consumption of fossil fuels during strict quarantine measures adapted across the countries (ESA, 2020; Wang and Su, 2020). Sharma et al., (2020) also reported that NO_2 emission has dropped over the India during Mar-Apr 2020 compared to past years average due to restricted emission from anthropogenic activities. Air Quality Space Observation Laboratory from NASA reported that the power generation over Indo-Pak region has reduced to 10-25% during pandemic lockdown period compared to past years in the same time frame (NASA, 2020).



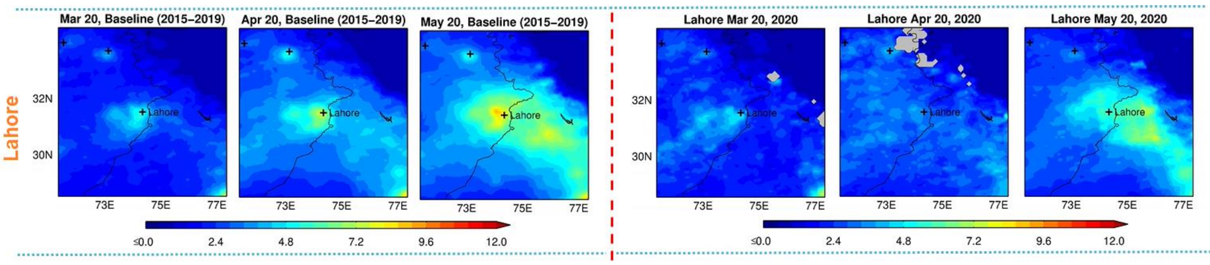


Figure 3. Changes in NO_2 emission in Apr, 2020 compared to the average of baseline 2015-2019 over the five major cities in Indo-Pak region: (NO_2 level represents in 10^{15} molecules/cm^2).

Moreover this study, also analyzed spatio-temporal variations of NO_2 emission from Mar-May, 2020 compared to the average of same time-frame in baseline period (2015-2019) over the five main cities (Karachi, Lahore, New Delhi, Ahmadabad, and Chennai) in Indo-Pak (**Figure 3**). images displayed in first three columns illustrate the NO_2 emission in baseline period (2015-2019) for Mar, Apr and May while next three columns illustrate the images for 2020 during Mar, Apr and May. Evidence from these data indicates dramatic reduction in NO_2 emission during 2020 especially during the strict lockdown (Apr-May) when compared with baseline data over all cities. For example, NO_2 emission over the New Ahmadabad (IND) was ~5×10^{15} molecules/cm^2 during Mar-May in past years average (2015-2019) while it has dropped to < 2.5 $\times10^{15}$ molecules/cm^2 in 2020 (**Figure 3**). The updated evidences from NASA (National Aeronautics and Space Administration) and ESA (European Space Agency) and from other researches have stated that, air pollution has significantly reduce over the metropolitan and industrialized regions from last several weeks (ESA, 2020; Nakada and Urban, 2020; NASA, 2020) due to strict lockdown measures adapted during epidemic (Chauhan and Singh, 2020; Sulaman et al., 2020). **Table S2** revealed percentage changes in NO_2 level over major cities of Indo-Pak regions in 2020 during different lockdown scenarios compared to baseline period (2015-2019). Its negative values represented the level of NO_2 emission dropped in April-2020 compared to past years (2015-2019). For example, a significant reduction in NO_2 emission was counted to ~ 19-35 % over Ahmadabad, 27-52 % over New Delhi, and 32-42 % over Chennai, 28-34 % over Karachi and 29-52 % over Lahore during 15 Mar – 31May, 2020 (lockdown) compared to past years. New data from the Copernicus Sentinel-5P satellite also revealed ~40-50% reduction in NO_2 emission over major cities across India (ESA, 2020).

Figure 4 illustrated the time series extracted over the 1^o x 1^o grid box drawn around the cities and indicates mean NO_2 emission and anomaly changes in 2020 compared to baseline average 2015-2019. Evidence from these results demonstrated that before lockdown (1 Jan – 15 Mar) running mean and anomaly time series is coinciding with average of 2015-2019 in a fluctuation trend. However after lockdown (15 Mar - Apr), mean NO_2 and anomaly values has dropped and running with lower values compared to average of 2015-2019 time series. It was seen that during first 10 week of 2020, the NO_2 emission is increasing compared to past years due to more industrial development and more emissions from transports while after the 10^{th} week of 2020 NO_2 level is declining and reached to the lowest value of past 5 years average. Mahato et al., (2020) has also reported that as a result of restricted anthropogenic emissions, the level of NO_2 has drastically slowed down just within few days during the lockdown period across the major cities of India. Some scientists reported that due to delcline in air pollution level the sky over the most polluted city (e.g., New Delhi) is clearly visible than before (Kohli, 2020; Wright, 2020). Restricted use of fossil fuels in transportation and in the industrial sectors during the pandemic lockdown has significantly improved the air quality from 40-54 % over the Indo-Pak region (Mahato et al., 2020). *Dahiya and Butt from* Centre for Research on Energy and Clean Air also reported that air pollution levels across main cities of Pakistan has also dropped drastically due to less fossil fuel consumption in transportation, industries and power plants in result of nationwide lockdown. The average drop in NO_2 emission over the major cities such as Mumbai, Pune and Ahmedabad was 40–49% during March 2020 (during the lockdown) when compared with March 2019 (Wright, 2020) which is consistent with less emission of effluents due to shutdown of industrial activities (Gandhiok, 2020).

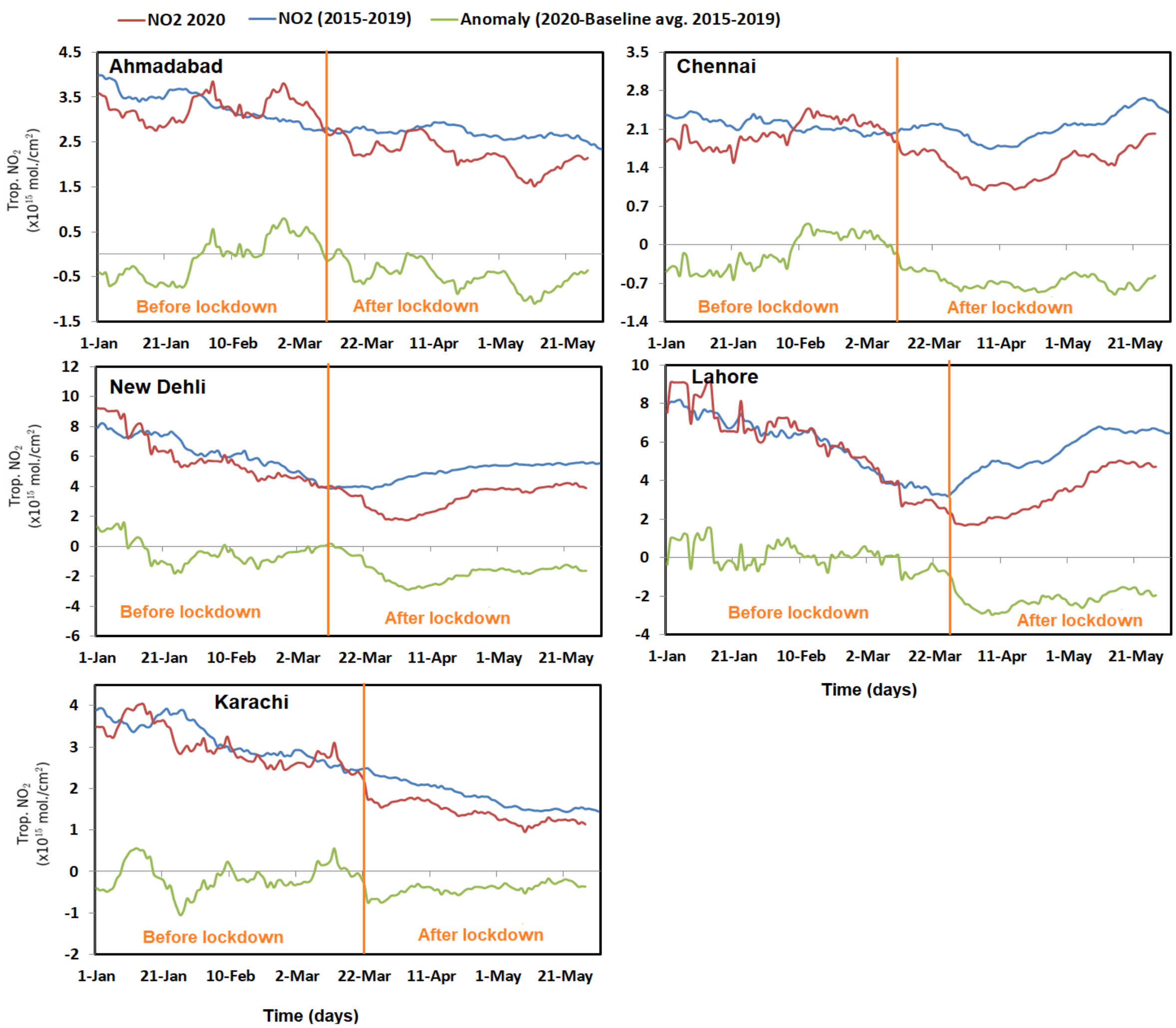


Figure 4. Daily time series of 15 days moving average of NO_2 emission and anomaly changes in 2020 compared to the baseline period 2015-2019 across the five major cities.

4.3 Airborne Aerosol Optical Depth (AOD) over Indo-Pak

Every year, aerosols released from human induced sources and contribute to unhealthy levels of air pollution over major cities in Indo-Pak (Murari et al., 2015). Higher value of aerosols optical depth of 1 or above indicates very hazy conditions while its value less than 0.1 over the entire atmospheric vertical column is considered “clean”. **Figure S2** depicted the recent images of AOD relaeased by NASA reported a reduction in aerosol optical depth over the Indo-Pak region during Mar –April 2020 (after lockdown) when compared with past years 2016 – 2019 (before lockdown) (NASA, 2020). It could be seen that AOD has reduced to greater extent in 2020 compared to past years especially at North Indo-Gangetic Plain. In this study, daily and monthly time series of aerosol optical depth (AOD) were retrieved from the MODIS on NASA’s Terra satellite and processed through NASA Giovanni user interface from I Jan – 30 May, 2020, and compared with past years (2015-2019) average.

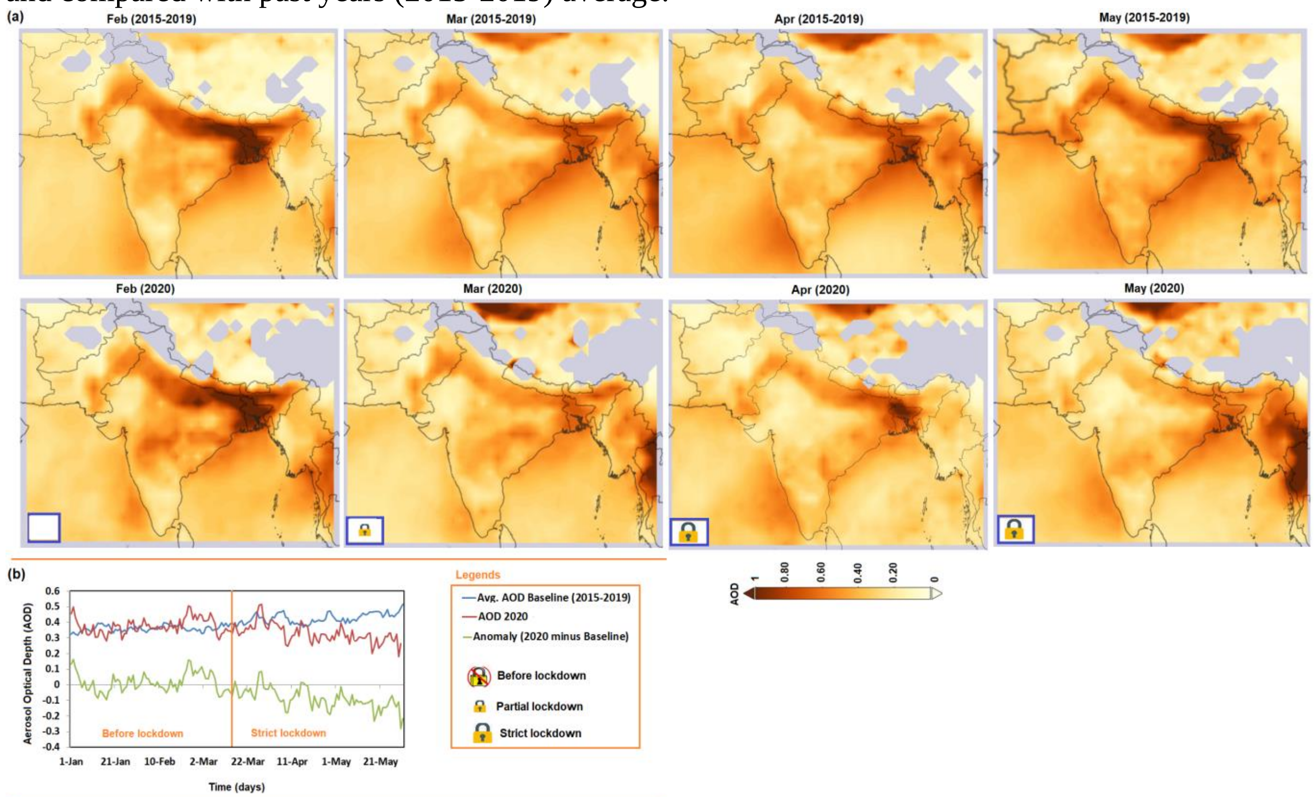


Figure 5. Changes in aerosol optical depth (AOD) in 2020 compared to past years average (a) monthly spatio-temporal changes in AOD during 2020 compared to baseline (2015-2019), and (b) daily AOD area avaged time series in 2020 compared to baseline (2015-2019) over Indo-Pak Gangetic Plain.

Spatial changes in aerosol particle depth during Feb-May, 2020 (lockdown period) were investigated and compared with past years average (2015-2019) (before lockdown), over Indo-Pak Gangetic Plain (**Figure 5a**). AOD maps clearly depicted that its spatial extent and magnitude is much higher over Indoian Gangetic Plain compared to Pakistan which can be explained by higher cost of transport emissions, and climate variations. It was seen that average monthly AOD during Feb-Mar 2020 is largely consistent with last year’s average (2015-2019) in same time-frame. However mean AOD of Apr-May, 2020 has reduced with a greater extend when compared with baseline (2016-2019). Reduction in AOD is consistent with epidemic lockdown due to less emission of particles (such as nitrogen, sulfates) from human induced activities. However huge reduction of about 45 % in AOD has foreseen over northern Indo-Pak Gangetic Plain in Apr, 2020 compared to past years average. Time series of daily aerosol optical

(AOD_550nm) averaged over Indo-Pak is shown in **Figure 5b**. It can be seen that AOD level is increasing during the first 11 weeks of 2020 compared to baseline period while after 11^{th} week (during the lockdown) it started to decline and reached to lowest observation on the date in MODIS record, due to less emission of particles from anthropogenic sources. NASA scientist at Marshall Space Flight Center "Pawan Gupta" from University of Space Research Association (USRA) claimed that, he never seen dramatic reduction in aerosol over the Indo-Pak Gangetic Plain during Mar-Apr, 2020, when compared with same time-frame over the past years average (NASA, 2020). According to Pawan Gupta, aerosol particle depth in northern plain was recorded as lowest in April, compared to past 20 years observations of MODIS (NASA, 2020). Majority of the aerosols formed in Indo-Pak regions are associated with anthropogenic emissions such as vehicles, coal-fired power plants, industrial sources, burning in agriculture farms (Guo et al., 2017). However, restricted use of fossil fuels in transportation and industrial sectors during the pandemic lockdown has decreased the emissions sources of airborne particles in atmosphere, (Mahato et al., 2020) subsequently air pollution across the countries has drastically slowed down just within few days (Isaifan, 2020; Sharma et al., 2020).

Geospatial statistical correlation between daily changes aerosol optical depth and NO_2 was investigated to analyze the possible relationship between bother variables. **Figure S3** illustrated the spatial correlation between AOD and NO_2 as well as time series correlation over the Indo-Pak region. It was seen that high negative spatial correlation exists between AOD and NO_2 emission over some region in south side of India, however in most of the regions spatial correlation was found to be positive in range of 0.23-0.50 especually over the Indo-Pak Gangetic Plain. The positive correlation depicted that a decrease in AOD may be exapnined by reduction in NO_2 to some extents. Overall correlation between AOD and NO_2 was found tobe 0.32 over the Indo-Pak region which illustrates that reduction in both variables may link to each other over the study region.

5. Conclusions

After an outbreak of novel infectious disease (COVID-19) which started at the end of 2019, later on it turned into a global pandemic and spread across 212 countries over the world. Many countries across the World went to strict lockdown measures which have been implemented by government authorities to reduce the further spread of disease infections. In this study, the effects of restricted human activities since mid -March of 2020 were highlighted on changes in air pollution across the Indo-Pak region. Comparison of space observations from last couple of years with current data helps to understand the potential effect of precautionary measures on environment during the lockdown period. Result of this study revealed that huge drop in air pollution was accounted as 40-50% in NO2 emission and 45 % in aerosol particle thickness over the whole Indo-Pak region. Moreover, all the major cities across the region also have shown the significant reduction in NO2 emission as ~ 19-35 % over Ahmadabad, 27-52 % over New Delhi, and 32-42 % over Chennai, 28-34 % over Karachi and 29-52 % over Lahore during 15 Mar – 31May, 2020 (lockdown) compared to past years. Significant correlation between AOD and NO2 further implies that changes in AOD may be proxies to reduction in trace gasses to some extents. Morover this study suggested that the reduction in aerosol particle thickness and NO_2 emission is associated with less consumption of fossil fuels during COVID-19 pandemic situation.

Author Contributions

A. Arshad, S. Hussain, F. Saleem and M. Shafeeque: Conceive the idea, Investigation, Data curation, Software, Visualization, Writing-original draft. **M. Shafeeque, S. N. Khan, M. S. Waqas and F. Saleem:** Writing, review & editing, Proof reading and article formatting.

Declaration of competing interest

The authors declare no conflict of interest.

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