Aerosol and Air Quality Research

Lockdown to Contain the COVID-19 Pandemic: An Opportunity to Create a Less Polluted Environment in India

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ABSTRACT

Keeping aside the economic consequences, the imposition of strict lockdown in order to break the chain of deadly infection of SARS-CoV-2, has potentially improved the global environmental quality by facilitating a significant reduction in atmospheric pollution. In the present study, the level of atmospheric pollutants in India *viz.,* NO_2, AOD, and $PM_{2.5}$ before and during lockdown 2020 were assessed and compared using standard methods. The study revealed a significant reduction in NO_2 i.e., > 10% change in 73.71% parts in India along with a high negative anomaly of AOD (< -1.0 in 32.92% parts in India) primarily in the Indo-Gangetic Plains, western, southern, and eastern parts during the lockdown. The five megacities observed a sharp decline in the daily mean concentration of $PM_{2.5}$ (*ca.* 32% (Delhi) to 59.62% (Bengaluru)) during the lockdown 2020 as compared to the analogous period of lockdown in 2019. The study exhibited the very less contribution of seasonal and meteorological variables in the abatement of pollution during the lockdown period. The findings may be useful in guiding future strategies to maintain environmental quality by adopting a well-planned lockdown strategy.

Keywords: NO_2, AOD, $PM_{2.5}$, Lockdown in India

1 INTRODUCTION

Coronavirus disease (COVID-19) caused by SARS-CoV-2 first reported in Wuhan, China in late December 2019 (Chen *et al.*, 2020). Subsequently, it spreads to the larger parts of the globe very rapidly through human transmission (WHO, 2020a). Globally 2,973,264 cumulative cases of infection with 6.95% (206,569) of deaths, and 29.22% (868,806) of recovery has been reported till 26 April 2020 (WHO, 2020b). In India, the first positive case of COVID-19 was reported on 30 January 2020 in Kerala, when a student arrived from China (Reid, 2020), and later a set of cases was recorded across Delhi with a tourist group of 14 Italian, and 01 Indian on 03 March 2020 (Perappadan, 2020). A major outbreak of COVID-19 started in the month of March 2020 through its increasing number of cases across the country leading to 5000 infected cases with 27 death tolls till 07 April 2020 (Jha, 2020), and it reached a total of 28,074 infected cases with 826 deaths by 26 April 2020 (MoHF, 2020; WHO, 2020b). A similar trend was also observed in the case of
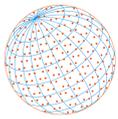
COVID-19 recovery from 75 to 5913 patients during the period (07–26 April 2020). Considering human transmission as one of the significant causes of the pandemic, the Government of India (GoI) forced a complete countrywide lockdown targeting minimized social interactions, and mass gathering from 25 March 2020 in a phased manner to break the chain of the deadly infection. It is the biggest lockdown in history with a ~1.3526 billion population under the direct impact. The phase 1 of lockdown in India was started from 25 March to 14 April 2020, which later extended to 03 May 2020 in phase 2, and again continued to 17 May 2020 in phase 3. This lockdown led to the shutdown of all industries, businesses, parks, educational institutions, rail, road, and air transportations, and other crucial social interactions. Very essential activities and services including medical, security, and food supply remained out of shutdown implementation.

The complete lockdown throughout the country had brought major economic disruption in supply chains, tourism, and business travel (Boone *et al.*, 2020; WTO, 2020). Though, the lockdown substantially affected the global economy, disrupt human lifestyle, mental health, as well as the livelihood of the marginal population at large, a positive impact on the environment has also been evident (Garg *et al.*, 2020; Lal *et al.*, 2020; Muhammad *et al.*, 2020; Patel *et al.*, 2020; Zalakeviciute *et al.*, 2020) in the form of recovery, and rejuvenation of various natural processes. The discontinuation of various anthropogenic activities primarily industries and automobiles brought a significant reduction in the level of atmospheric pollution from local (Li and Tartarini 2020; Şahin 2020; Sfîcă *et al.*, 2020; Wan *et al.*, 2020) to global scales (Cadotte, 2020; Sharma *et al.*, 2020; Spinelli and Pellino, 2020) as it linked with global warming, that exuberates climate change (Lahsen, 2008; Cushman, 2011; McLaughlin, 2011). Large scale planning forums like the Intergovernmental Panel on Climate Change (IPCC), International Union of Air Pollution Prevention and Environmental Protection Associations (IUAPPA), United Nation Environment Programme (UNEP), United Nation Framework Convention on Climate Change (UNFCCC) have continuously been working since long to deduce the solutions through ecosystem-based disaster risk reduction (EbDRR), and nature-based solutions (NBS) (Parry and Carter, 1998; de Nazelle *et al.*, 2011; IPCC, 2018; Saikia *et al.*, 2020).

Considering the environmental impacts of lockdown, an attempt has been made to quantify the spatio-temporal changes in the level of atmospheric pollution in India during the post lockdown period as compared to the previous. The objectives of the study were (i) to assess and compare the level of atmospheric pollutants (e.g., NO_2 and AOD) before and during the lockdown in the country including the concentration of $PM_{2.5}$ in the five megacities of India, and (ii) to study the effectiveness of the lockdown in improving the environmental quality.

2 DATA USED AND METHODOLOGY

Satellite-based pollution data and pollution station data were used to monitor the variability in atmospheric pollutants for the pre lockdown (01–24 March 2020), and lockdown periods (25 March–20 April 2020). Tropospheric nitrogen dioxide (NO_2) column density datasets were acquired from the Sentinel 5-P TROPOMI sensor (Veefkind *et al.*, 2012) were compared with the pre-lockdown to lockdown period in 2020 and analogous periods in 2019. Later, the percentage change of NO_2 was estimated using Eq. (1).

Percentage Change of NO_2 = $((NO_2\ 2019_{LD} - NO_2\ 2020_{LD})/NO_2\ 2019_{LD}) \times 100$ $\qquad$ (1)

Daily aerosol optical depth (AOD) was acquired from MODIS Terra/Aqua MOD08, and MYD08 land datasets (Platnick *et al.*, 2014, 2015) for the pre-lockdown period (01–4 March), lockdown period (25 March–20 April) in 2020, and analogous lockdown periods in 2019. Long-term observations (2000–2020) of the analogous periods of pre-lockdown, and lockdown were considered for anomaly estimation. Also, the standardized anomaly was calculated for the long-term variability of AOD (Eqs. (2) and (3)).

Normalized Anomaly = Observation – climatological mean $\qquad$ (2)

Standardized Anomaly = Normalized anomaly/Standard deviation $\qquad$ (3)
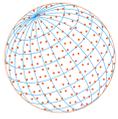
Station data of $PM_{2.5}$ of five megacities of India *viz.,* Delhi (24 stations), Mumbai (10 stations), Kolkata (7 stations), Chennai (4 stations), and Bengaluru (7 stations) were acquired from Central Pollution Control Board (CPCB) (https://www.cpcb.nic.in/). The daily mean of all stations of each megacity was used to map the temporal variations of $PM_{2.5}$ during the pre-lockdown and lockdown periods (25 March to 30 April) in 2020 and analogous lockdown periods in 2019. The TRMM based daily cumulative precipitation data were acquired from Giovanni (https://giovanni.gsfc.nasa.gov/giovanni/) and used to deduce its possible influence in the reduction of pollution levels in the select megacities.

3 RESULTS AND DISCUSSION

3.1 Variability in Atmospheric Pollution

A low to moderate reduction was observed in the concentration of tropospheric NO_2 during lockdown 2020 (0.00004–0.00006 mol m^{-2}) as compared to the pre-lockdown period (~ 0.00006–0.00007 mol m^{-2}) in the larger part ($\sim 73.71\%$) of India, primarily evident in the Indo-Gangetic Plains (IGP), and western parts (Figs. 1(a)–1(b)). When compared with the analogous lockdown period in 2019 (i.e., from 25 March to 20 April 2019), a moderate to a high reduction in NO_2 (~ 0.00001 to 0.00004 mol m^{-2}) was observed during lockdown 2020 that clearly exhibited the impact of the total shutdown of human activities on the atmosphere (Figs. 1(b)–1(c)). Approximately ⅕th (18.78%) part of India observed high to very high reduction ($> 20\%$) in NO_2, which is primarily evident in the (a) eastern to south-western parts, as well as (b) in the northern to western parts of India (Fig. 1(d)). Although a large part of the country observed a sharp reduction in NO_2 primarily in the regions of major sources due to sudden suspension of development activities (*viz.,* mining activities, power generation, small to large sector industries, high vehicular movements, urban hubs, slash and burn agriculture), a few regions in eastern and north-eastern India observed a slight increase in NO_2 may be attributed to an increase in mining, power generation, and associated activities during the lockdown period (Ranjan *et al.,* 2020).

The lockdown 2020 due to the COVID-19 pandemic led to a decrease in the atmospheric pollutants and suspended particulate matters resulting in a decrease in AOD. The standardized anomalies (SAs) of AOD during the pre-lockdown period with respect to long-term observations (2000–2020) of analogous periods exhibited an overall high positive AOD anomaly (> 1.0) in major parts of India (Fig. 2(a)). The SA of AOD during the lockdown 2020 showed a significant reduction
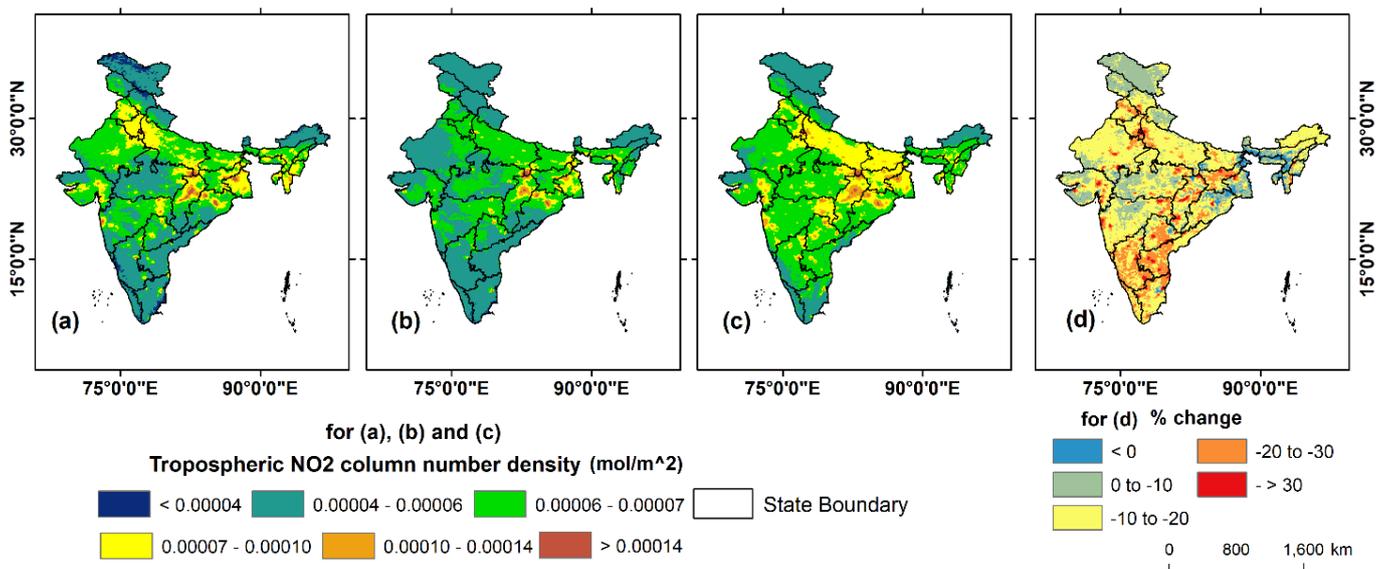

Fig. 1. Distribution of tropospheric NO_2 during (a) pre-lockdown 2020, (b) lockdown 2020, (c) its comparison with analogous lockdown period in 2019, and (d) percentage change in NO_2 concentration during lockdown 2020, and analogous lockdown period in 2019.
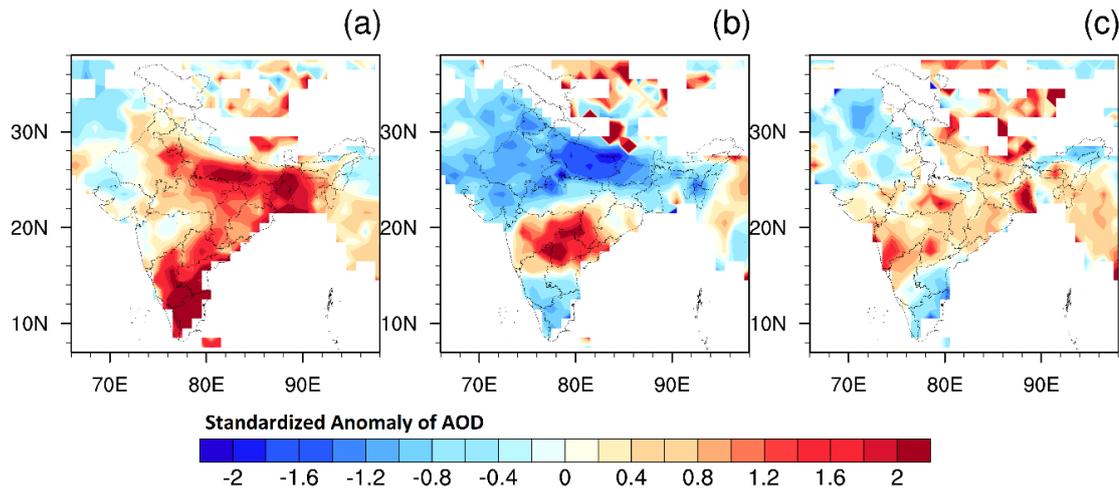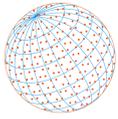
Fig. 2. Long-term observations (2000–2020) based standardized anomaly of AOD of (a) pre-lockdown 2020, (b) lockdown 2020, and (c) its difference with analogous lockdown period in 2019.

as apparent from the negative anomaly (< -1.0) in the 32.92% parts of India. Considerable reduction in AOD was observed in the IGP (~-0.4 to -1.2) followed by western (~-0.4 to -0.6), southern (~-0.2), and eastern (~ -0.4) parts of India. However, ~8.38% of the total geographical area comprising lower central India covering the states of Chhattisgarh, Maharashtra, and Odisha had a high positive AOD anomaly (> 1.0) during the lockdown 2020 (Fig. 2(b)). The analogous lockdown period in 2019 exhibited a large part of the country under positive low (0.4–0.8) to high (> 1.0) anomaly of AOD, barring parts of extreme southern, western, and north-eastern India. While comparing the periodic observations of lockdown 2020 with analogous lockdown period in 2019 (Fig. 2(c)), a sharp reduction in AOD was evident illustrating its disassociation with seasonal variation.

An episodic variation in the concentration of $PM_{2.5}$ was observed during the pre-lockdown period (2020) but remained high in most of the stations in Delhi (major range: 200–400 µg m^{-3}; daily mean: 133 µg m^{-3}) followed by Kolkata (50–300 µg m^{-3}; daily mean: 80 µg m^{-3}), Mumbai (50–200 µg m^{-3}; daily mean: 57 µg m^{-3}), Bengaluru (50–150 µg m^{-3}; daily mean: 40 µg m^{-3}), and Chennai (30–80 µg m^{-3}; daily mean: 37 µg m^{-3}) during working days, and low during weekends (Fig. 3). The study illustrated a sharp decline (*ca.* 46–75% reduction) in the daily mean concentration of $PM_{2.5}$ in all the five megacities during the lockdown 2020 (25 March to 20 April) as compared to the pre-lockdown period (01–24 March) in 2020. A significant reduction in $PM_{2.5}$ was observed in Mumbai (–75.44% change in daily mean), followed by Kolkata (–64.62%), Delhi (–58.87%), Chennai (–54.01%), and the least reduction in Bengaluru (–46.88%) during lockdown 2020 than pre-lockdown 2020 (Table 1). It is to note that the variations in the concentration of $PM_{2.5}$ coincide with the phases of lockdown. A rise in the concentration of $PM_{2.5}$ (100–200 µg m^{-3}) was observed after the end of the first phase of lockdown (14 April 2020) in Delhi, that may be attributed to the resumption of certain official activities with limited employees (~33%) led to the movement of automobiles. In contrast, Mumbai (50–70 µg m^{-3}), and Kolkata (20–50 µg m^{-3}) observed continuous decline during the subsequent phases (barring minor exceptions) exhibited the implication of a total shutdown of anthropogenic activities (Fig. 3).

The comparative analysis of the concentration of $PM_{2.5}$ during the lockdown period of 2020 and its analogous periods in 2019 exhibited a reduction of *ca.* 32% (Delhi) to 59.62% (Bengaluru) illustrating the implications of COVID-19 induced lockdown and its disassociation with seasonal variations. Looking into the possible influence of meteorological variables in a reduction of the concentration of $PM_{2.5}$, the daily cumulative precipitation in the select megacities was analyzed. The study exhibited a very few episodic incidences of moderate precipitation (> 50 mm day^{-1}) during the lockdown period (2020) primarily in Chennai (02 incidences), and Bengaluru (01 incidence), in contrast, low precipitation (20–50 mm day^{-1}) in Kolkata (02 incidences), and Bengaluru (01 incidence) that led to a slight reduction in the concentration of $PM_{2.5}$. Barring these few exceptions, the major reduction in the concentration of $PM_{2.5}$ is primarily attributed to the
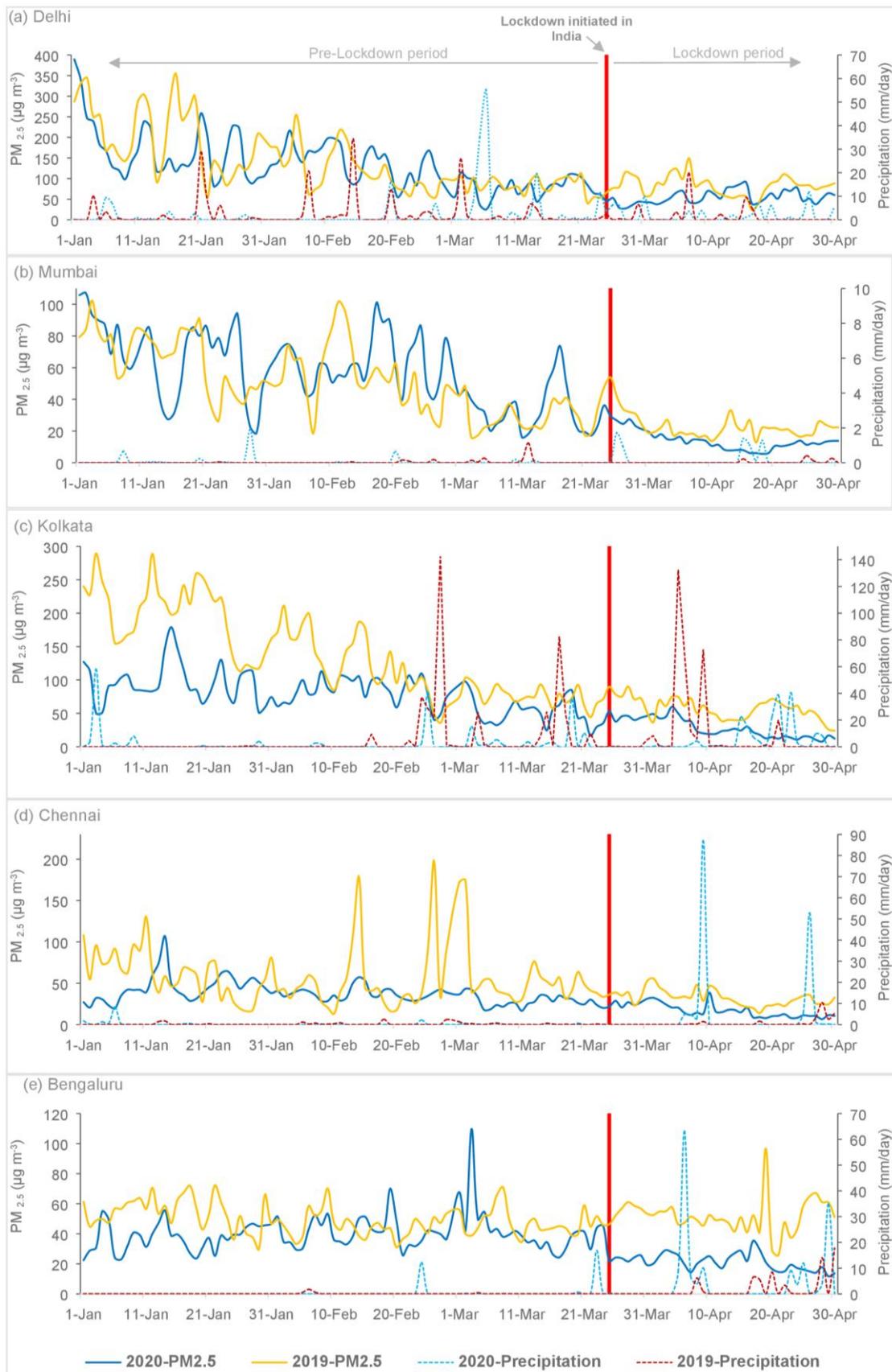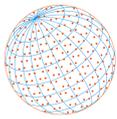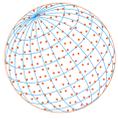
Fig. 3. Variability in the concentration of PM$_{2.5}$ in (a) Delhi, (b) Mumbai, (c) Kolkata, (d) Chennai, and (e) Bengaluru during pre-lockdown 2020, during lockdown 2020, and analogous periods (pre-lockdown and lockdown) in 2019 (source: https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing).

Table 1. Daily mean concentration of $PM_{2.5}$ in five megacities in India during pre and post lockdown 2020.

Megacities	Pre-lockdown 2020 (01 January–24 March 2020)	Lockdown 2020 (25 March–30 April 2020)	Analogous Period of Lockdown (25 March–30 April 2019)	% Change during pre-lockdown and lockdown period in 2020	% Change during lockdown 2020 and analogous lockdown in 2019
Delhi	133	55	82	–58.87	–32.92
Mumbai	57	14	24	–75.44	–41.66
Kolkata	80	28	58	–64.62	–51.72
Chennai	37	17	32	–54.01	–46.87
Bengaluru	40	21	52	–46.88	–59.62
Average	69.4	27	49.6	–59.964	–46.558

suspension of human activities during the lockdown period 2020. The least reduction in the $PM_{2.5}$ in Bengaluru during the lockdown period was also attributed to the early state-wide lockdown (19 March 2020) than that of other megacities (25 March 2020).

The present study is a modest attempt to assess the impacts of national lockdown on the quality of the environment in terms of emission of NO_2, AOD, and $PM_{2.5}$. We agree that the findings of this study are based on data for a relatively short time period, and the availability of more data on various emission parameters might potentially bring further clarity on the degree to which the lockdown has contributed to improving the environmental quality. Nonetheless, the results till now have shown a clear trend on the improvement in the quality of the environment. We strongly believe that the availability of emission data in the coming days would conform to and reinforce the findings of the present study.

4 CONCLUSIONS

The lockdown resulted in substantial improvement in the environmental quality with a sharp reduction in the concentration of various atmospheric pollutants. The daily mean $PM_{2.5}$ decreased by *ca.* 46 to 75% in different megacities from the pre-lockdown period to ~37 days after the lockdown 2020. Although the atmospheric pollutants are influenced by meteorological variables, there were very limited incidences of moderate and low precipitation during the lockdown 2020. Also, the concentration of $PM_{2.5}$ during the lockdown period of 2020 was reduced by *ca.* 32% (Delhi) to 59.62% (Bengaluru) while comparing with the analogous periods in 2019, exhibiting the direct influence of COVID-19 induced lockdown in the abatement of atmospheric pollutants ($PM_{2.5}$) in the country. Similarly, there was a significant reduction in NO_2 ($>$ 10% reduction in NO_2 evident in 73.71% of India), and AOD (SA of $<$ –1.0 in 32.92% of India) during the 27 days of lockdown 2020. The findings of this study may be useful for the government as well as different national and international organizations in developing effective management strategies for curbing environmental pollution in the future.

ACRONYM

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AOD	Aerosol Optical Depth.
CPCB	Central Pollution Control Board.
EbDRR	Ecosystem-based disaster risk reduction.
IPCC	Intergovernmental Panel on Climate Change.
IUAPPA	International Union of Air Pollution Prevention and Environmental Protection Associations.
LD	Lockdown.
MoHFW	Ministry of Health and Family Welfare, Government of India.
NA	Normalized Anomaly.
NBS	Nature-based solutions.
NO_2	Nitrogen Dioxide.
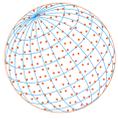
PM$_{2.5}$ Particulate Matter less than 2.5 micrometer.
SA   Standardized Anomaly.
UNEP   United Nation Environment Programme.
UNFCCC   United Nation Framework Convention on Climate Change.
WHO   World Health Organization.
WTO   World Trade Organization.

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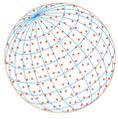
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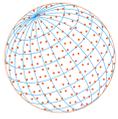
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