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Variation in Aerosol Optical Depth (AOD), NO_2 and Tropospheric Ozone Column during the Lockdown Period Amid COVID-19 Pandemic over India

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With the emergence of COVID-19 in late December 2019 in China and its exponential spread around the globe, on 11th March 2020 WHO declared it global pandemic. The first case of novel coronavirus in India was reported on 30th January 2020 in Kerala state of India. India is currently experiencing the worst situation amid COVID-19 pandemic with its 3rd position having the highest number of confirmed cases amongst the countries around the world with huge social and economic losses. Many studies reported that there is an improvement in air quality around different parts of the world due to cessation of vehicular, industrial and anthropogenic activities. The present study highlights the impact of COVID-19 pandemic on air quality over India during the lockdown period amid COVID-19 pandemic. Results revealed the significant decline in NO_2 and aerosol optical depth (AOD) all around in India except for ozone. There has been a considerable decline in air pollution because of restricted activities during COVID-19 pandemic over India. Meteorological factors may not be directly related to the number of outbreaks. Although the COVID-19 lockdown has a negative impact on economic aspects but it has a positive impact on air quality. The COVID-19 pandemic impacted the lives of millions and having numerous global implications made humans believe that nothing will be normal as earlier. The study may help authorities and policy makers on taking specific measures for the pandemic it can be helpful in future to frame policies to reduce air pollution by policy makers.

Keywords: Air quality, COVID-19 pandemic, Tropospheric ozone column, Aerosol optical depth, NO_2, Lockdown, India.

INTRODUCTION

Recent urbanization in India has drastically deteriorated the air quality mainly in urban spheres, air pollution is not only impacting the public health and environment but also have numerous psychological, economical and social impacts [1]. According to Global Burden Disease Air pollution is responsible for 620,000 premature deaths yearly in India which is attributed to numerous diseases such as stroke, COPD, ischemic heart disease, lower respiratory infection and lung cancer caused by numerous pollutants including PM_{10}, $PM_{2.5}$, CO, SO_2, O_3 and NO_X [2]. According to a study higher mortality rate is linked to unhealthy levels of CO, NO_2 and $PM_{2.5}$ [3].

The exponential spread of novel corona virus is a global health concern. COVID-19 has been identified in Wuhan, China in December 2019 and it has infected more than 100 countries within three months. The global explosion of novel corona virus infection has made it global pandemic [4]. As COVID-19 infection spreads all around the globe, India is at crucial stage to fight against coronavirus pandemic. With the onset of global pandemic COVID-19, different measures have been taken in India including Janta Curfew and complete lockdown of the country. The first case of COVID-19 in India was reported on 30 January 2020 in Kerala. As of June 1, 2020, the outbreak of the corona virus disease (COVID-19) had been confirmed in around 210 countries or territories. The virus had infected 60,57,853 people worldwide and the number of deaths had totalled 371 166 the most severely affected countries include the U.S., Spain, Italy, the United Kingdom, India, *etc.* (WHO).

Since March 24, 2020 complete lockdown measures were implemented in India with the cessation of vehicular, anthropogenic and economic activities to flatten the COVID-19 pandemic curve but at the same time reduction of these activities led to a substantial reduction in urban air quality. Indian government has implemented different control and mitigation strategies to abate the further spread of novel corona virus including social distancing, strict quarantine, Janta curfew and complete nationwide lockdown for 21 days. A recent study reported the effect of outdoor pollutants and lockdown during COVID-19 it has been found that reducing air pollution can decrease the COVID-19 infection and effective lockdown strategies that prohibit inter/intra city movement are crucial for controlling the COVID-19 [5].

While the economic loss are enormous while enforcing these preventive measures but there are many social and environmental benefits, among them locking down cities brings reduction in air pollution levels in different countries. The COVID-19 pandemic impacted the lives of millions and having numerous global implications made humans believe that nothing will be normal as earlier. The recent studies flooded with the work on evaluating the factors that impact, taking precautionary measures and finding the treatment are the prime concerns amongst the researchers. Climatic factors such as temperature, humidity, air pollution and human health are among the crucial parameters which are associated with the COVID-19 pandemic. The pandemic has drastically impacted the global economy while it has positive impact on air quality globally which is evident from recent studies including China, Brazil, US, Spain and Italy [4-17]. Many countries have witnessed the improved air quality through satellite imagery during this COVID-19 lockdown, present study carried out to investigate the COVID-19 lockdown effect on air quality in India through MODIS data. Using satellite data for studying particular events that affect air quality is commonly reported in studies, in some cases, scientist monitored the global air pollution over land from the earth observing system terra MODIS (moderate resolution imaging spectroradiometer) [18]. Temporal and spatial variability and AOD were evaluated over Iran using MODIS data [19]. Zhang estimated the cloud effects on air temperature using MODIS LST based on ground measurements over Tibetan Plateau [20] MODIS Water vapour products over china were studied using radiosonde data [21]. Numerous studies have been reported on MODIS application in air quality because it has dedicated atmosphere products such as aerosols including more straightforward parameters for air quality research and MODIS data is having daily global coverage and it is easily accessible for researchers [22]. Several studies related to air pollution reduction due to the lockdown imposed in various countries because of COVID-19 pandemic are summarized in Table-1.

The present study is intended to explore the applicability of MODIS atmosphere products as a subsidiary source for monitoring the national air quality before and during COVID-19 pandemic lockdown over India. The aerosol optical depth (AOD), NO_2, total column ozone (TCO), total precipitable

TABLE-1
STUDIES RELATED TO COVID-19 PANDEMIC AND REDUCTION IN AIR POLLUTION AROUND THE WORLD

Country/city	Study/outcome	Ref.
Global (China, France, USA, Spain, Italy	Air pollution reduced by 30 %	[14]
India	Significant reduction (50%) in (aerosol optical depth (AOD) in Indian region	[15]
Morocco	PM_{10}, NO_2 and SO_2 concentrations were reduced by more than half during the Covid-19 lockdown period.	[17]
China	The overall ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2) air quality was improved during the control of Covid-19 and O_3 actually increased.	[10]
South Asia (Manila, Bangkok, Kuala Lumpu)	Reductions in PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO are 26-31%, 23-32%, 63-64%, 9-20%, and 25-31%, respectively in Malaysia (urban), Large reductions (~27%-34%) of tropospheric NO_2 over urban agglomerations	[23]
Northern China	The concentrations of SO_2, $PM_{2.5}$, PM_{10}, NO_2 and CO decreased by 6.76%, 5.93%, 13.66%, 24.67% and 4.58%, respectively.	[24]
Milan	Lockdown determined a significant reduction of PM_{10}, $PM_{2.5}$, BC, benzene, CO and NOx, SO_2 remained unchanged in the more peripheral areas, ozone increased probably due to the lower NO measured during lockdown.	[25]
Barcelona	NO_2 and BC concentrations were reduced by half during the lockdown, PM_{10} decreased in a much lower Proportion, O_3 concentrations increased by around 50%.	[7]
China (Yangtze River Delta Region)	Reduced SO_2, NO_X, $PM_{2.5}$ and VOCs emissions by approximately 16-26%, 29–47%, 27–46% and 37–57% during the lockdown.	[25]
Major Cities of the world (Rome, Shanghai, Mumbai, Dubai, Delhi, Beijing, Los Angeles, NewYork, Zaragoza)	Reduced $PM_{2.5}$ Concentration around the world	[26]
Southern Europe (Nice, Rome, Velencia Turin) and Wuhan (China)	Reduction in NO_2 in all cities (-56) was found, Reductions in PM were much higher in Wuhan (~ 42%) than in Europe (~ 8%), The lockdown caused an ozone increase in all cities (17% in Europe, 36% in Wuhan)	[27]
China	Satellite data show a sharply decline in NO_2, an indicator for environment.	[10]
Sao poulo State	Up to 64.8% decrease in CO concentrations (ppm) were observed, 77.3% decrease in NO and 54.3% in NO_3 concentrations (μg m^{-3}) were observed in urban Road and 30% increase in O_3 concentrations (μg m^{-3}) were observed	[8]
Rio de Janerio	CO, NO_2 and PM levels were reduced and O_3 concentration increased	[9]
Delhi	Reduction of PM_{10} and $PM_{2.5}$ were observed as high as about 60% and 39% respectively, NO_2 (-52.68%) and CO (-30.35%) were also reduced.	[6]

water (TPW) and air temperature has been extracted from their corresponding products.

EXPERIMENTAL

Site description: The study focuses on the south-Asian country; India. India is the 7th largest country in the world in terms of size and 2nd most populated country in the world. Country is positioned between the latitudinal and longitudinal extend of 8º4′N and 37º6′N latitudes and 68º7'E and 97º25′E longitudes. Across this varying topography and large geographical scales, the climate of the country is easily generalized and shows a wide range of weather conditions. The climate of the country mainly hosts about six climatic subtypes, according to the Koppen's system of climate classification. The country has four seasons: the winter (December to February), the spring (March to May), the summer (June to August) and the Autumn (September to November). Moreover, most of the regions in the country shows a starkly different microclimate. Most regions of the country are not likely to experience temperature below 10 ºC even in winter. With a large population, crowded cities, substantial industrial and vehicular emissions, the country remain disproportionately affected by toxic air and so-called pollution-related problems. Also, the southern part of the country is less affected by air pollution and related problems, while northern states are more predominant to the same.

Data analysis

Satellite sensor	Resolution	Duration
OMI (ozone monitoring instrument)	0.25°	January to April 2019 and 2020

The Dutch-Finnish ozone monitoring image spectrometer, ozone monitoring instrument (OMI) data are used for the study. The instrument is very efficient for distinguishing ozone and other atmospheric species. The sensor has a spectral region of 264-504 nm, a spectral resolution of 0.42-0.63 nm and a resolution of 0.125 × 0.1250. The acquisition and measurement from tropospheric and stratospheric levels of the earth's atmosphere is the main objective of the instrument's mission. OMI is having a unique capability for measuring trace gases (O_3/SO_2/NO_2/HCHO/BrO and OCIO) with minimal footprint and daily global coverage.

For the study of total column ozone, the TOMS-like OMTO3e product has been used. This product data falls in the 0.25 × 0.25-degree global grids. For the study of the tropospheric column, NO_2OMNO2d data product has been selected. It is a Level-3 gridded product where data is falling into 0.25 × 0.25-degree global grids, with less than 30% cloud fraction. Similarly, for the study of aerosol optical depth (AOD), the OMAEROe product has been selectedbased on the multi-wavelength algorithm that uses up to 20 wavelength bands between 331 and 500 nm. Monthly averaged satellite data from the month of January to April are taken from NASA's Goddard Space Flight Center data repository and are used for the study from the years 2019 and 2020. Obtained data were processed and visualized using high level computing languages for better analysis. GIS tool has been used especially for mapping and for managing the geographical data information during the processing and interpretation of satellite data. Plots were generated using Origin 8 software for the temporal analysis of the data obtained for each selected parameter.

RESULTS AND DISCUSSION

The results of the air quality assessment over India have been represented as monthly variations in the pollutant concentration due to restricted activities during lockdown in India. Analysis of various air pollutants (AOD, NO_2 and TCO) and meteorological parameters (temperature, total precipitable water (TPW) have been carried out which emphasized the effect of temperature and TPH on the air pollution over India during COVID-19 lockdown.

NO_2: Fig. 1 represents the comparison of NO_2 levels during January-March 2019 *vs*. January-March 2020. Similar trends of NO_2 levels were observed for the month of January and February in both consecutive years but NO_2 levels were reduced in the month of March 2020 as comparison to 2019 over India as the all the anthropogenic, vehicular and economic, activities had been recessed due to COVID-19 pandemic. Fig. 2 shows the comparison of NO_2 levels of March 22-May 3 2019 *vs*. March 22-May 3 2020. The figure demonstrated the reduced levels of NO_2 in March 22-May 3 2020 as compare to March 22-May 3 2019 as the lockdown period had been extended till 3rd of May 2020. Same trends of reduction of NO_2 levels have been observed in China before and during COVID-19 pandemic lockdown [10]. Tobias *et al.* [7] has reported the reduction in NO_2 concentration by half during COVID-19 lockdown period in Spain. NO_2 is a criteria air pollutant which mainly produced by vehicular activities and thermal power plants and some natural sources such as lightening and soil processes and it is responsible for various chronic diseases in humans such as respiratory diseases including hypertension, heart and cardiovascular diseases and in some cases death. Ogen *et al.* [28] reported NO_2 as a most significant factor in contributing deaths during COVID-19 pandemic.

Total column ozone: In contrast to other ambient air pollutants, an incline has been observed in total column ozone (TCO) over India during COVID-19 lockdown. Fig. 3 represents the comparison of TCO levels during January-March 2019 *vs*. January-March 2020. Similar trends of TCO levels were observed for the month of January in both consecutive years but TCO levels were increased in the month of February and March 2020 as comparison to 2019 over India during COVID-19 lockdown period. Fig. 4 shows the comparison of TCO levels of March 22-May 3 2019 *vs*. March 22-May 3 2020. The figure demonstrated the increased levels of TCO in March 22-May 3 2020 during lockdown period. The increasing trend of ozone due to more favourable conditions for photochemical reactions which can be attributed to more solar insolation, secondly as NO_2 is a quencher of ozone so the increase in TCO can be majorly attributable NO_X decreases as less O_3 is quenched [29,30]. Sicard *et al.* [27] has reported the ozone amplification during COVID-10 pandemic lockdown period in Europe and China. Reduction in NO_2 levels is primarily attributed to i.ncrease

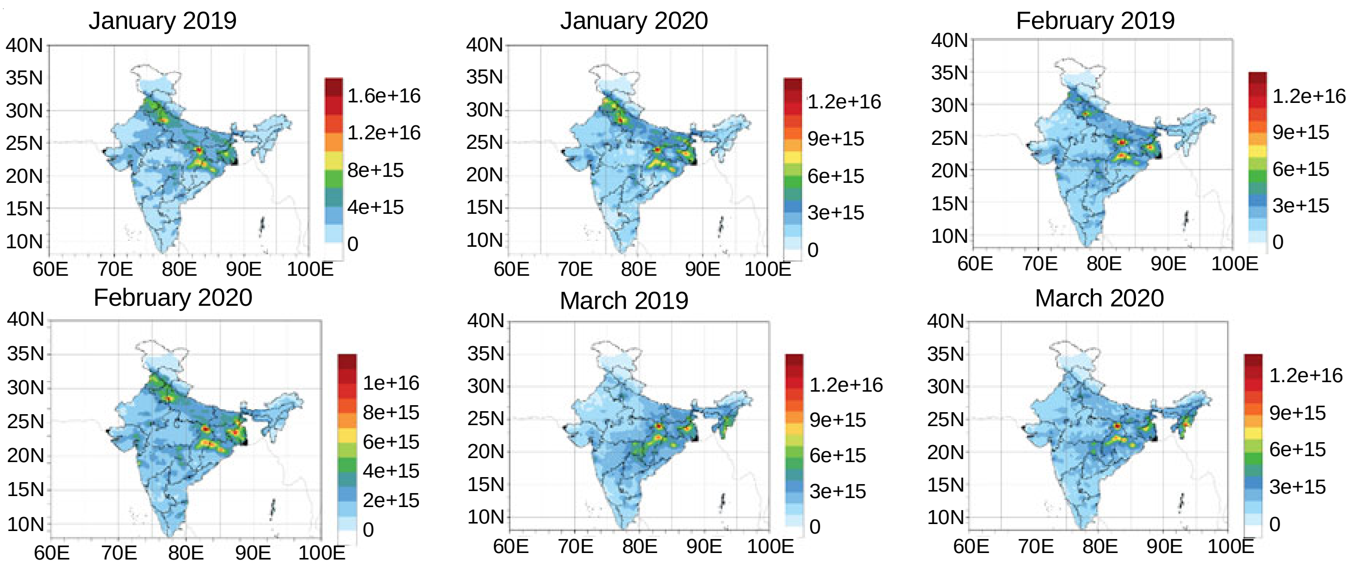

Fig. 1. Changes in NO_2 concentration during January-March 2019 *vs.* January-March 2020

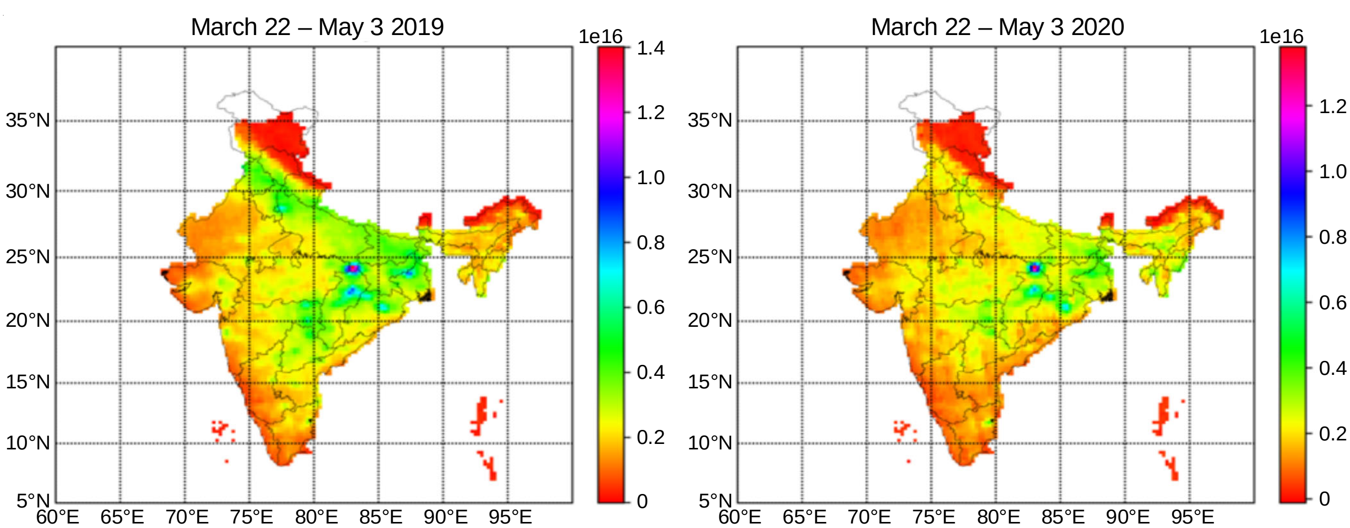

Fig. 2. Changes in NO_2 concentration during March 22-May 3 2019 *vs.* March 22-May 3 (complete lockdown period) 2020 over India

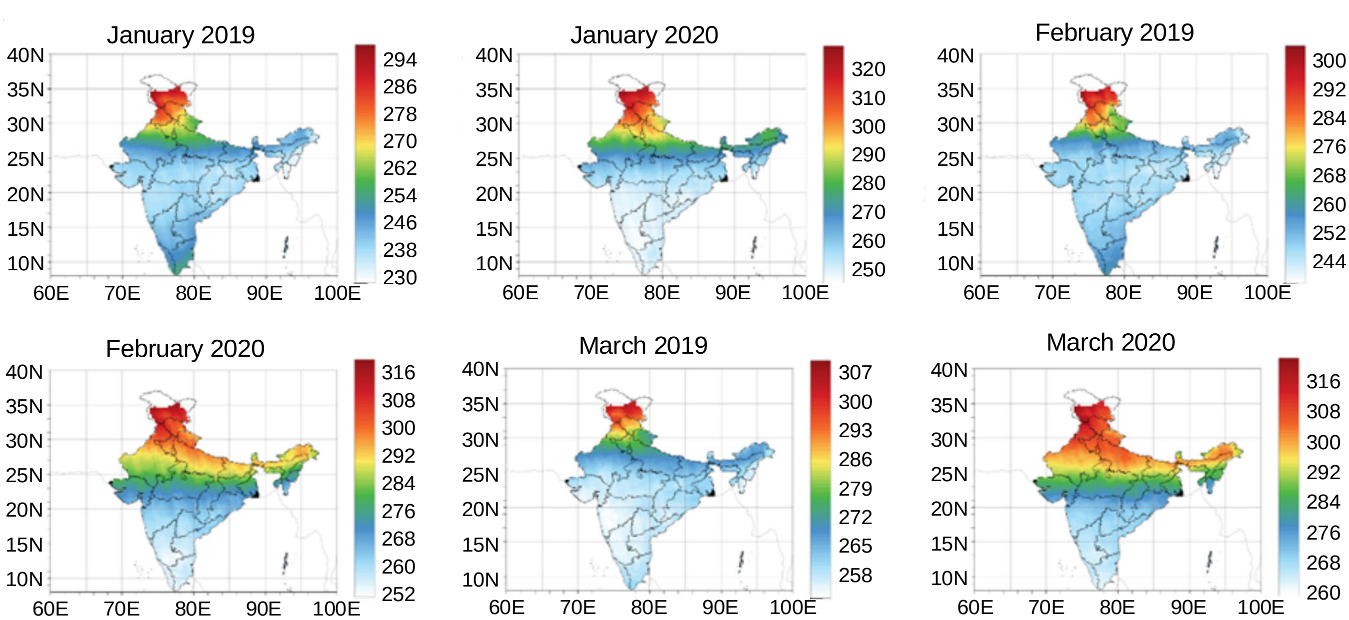

Fig. 3. Changes in total column ozone concentration during January-March 2019 *vs.* January-March 2020

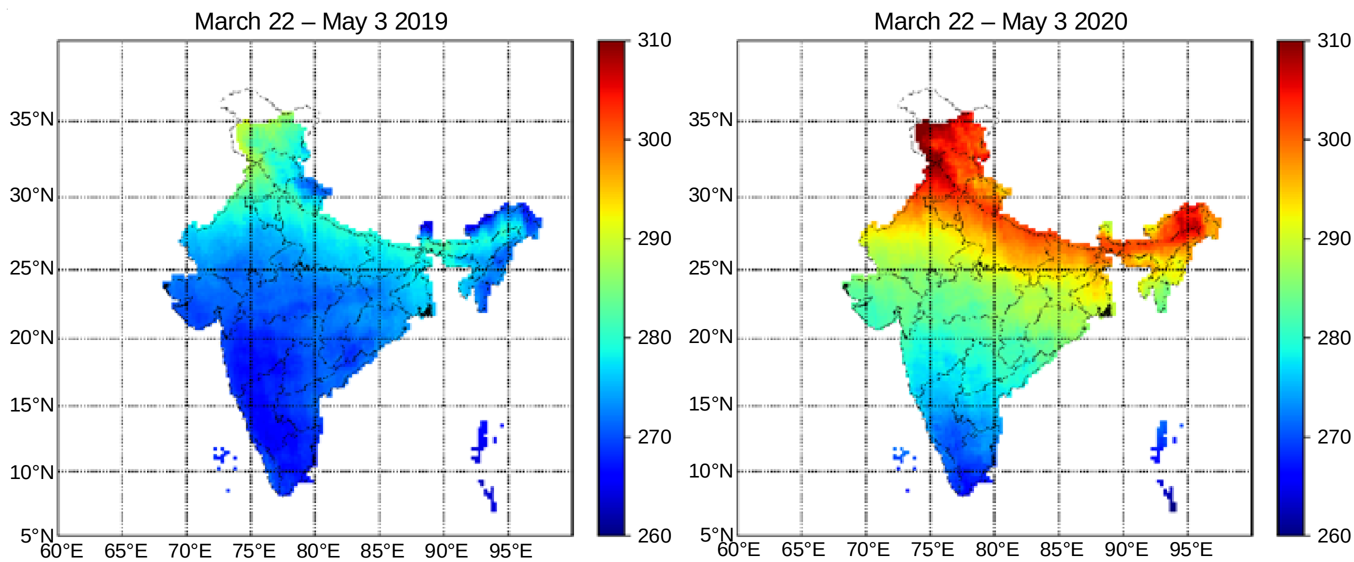

Fig. 4. Changes in total column ozone concentration during March 22-May 3 2019 *vs.* March 22-May 3 (complete lockdown period) 2020 over India

in ozone concentration during lockdown [31]. Tropospheric ozone is an ambient air pollutant and severely impacts human health and ecosystem. It is a secondary air pollutant which is produced by the pollutants released by the traffic sources, thermal power plants. It is produced when volatile organic compounds (VOCs) and oxides of nitrogen (NO_X) photo chemically react in the presence of UV radiation and it can be transported to long distances by wind. It can cause number of diseases in human beings such as throat irritation, chest pain, coughing, airway inflammation, bronchitis, emphy-sema and affects lung functioning [32].

Aerosol optical depth (AOD): The result exhibited an overall reduction in aerosol concentrations over India. Fig. 5 represents the comparison of AOD levels during January-March 2019 *vs.* January-March 2020. AOD levels were recorded high for January-March 2020 as compared to January-March 2019. AOD levels were increased in the month of February and March 2020 as comparison to 2019 over India during COVID-19 lockdown period. Fig. 6 shows the comparison of AOD levels of March 22-May 3 2019 *vs.* March 22-May 3 2020 and depicted the reduced concentration of AOD in March 22-May 3 2020 during lockdown period. A recent study has also been reported the substantial reduction in AOD over Indian region [33]. Aerosols are found in varying sizes and chemical composition and dispersed in the atmosphere in the form of gas, liquid and gases. Due to various sources and formation processes, aerosols differ in size and composition and either emitted directly or generated in the atmosphere. Aerosols are

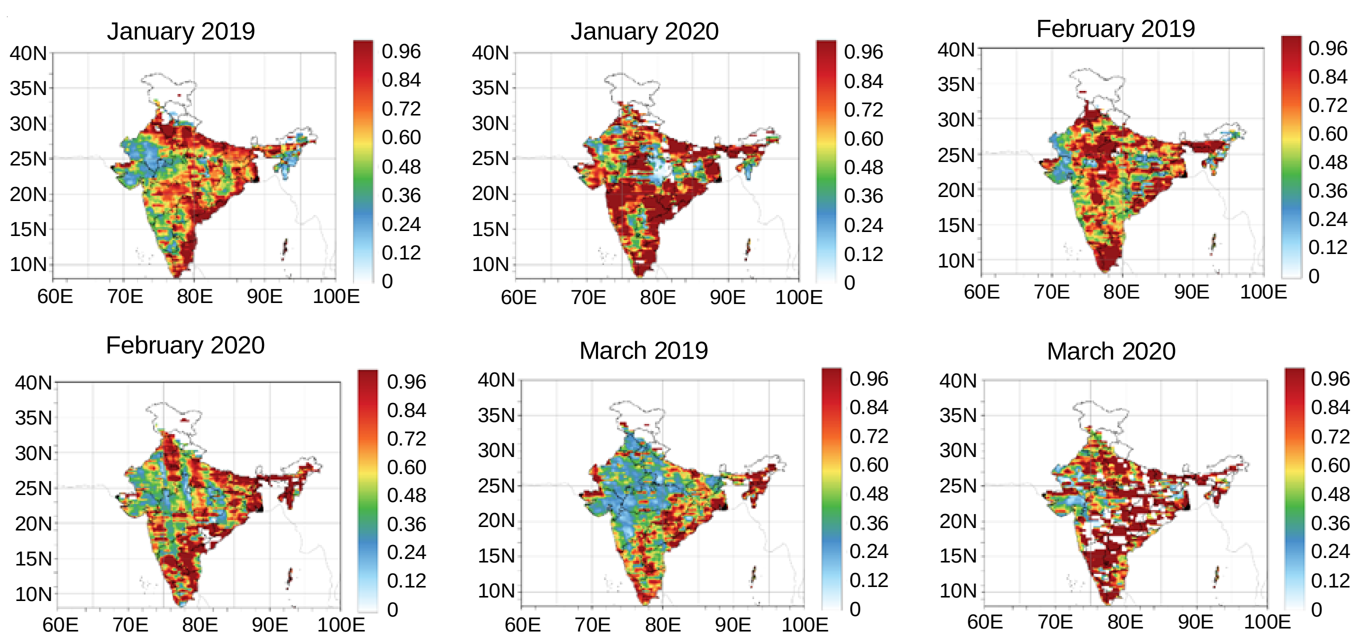

Fig. 5. Changes in aerosol optical depth (AOD) concentration during January-March 2019 *vs.* January-March 2020

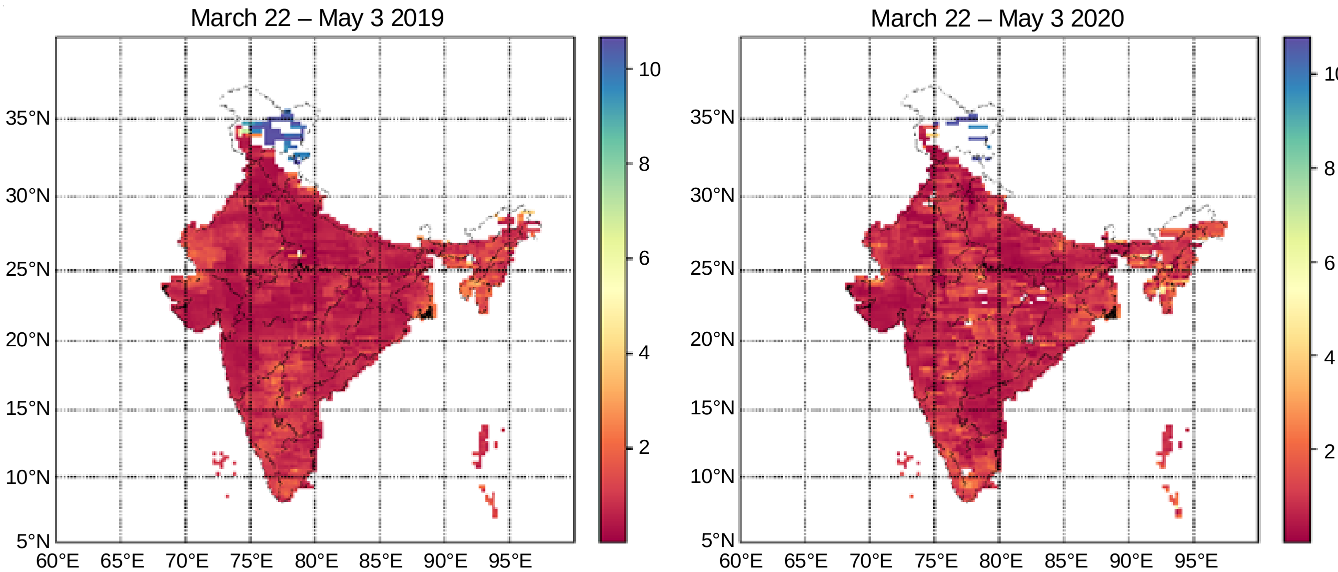

Fig. 6. Changes in aerosol optical depth (AOD) concentration during March 22-May 32019 *vs.* March 22-May 3 (complete lockdown period) 2020 over India

mainly generated from biomass burning, combustion and plant/ microbial materials, *etc*.

Meteorological factors and the transmission of COVID-19 pandemic: Figs. 7 and 8 show the averaged temperature and total precipitable water variations recorded during January-March 2019 *vs.* January-March (during the transmission of COVID- 19 pandemic) 2020. In general, meteorological factors may not be directly related to the number of outbreaks. In China, where the pandemic started, the average recorded temperature in cities with COVID-19 spread was 6-8 ºC (range -17 to 21 ºC), with 46-100% relative humidity up to March 22, 2020, globally, the pandemic spread over a temperature range of 3-17 ºC and 13-39% relative humidity. Temperature and water vapour has been reported as significant contributor in seasonal transmission of COVID-19 pandemic [10].

Conclusion

The present study highlights the impact of COVID-19 pandemic on air quality over India during the two time periods. First, between January-March 2019 and January-March 2020 secondly, between March 22-May 3 2019 and March 22-May 3, 2020 (during the complete lockdown period) amid COVID-19 pandemic. Results revealed the significant decline in NO_2 and aerosol optical depth (AOD) over India except for ozone. With the onset of global pandemic and with enforced lockdown India has witnessed numerous short term changes caused by

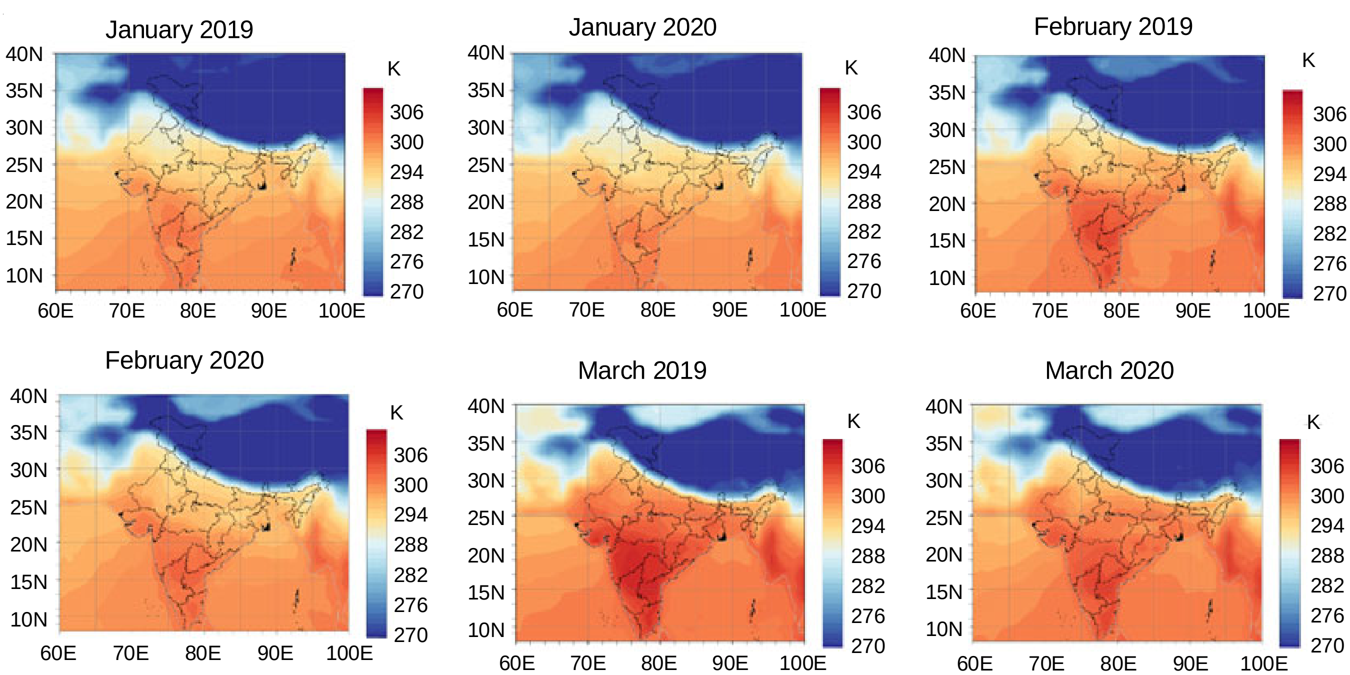

Fig. 7. Monthly averaged temperature (January-March 2019 *vs.* January- March (during the transmission of COVID-19 pandemic) 2020 over India)

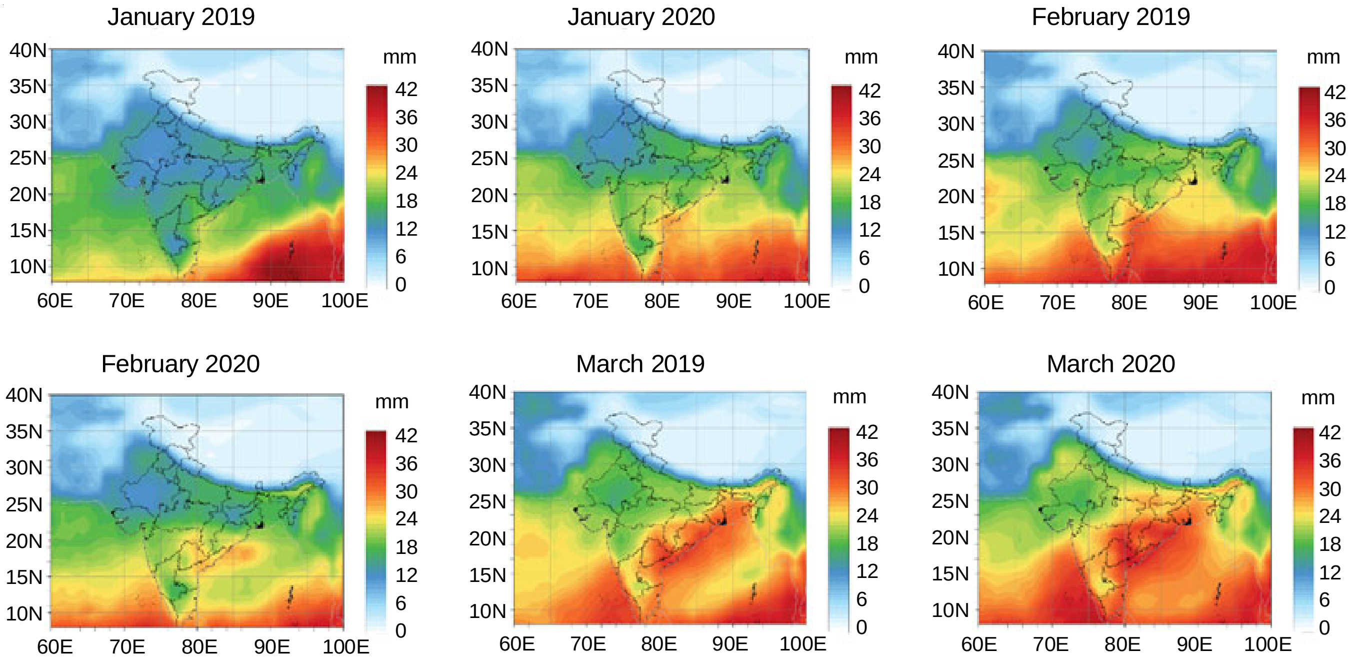

Fig. 8. Monthly averaged total precipitable water (TPW) January-March 2019 *vs.* January-March (during the transmission of COVID-19 pandemic) 2020 over India

pandemic. The pandemic caused huge loss in terms of economic and social aspects. But it has positively impacted the air quality over India. Based on the discussions, it can be

concluded that there has been a considerable decline in air pollution because of restricted activities during COVID-19 pandemic over India. Meteorological factors may not be directly related to the number of outbreaks. Although the COVID-19 lockdown has a negative impact on economic aspects but it has a positive impact on air quality. The pandemic has also highlighted how even when the world shuts down and fossil fuel usage and air pollution plummet as a result. The COVID-19 pandemic impacted the lives of millions and having numerous global implications made humans believe that nothing will be normal as earlier. The study results may help authorities and policy makers on taking specific measures for the pandemic it can be helpful in future to frame policies to reduce air pollution by policy makers.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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