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Effects of COVID-19 pandemic lockdown: A satellite data-based appraisal of air quality in Guwahati, Assam

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ABSTRACT

Moderate Resolution Imaging Spectroradiometer (MODIS) and Ozone Monitoring Instrument (OMI) based data are used to evaluate the effects of the COVID-19 lockdown on the concentrations of pollutants such as aerosol optical depth (AOD) and tropospheric columns of nitrogen dioxide (NO_2) along with sulfur dioxide (SO_2) respectively for the period of January 2017 to September 2021 over the capital city of Assam, Guwahati. In India lockdown due to COVID-19 was first imposed from 24th March to 14th April as phase I and then it extended from 15th April to 3rd May as phase II in the year 2020. The concentration of all pollutants was usually fall during the lockdown period as compared to their average during the 5-year period over the study area. The results showed that Pre-monsoon (March-May) seasonal AOD for the pandemic year 2020 was decreased by $\sim$ 23% after lockdown as compared to same season of normal years over the study location. The seasonally averaged AOD reached its peak value in pre-monsoon (0.78 ± 0.09), followed by winter (0.59 ± 0.10) and monsoon (0.52 ± 0.05), with the minimum taking place in post-monsoon (0.38 ± 0.08) season. The monthly average AOD varies from its highest value (0.82 ± 0.18) in May to its lowest value (0.36 ± 0.10) in October for the study period over Guwahati. Tropospheric column NO_2 exhibits same seasonality as AOD with highest value (0.21×10^{16} molecules cm^{-2}) in pre-monsoon and lowest value (0.13×10^{16} molecules cm^{-2}) in post-monsoon season which may be due to same source of origination of both NO_2 and AOD. Conversely, SO_2 does not vary much from the five-year average value during the lockdown period. Significant reduction in $PM_{2.5}$ mass concentration value during Covid-19 lockdown months has been observed which indicates short term improvement of air quality over Guwahati.

Selection and peer-review under responsibility of the scientific committee of the XII th Biennial National Conference of Physics Academy of North East (PANE 2021).

1. Introduction

The novel Coronavirus disease 2019 (COVID-19) affects many countries and created unpredicted situations all over the world since the first case has been reported on December 31, 2019 in Wuhan, China. The World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern on 30th January 2020, and a pandemic on 11th March 2020. The COVID-19 virus spread in early 2020 that affected millions of people around the world. India is among the various countries which have been worst affected by this pandemic. In India, the first cases of COVID-19 were reported on 30th January 2020 in Kerala, and the number continued to rise as days passed by and finally became a matter of great concern. To impede the spread of COVID-19, the government of India had declared countrywide lockdown in a phased manner viz. Phase I from 25th March to 14th April, Phase II from 15th April to 3rd May, Phase III from 4th-17th May, and Phase IV from 18th-31st May 2020. Guwahati, as being the largest city in North-East India has been worst affected by Coronavirus. The first case of the COVID-19 pandemic in Assam was reported on 31st March 2020. To control the rising number of COVID-19 cases in Guwahati, Assam Government imposed 14-days lockdown in 11 wards covering main areas like Kamakhya, Maligaon, Fatasil, Panbazar and Fancy Bazar etc. from 23rd June 2020 onwards. Due to the rapid increase in the number of COVID-19 cases in the city, the government announced a complete lockdown in Guwahati city from 28th June 2020 till 12th July 2020. Later on, the government

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again announced further extension of lockdown by a week till 19th July 2020. The lockdown was imposed very successfully throughout the state wherein all educational, religious, transport, business, political and entertainment activities were completely restricted excluding essential services like medical and fire services were kept operational and for the period. The impact of the lockdown mostly on air quality has been examined by a large number of researchers until now. The NO_x, nitrogen dioxide (NO_2), CO, sulfur dioxide (SO_2), Black Carbon (BC), PM (Particulate Matter) concentrations dipped significantly over Northeast India and its nearby countries during COVID-19 lockdown period [1]. Significant improvement of air quality over Delhi during the first phase of COVID-19 lockdown with the maximum reduction (~30%) in finer particulate concentration had been reported [2]. From the satellite data-based assessment of air quality over five megacities (Delhi, Mumbai, Bengaluru, Chennai and Kolkata) of India, a decrease in NO_2 and SO_2 concentrations has been observed during the lockdown period [3]. Significant correlation (0.66) between COVID-19 and $PM_{2.5}$ emission had been reported [4] over India. On average 34% and 60% reduction in $PM_{2.5}$ and NO_x concentrations respectively at different locations in India was reported [5]. Also, $PM_{2.5}$ concentrations reduced by about 23%, 16%, 32%, and 28% in small, medium, large and megacities of India respectively. This study is aimed to determine whether the COVID-19 pandemic lockdown imposed by the government have had an impact on local air quality over Guwahati. The dynamics of the satellite based concentrations of pollutants such as aerosol optical depth (AOD), tropospheric columns of NO_2, SO_2, $PM_{2.5}$ and BC were studied for the period of pre-Covid to post-Covid year. The results of this research provide information on how the lockdown due to COVID-19 pandemic can improve short term air quality over a location.

2. Approach

2.1. Study region

The study location Guwahati (26.2°N, 91.7°E, 55 m above mean sea level (AMSL)) is the largest and rapidly growing metropolitan city of the state of Assam in North-Eastern region of India (NEI) with an area of 216 sq. km (Fig. 1).

The NEI consists of eight states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, and Sikkim sit-

Fig. 1. Map of India showing the study location Guwahati (red circle) in North-East India. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

uated at the transition between South and Southeast Asia. This is the eastern-most region of India which covers an area of 255,168 km^2 with ~ 66% [6] of the total geographical area is being covered by forest. The height of the region varies from 50 m above mean sea level (AMSL) in the lower Brahmaputra region to a higher height of 7,000 m AMSL of Himalaya [7]. Guwahati city lies between the huge Brahmaputra river bank and the foothills of the Shillong plateau. The southern, eastern and a part of the western side of Guwahati city area bounded by hills and hillocks whereas in the north the powerful river the Brahmaputra flows in north-east to south-west direction. The physical background of this NEI region is mainly dominated by stony surface, alpine flora, along with snow-capped high peaks where nearly 72% of the area is under hilly environment. The region experiences biomass burning, especially as a part of shifting cultivation (slashes and burn cultivation), locally known as Jhuming which is maximum in the month of March-April-May months [8]. The study location is the Gateway of NEI and a key centre of socio-cultural, industrial, trade and business of the entire NE region. It is a major metropolis of eastern India and is the fifth fastest-growing city of India in terms of urbanization with population density 4,460 km^{-2} [9]. Guwahati metropolitan area and Guwahati municipal area had a population of 968,549, and 963,429 respectively as per as the record from 2011 census. Based on the meteorological condition of NEI region, Guwahati is divided into four seasons: Winter (December, January, and February), Pre-monsoon (March, April, and May), Monsoon (June, July, August, and September) and Post-monsoon (October, and November) [8]. MERRA-2 Rainfall data were used to check the rainfall pattern in Guwahati for the period of January 2017 to May 2021. Highest rainfall is observed in monsoon season over Guwahati (Fig. 2). A decreasing trend of rainfall has been observed for the study period.

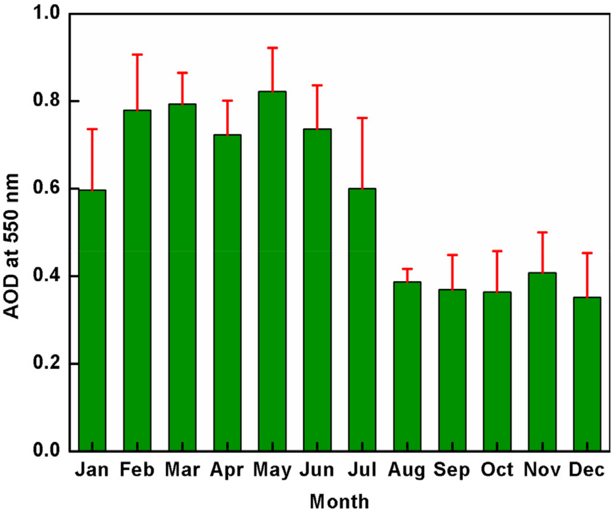

Fig. 3. Monthly variation in MODIS AOD at 550 nm for the period of June 2017 to May 2021 over Guwahati.

2.2. Data sources

The MODerate resolution Imaging Spectroradiometer (MODIS) sensor onboard the NASA Earth Observing System (EOS) Aqua satellite-based AOD data at 550 nm are used for the period of January 2017-September 2021 which has the facility to characterize aerosols over global field[10]. MODIS is a NASA's onboard twin satellites (Terra and Aqua) which perform near-global daily observations of aerosols with 36 spectral channels which includes visible to thermal infrared region. The everyday Level 3 data set of AOD at 550 nm with quality assured Collection 6 data has 1° × 1° global resolutions [11]. For the current study, daily mean level-3 collection-6 MODIS AOD data sets are downloaded from the Giovanni web service (https://disc.sci.gsfc.nasa.gov/giovanni) on a 1°×1° spatial resolution, centered at Guwahati. Ozone Monitoring Instrument (OMI) onboard NASA EOS Aura satellite-based trace gases tropospheric columns of nitrogen dioxide (NO_2) and SO_2 column amount (Planetary Boundary Layer) data are used from January 2017 to September 2021 over Guwahati. The OMI is a part of the A-train satellite group [12] which has the remarkable benefit of giving information on optical properties of aerosols by utilizing large sensitivity to absorption of aerosol in the near-UV spectral region [13]. Comparisons with in situ data propose that the OMI's tropospheric NO_2 columns data have high biased (0–30%) which

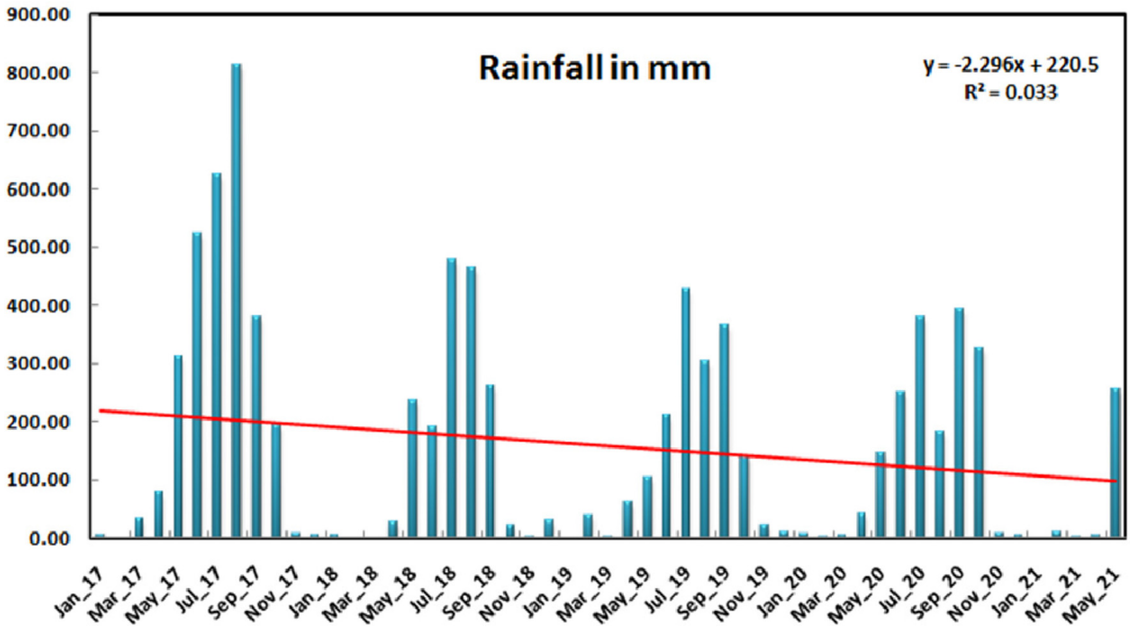

Fig. 2. Temporal variation of rainfall over Guwahati.for the period of June 2017 to May 2021 (solid straight line represents linear best fit).

depends on the validation data set [14]. Daily mean OMI level-3 NO_2 and SO_2 data at a spatial resolution of 0.25° × 0.25° has been used for this current study. The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) provides data starting from 1980. To substitute the original MERRA dataset, MERRA-2 was introduced due to the advances made in the assimilation system that enable assimilation of modern hyper spectral radiance as well as microwave observations, together with Global Positioning System (GPS)-Radio Occultation datasets. MERRA-2 is the first long-term global reanalysis to assimilate the space-based observations of atmospheric aerosols and characterize their connections with other physical processes in the climate system. Ozone profile of NASA's observations was used by it since late 2004. Both the Goddard Earth Observing System (GEOS) model and the Gridpoint Statistical Interpolation (GSI) assimilation system are incorporated in MERRA-2. Spatial resolution of MERRA-2 is about 50 km in the latitudinal direction which is nearly same as in MERRA. $PM_{2.5}$, BC and rainfall data were obtained from MEERA-2 for the period of January 2017 to September 2021.

3. Results and discussion

3.1. Temporal variation of AOD

Daily mean MODIS Aqua AOD data at 550 nm are used for the period of January 2017-September 2021 to examine the temporal variation of it over Guwahati. The monthly variation of AOD is shown in Fig. 3.

The vertical red line in the figure represents the standard variation of AOD. It is seen from the figure that the monthly average AOD varies from its highest value (0.82 ± 0.18) in May to its lowest value (0.36 ± 0.10) in October over Guwahati. The seasonal variation of AOD at 550 nm over Guwahati is shown in Fig. 4. The seasonally averaged AOD reached its peak value in pre-monsoon (0.78 ± 0.09), followed by winter (0.59 ± 0.10) and monsoon (0.52 ± 0.05), with the minimum taking place in post-monsoon (0.38 ± 0.08) season. The seasonal variation of AOD over Guwahati shows peak value during pre-monsoon season due to the intense biomass burning activities and dip in the post-monsoon season mostly due to wash out of aerosols by rain in the previous months exclusive of adequate substitute. Similar seasonal variation of AOD with maximum in the pre-monsoon (~0.45 ± 0.05) and minimum in the post-monsoon (~0.19 ± 0.06) season over Dibrugarh for the period of October 2001 to December 2007 had been reported [8].

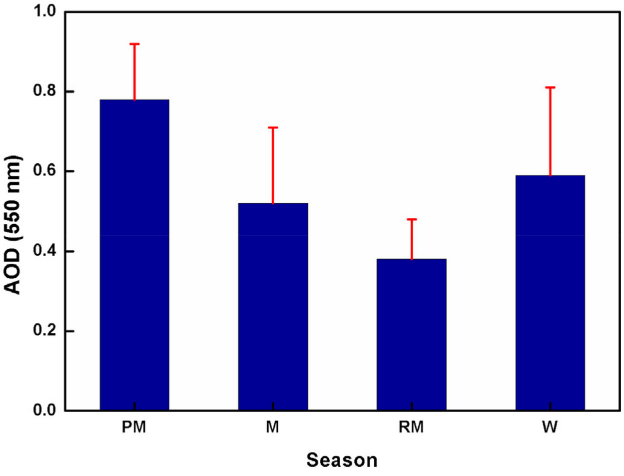

Fig. 4. Seasonal variation of AOD at 550 nm along with standard deviation for the period June 2017 to May 2021 over Guwahati.

Table 1
Seasonal mean, standard deviation and co-efficient of variation of AOD at 550 nm for the period June 2017 to May 2021over Guwahati.

Season	Average AOD (at 550 nm)	Standard deviation	Coefficient of variation (%)
Pre-monsoon	0.78	± 0.09	11.54
Monsoon	0.52	± 0.05	9.68
Post-monsoon	0.38	± 0.08	20.86
Winter	0.59	± 0.10	16.89

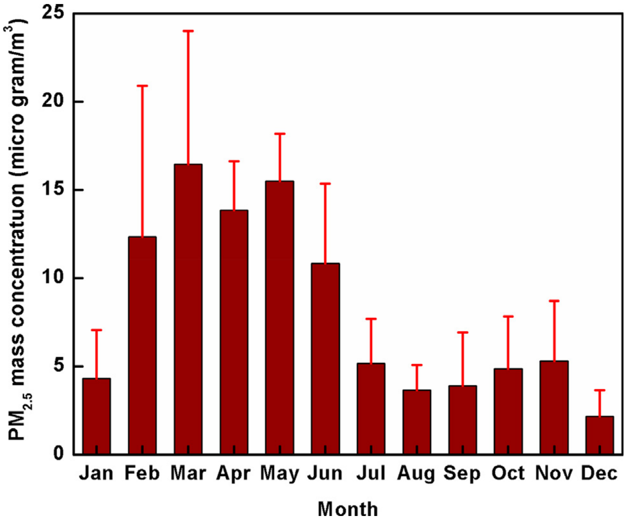

Fig. 5. Monthly variation in $PM_{2.5}$ mass concentration for the period of June 2017 to May 2021 over Guwahati.

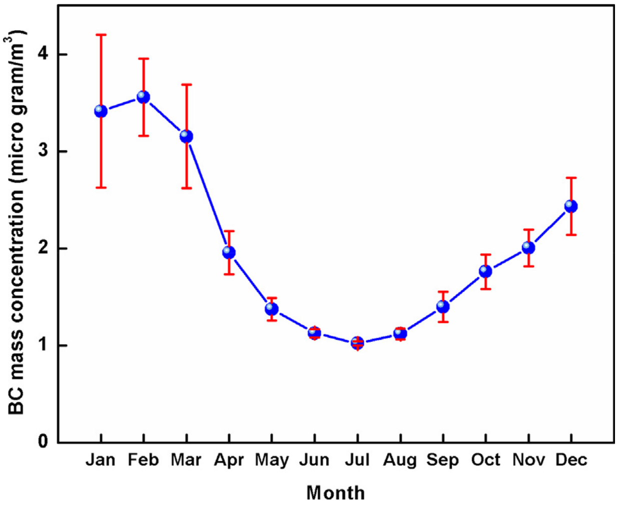

Fig. 6. Monthly variation in black carbon mass concentration for the period of June 2017 to May 2021 over Guwahati.

Anthropogenic biomass burning is the main contributor of atmospheric aerosols in the pre-monsoon season over Dibrugarh [6]. Similar seasonality in AOD was reported with a peak in the pre-monsoon and dip in the post-monsoon over nine locations in NE India and its adjoining areas [15]. Longitudinal gradient in seasonal aerosol distribution over NE India with higher AOD values in the western part [9] (including Guwahati), which is mostly attributed to the variability of source types and closeness to the

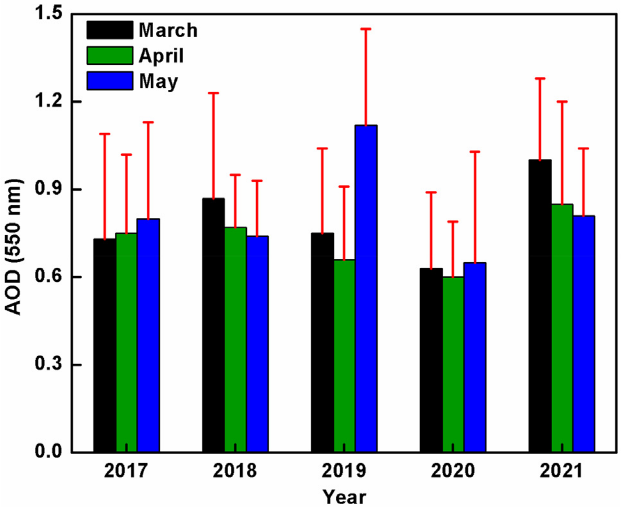

Fig. 7. Pre-monsoonal variation in AOD in 550 nm for the period of June 2017 to May 2021 over Guwahati.

western influences through transportation [6,16,17] had been reported. The seasonally averaged data of AOD, standard deviation, and coefficient of variation (COV) (in %, calculated as (ratio of the standard deviation to mean) × 100)) for the study period are shown in Table 1.

Higher value of COV shows greater the level of dispersion around the mean while lower value of it indicates more accurate estimate. It is observed that variability in AOD in Guwahati is quite high in magnitude with the COV ranging from a minimum of 9.68% in the monsoon season to a maximum of 20.86% in the post-monsoon season.

3.2. Temporal variation of $PM_{2.5}$ and BC

The Modern-Era Retrospective analysis for Research and Applications, Version 2 data were analysed to check the temporal

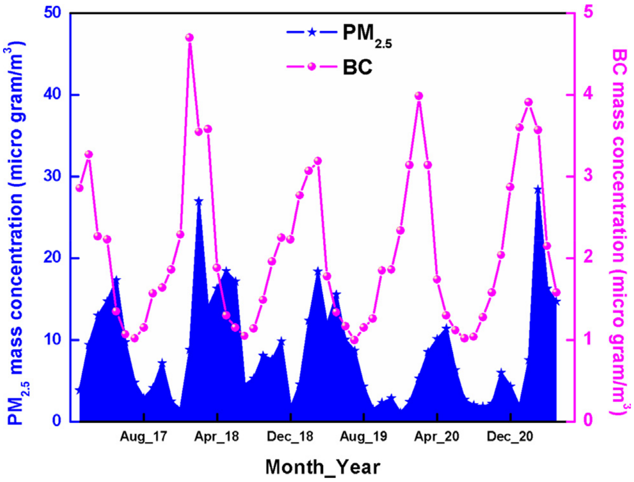

Fig. 9. Monthly variation in $PM_{2.5}$ and black carbon mass concentration for the period of June 2017 to May 2021 over Guwahati.

variability particulate matter of size range less than 2.5 µm ($PM_{2.5}$) and black carbon concentration for the period of January 2017 to September 2021.The annual variation of $PM_{2.5}$ (Fig. 5) shows highest value (15.26 ± 4.67 µg/m^3) during pre-monsoon and lowest in post-monsoon (5.07 ± 2.98 µg/m^3) season.

Highest $PM_{2.5}$ during pre-monsoon season over the study location may be due to Jhum cultivation practice over the region and lowest in post-monsoon season may be due to wash out of pollutants during monsoon months. Positive co-relation between $PM_{2.5}$ and MODIS retrieved fire counts mostly associated with the biomass burning activities over Dibrugarh [18] had been reported. A seasonal variation in BC mass concentration mostly happens over a location due to differences in the atmospheric boundary layer depth with differences in sources of production [19]. Peak value of BC (Fig. 6) is observed during winter (3.18 ± 0.71 µg/m^3) season due to enhancement indoor/outdoor burning

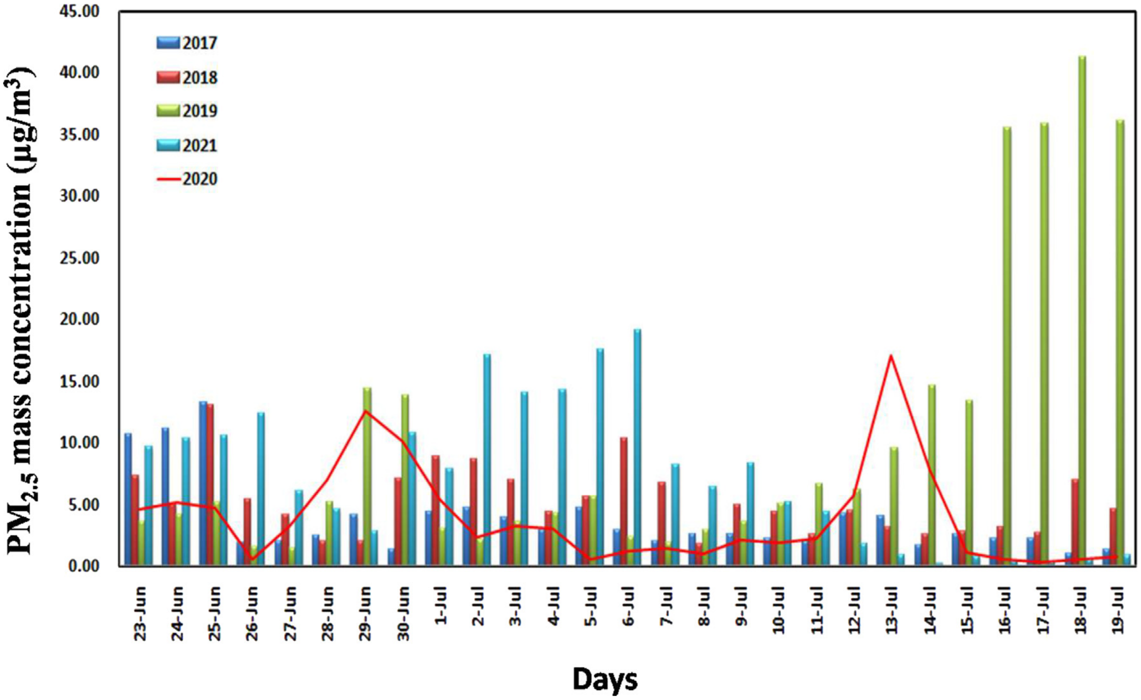

Fig. 8. Daily variation in $PM_{2.5}$ mass concentration from 23rd June to 19th July for the year 2017 to 2021 over Guwahati.

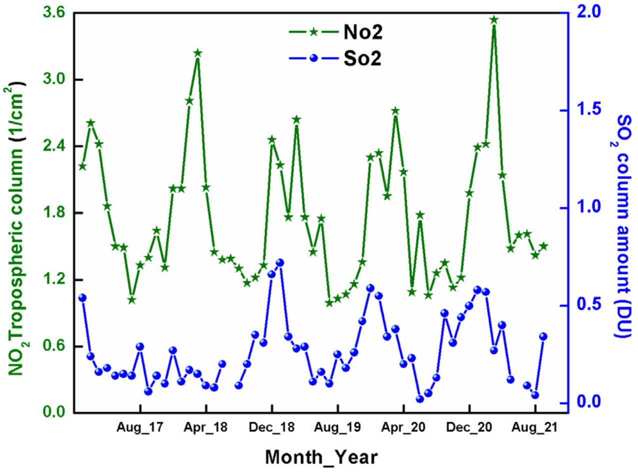

Fig. 10. Monthly variation in NO_2 Tropospheric column and SO_2 column amount for the period of June 2017 to May 2021 over Guwahati.

activities along with vehicular emissions and least in monsoon (1.17 ± 0.16 μg/m^3) season mainly due to wash out by rainfall. During monsoon season the boundary layer height increases due to which spread of the near surface pollutants including BC occurs. Increasing boundary layer height and reducing local burning activity results in decreasing the concentration level of BC aerosol particles. Less rainfall along with continuous generation of BC that last longer lifetime in atmosphere resulted in a stable raise in BC concentration level during the winter season. By using ground based instrument like Aethalometer, similar seasonal variation of mean BC mass concentration had been found over Dibrugarh [19].

3.3. Variation in air pollutants during the lockdown period

To check the effect of lockdown on AOD, we have compared the AOD for the month of March, April, and May from the year 2017 to 2021 over the study location (Fig. 7).

Pre-monsoon (March-May) seasonal AOD for the pandemic year 2020 was decreased by ~ 23% after lockdown as compared to same season of normal years over Guwahati. To check the direct effect of COVID-19 lockdown on local pollutant level, we have studied the MEERA-2 hourly $PM_{2.5}$ surface mass concentration data for the lockdown period in Guwahati. Fig. 8 shows the daily $PM_{2.5}$ concentration variation from 23rd June to 19th July for the year 2017–2021. Almost all the lockdown days in the year 2020 shows lower concentration value as compared with those days of Pre-Covid and Post-Covid year. The daily average $PM_{2.5}$ concentration during lockdown period in Guwahati is nearly ~ 60.63% and ~ 54.37% less than that for the Pre-Covid and Post-Covid period respectively which clearly shows improvement of air quality over the study location.

The monthly variation of $PM_{2.5}$, BC and NO_2 Tropospheric column along with SO_2 column amount over Guwahati including Covid-19 lockdown period is shown in Fig. 9 and Fig. 10 respectively.

Significant reduction in $PM_{2.5}$ mass concentration value during Covid-19 lockdown months has been observed which indicates short term improvement of air quality over Guwahati. Tropospheric column NO_2 exhibits same seasonality as AOD with highest value in pre-monsoon and lowest value in post-monsoon

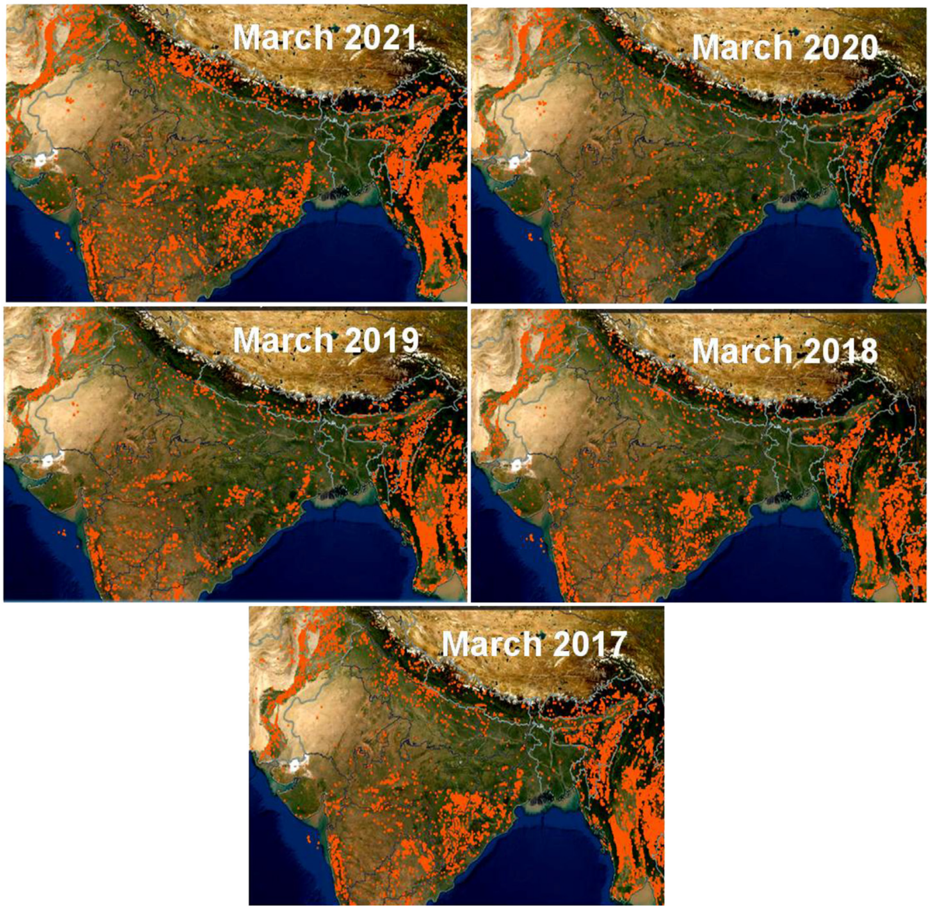

Fig. 11. March month MODIS fire count map covering North East India from the year 2017 to 2021.

season which may be due to same source of origination of both NO_2 and AOD.

Both NO_2 and SO_2 show lower value during Covid-19 lockdown months over Guwahati. A significant correlation between AOD and tropospheric NO_2 (correlation coefficient of 0.8 and 0.6 respectively) over Western and Eastern Europe has been reported [20] which clearly indicates the sources that emit NO_x also drive the AOD. Sudden rise of $PM_{2.5}$ value during March 2021 may be due to increasing fire related activity during pre-monsoon over NE Indian region (Fig. 11). Higher burning activity during pre-monsoon season over North-East India is mainly due to widespread biomass burning activity especially as a part of Jhum cultivation which involves burning of stretches of forests and growing a number of crops after every 4–5 in this region [18].

Fire emissions contributed more than 1 $\mu g/m^3$ of daily average $PM_{2.5}$ concentrations during more than 30% of days of fire season in the western USA and northwestern Canada [21].

4. Summary and conclusion

The Covid-19 lockdown results considerable reduction of AOD, $PM_{2.5}$ and BC level over Guwahati. A main reason for this is due to reduction of air pollutant from transportation, power plants, industries, residential plus constructive activities, biomass burning, road dust etc. during the lockdown period. Pre-monsoon (March-May) seasonal AOD for the pandemic year 2020 was decreased by $\sim$ 23% after lockdown as compared to same season of normal years over Guwahati. The seasonally averaged AOD reached its peak value in pre-monsoon (0.78 ± 0.09), followed by winter (0.59 ± 0.10) and monsoon (0.52 ± 0.05), with the minimum taking place in post-monsoon (0.38 ± 0.08) season. The monthly average AOD varies from its highest value (0.82 ± 0.18) in May to its lowest value (0.36 ± 0.10) in October for the study period over Guwahati. Tropospheric column NO_2 exhibits same seasonality as AOD with highest value (0.21×10^{16} molecules cm^{-2}) in pre-monsoon and lowest value (0.13×10^{16} molecules cm^{-2}) in post-monsoon season which may be due to same source of origination of both NO_2 and AOD. Conversely, SO_2 does not vary much from the five-year average value during the lockdown period. Higher emission of SO_2 is mainly due to increase of the burning of fossil fuels in power stations, oil refineries, cement, fertilizer, industries etc. Less number of such types of emission sources near the study location may be the reason due to which SO_2 column amount does not affect much during Covid-19 lockdown period. The daily average $PM_{2.5}$ concentration during lockdown period in Guwahati is nearly $\sim$ 60.63% and $\sim$ 54.37% less than that for the Pre-Covid and Post-Covid period respectively which clearly shows improvement of air quality over the study location. Significant reduction in $PM_{2.5}$ mass concentration value during Covid-19 lockdown months has been observed which indicates short term improvement of air quality over Guwahati. Restriction of movements of all types of vehicles along with shut down of industrial activities resulted in decrease of atmospheric pollutants which clearly establishes the direct effect of anthropogenic on ambient air quality.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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