Significant change in air quality parameters during the year 2020 over 1st smart city of India: Bhubaneswar

Saroj Kumar Sahu1 · Bhishma Tyagi2 · Gufran Beig3 · Poonam Mangaraj1 · Chinmay Pradhan1 · Shilpa Khuntia1 · Vikas Singh4

Received: 11 August 2020 / Accepted: 3 November 2020 / Published online: 12 November 2020 © Springer Nature Switzerland AG 2020

Abstract
Prevention of Coronavirus results in lockdown in India from 24 March 2020 to 31 May 2020. Eastern India, which is having a dense cluster of coal-fired power plants and home to many mines, mineral industries, has not shutdown power plants and coal mines during this lockdown period, though other industrial and vehicular emissions were almost zero. The present study attempts to find the change in various atmospheric pollutants during this lockdown period over an eastern tropical Indian station—Bhubaneswar, which is the first smart city proposed in smart city mission of Government of India. The study analyses hourly concentrations of PM2.5, PM10, NO\textsubscript{X}, O\textsubscript{3}, and CO for March–May 2019 and 2020. The study shows a significant increase (rather than decrease) in PM2.5 and PM10, increase in O\textsubscript{3} and a decrease in CO and NO\textsubscript{X} during the lockdown period. Results are advocating the impact of transported pollution over the study area for maintaining the PM2.5 and PM10 values even during the lockdown situation.

Keywords Air pollution · Particulate matter · Nitrogen dioxide · Sulphur dioxide

1 Introduction
The year 2020 marked the global spread of the novel Coronavirus, which was declared as a pandemic by WHO on 30 January 2020 [33]. Following the news, various countries put strict restrictions on the movement of people, eventually resulting in the complete stop for movement and work, known as “lockdown” for a certain period in most of the countries. The Government of India announces the first lockdown on 24 March 2020 (https://www.mygov.in), which was extended in phases till 31 May 2020 over the whole country. Lockdown emerges as a measure for controlling the movement of people globally, useful in stopping the spread of Coronavirus [17]. Lockdown observance by the stoppage of vehicular and industrial emissions positively affected the environment and most of the places observed cleaner air and better water qualities [1, 2, 18].

Air pollution is one of the leading causes of mortality worldwide, and ~4.2 million people die every year due to various air pollution impacts globally (https://www.who.int). The impact of air pollution on health is a slow pace process, and most of the megacities in developing countries have poor value of air quality throughout the year [16]. The lockdown phase related to coronavirus in 2020, allows an unprecedented low values of pollution in last couple of decades over many places globally [5, 29]. The mark of pollution change due to Coronavirus lockdown is tremendous in developing countries like India and China (e.g. [2, 4, 13, 19, 28]). Though most of the studies focused on Indian region reported either megacities of India (e.g. Kumar et al. [29]), or focused on Indo-Gangetic plain and...
other megacities (e.g., [13, 15, 29]). In general, the studies over India reported a decrease in aerosols, NO\textsubscript{x}, SO\textsubscript{x}, CO and CO\textsubscript{2} and increase in surface ozone (O\textsubscript{3}) (where the percentage varies with pollutant and city) during the lockdown period, and advocated the cleaner environmental benefits due to lockdown [20]. Though, the lockdown had restricted vehicular movement and limited industrial operations, the consumption of electricity decreased only by 9.2% (overall value) during the period, with even higher consumptions at few places [27].

In India, most of the power plants producing electricity are coal-fired thermal power plants [23], and the coal burning in these plants produces high emission of NO\textsubscript{2}, SO\textsubscript{2} and aerosols (to a radius of ≥ 100 km surrounding the plant location) [11]. Eastern India, which is home to many high capacity coal-fired thermal power plants [10], has not reported significant studies of pollution changes during Coronavirus lockdown period over India. The present work analyses the data of Particulate Matter (PM\textsubscript{2.5}, PM\textsubscript{10}), Nitrogen Oxides (NO\textsubscript{x}), surface ozone (O\textsubscript{3}), and Carbon Monoxide (CO) before and during the Coronavirus lockdown over the first smart city of India-Bhubaneswar [24], which is the state capital of eastern Indian state Odisha. To mark the difference in concentrations visually, we also compared the data of 2020 with same period data of 2019 over the site. The objective of present work is to identify how the pollutants are changing during lockdown over eastern Indian tropical cities and whether the decrease is matching with the reported percentage over other parts of the country. The present study also employs back trajectory analysis based on 2-day back trajectory made by lagrangian model HYSPLIT to investigate if the source regions differ during the lockdown period.

2 Site description, data and methodology

The sampling site for the present study is Bhubaneswar, which is the capital city of state Odisha, and was adopted as the first smart city by Government of India in March 2016 (Smart City Mission [31]). The monitoring station is set up in the premises of Utkal University (20.18°N, 85.50°E, 45 above MSL), Bhubaneswar, which is ~ 500 m away from the National highway. The city is an important centre for socio-economic and cultural activities, making it a destination hub for tourists in eastern India, with many eateries around the town, including few using traditional wood and coal burning. The site location is shown in Fig. 1.
which marks that the study site is surrounded by highly urbanised areas, and nearby to the Kuakhai River, which is a tributary of the famous Mahanadi River. The study site is at ~4 km spatial distance from Kuakhai River (to the eastern side to the site) and at ~6.2 km spatial distance (in south-west direction) to the Biju Pattnaik International airport of Bhubaneswar. Further details of the site can be obtained from Sahu et al. [24]. Bhubaneswar comes under Khorda district of Odisha, which marks the Coronavirus impact significantly with a total of 11,288 Coronavirus cases till 22 October 2020 (https://health.odisha.gov.in/). The first case of Coronavirus in Odisha state was reported in Bhubaneswar on 16 March 2020, and the first death due to virus of Odisha state was also reported in Bhubaneswar on 6 April 2020 (https://health.odisha.gov.in/).

The present study analyses hourly data of Particulate Matter (PM$_{2.5}$, PM$_{10}$), Nitrogen Oxides (NO$_x$), surface ozone (O$_3$), and Carbon Monoxide (CO) concentrations through US-EPA approved analyzers and meteorological parameters (humidity, solar radiation, temperature, wind speed and direction) for March 2019–May 2019, and March 2020–May 2020. The details of instruments model and make can be obtained from Sahu et al. [24] and https://www.safar.tropmet.res.in. Details about Coronavirus lockdown dates are obtained from the Government of India website (https://www.mygov.in).

The study analyses data in two ways to understand the variation of various pollutants: (a) Weekly variation from 1 March–31 May 2020 and 1 March–31 May 2019, and (b) percentage change for the weekly analysis. We also analyse the data for total lockdown period (i.e. 24 March–31 May 2020) and similar period of 2019 to get an overall picture of variation. To get the percentage variation in various pollutants, we calculated the percentage change in values of 2020 from that of 2019. The study used NOAA (National Oceanic and Atmospheric Administration) HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectories) model for computing back trajectories. Two days (48 h) isentropic back trajectories were calculated at every three hours using GDAS (Global Data Assimilation System) 1°×1° data sets [7].

3 Results

3.1 Variation in particulate matter (PM$_{2.5}$ and PM$_{10}$) before and during the lockdown

The particulate matter (PM) variation accounts for an essential component of air quality index at any place and is frequently used independently as a proxy for defining air pollution (e.g. [3, 8, 24]). For Coronavirus lockdown most of the researchers have reported a drastic decrease in aerosols/PM over the Indian region [13, 19, 29]. For the present study, variations of PM$_{2.5}$ and PM$_{10}$ for 1 March – 31 May 2020 and 2019 are compared in Fig. 2. It is observed that the values are generally lower for both PM$_{2.5}$ and PM$_{10}$ from the third week of March in both 2020 (Fig. 2a, c) and 2019 (Fig. 2b, d). These reduced values from third week of March are related to frequent thunderstorms occurring over the region [22], associated with a short, intense spell of rainfall washout/rainout the pollutants. Analysing the PM for 2020, during the lockdown period, the values of both PM$_{2.5}$ and PM$_{10}$ remain significant. In comparison to 2019, there is no such decrease as reported by other researchers in different locations of India. The last three weeks are showing a marked increase in PM$_{2.5}$ and PM$_{10}$ in 2020 compared to 2019. Though the mean and median for lockdown period of 2020 is at par with that of 2019, the 99% values are lower in 2020. Lower values of 99% data in 2020 signify that the episodic values recorded in previous years [14, 24] are not observed during the lockdown period of 2020.

The percentage change is giving a clear indication of PM not decreasing as found at various other Indian sites so far (Table 1). The PM$_{2.5}$ values were higher in 2019 for W2–W5 and W12. Similarly, PM$_{10}$ values were higher in W5–W7 and W12–W13 over the site in 2019. For rest, all the weeks both PM$_{2.5}$ and PM$_{10}$ were on the more upper side in 2020, irrespective of lockdown. Here, when we are analysing lower values of PM in certain weeks, we must consider more thunderstorms as one possible reason over the study site and nearby locations in 2020, which will washout the transported pollution and may give a lower percentage of PM at the site in 2020 (https://www.imd.gov.in). The results show that the site is experiencing 37–144% increase in PM$_{2.5}$ and ~2–219% increase in PM$_{10}$ during the lockdown period, contrary to decreasing values of most of the studies.

We also compared the average, standard deviation in variation and median of both PM$_{2.5}$ and PM$_{10}$ for the complete lockdown period of 2020 (i.e. 24 March–31 May), with the same period of 2019 (Table 2). For the total lockdown period, it is observed that there is an increase of 40.26% in PM$_{2.5}$ values, whereas the increase in PM$_{10}$ is only 1.92%. The standard deviation value for PM$_{10}$ was less in 2020 (52.04) compare to 2019 (71.09), whereas for PM$_{2.5}$, the standard deviation values are higher in 2020 (39.91) to 2019 (36.26). Similar to average values, the median values for both PM$_{10}$ and PM$_{2.5}$ are also showing higher concentrations in 2020 during the lockdown period.

The results are surprising as one expects a significant reduction in values during lockdown due to the complete stop of vehicular pollution and industries. The reason for not reducing PM values over Bhubaneswar during lockdown period may be related with the operational
coal-fired thermal power plants in Eastern India [23] and
the non-stop operation of coal-mines in the area [21]. As
the lifetime of PM is of the order of 1–2 weeks (depend-
ing on the size of PM, there is a possibility that PM emit-
ted from these power plants and mining region will travel
to the study region, and maintains the level of PM$_{2.5}$
and PM$_{10}$ on the higher side as visible in Fig. 2c. Such
maintaining high-level PM values are also not
reported so far over global lockdown studies (e.g. [2, 5,
6, 18]). We believe that continuous coal mines operation
during lockdown [21] and coal-fired thermal power plants
emissions in the eastern and central Indian region, where
they are located in a very dense cluster, are the main rea-
sons for not showing decrease in PM values for 2020 even
during lockdown. Another contributory factor may be
residential burning of coal and wood in the region due to
their availability as a cheap/free source of energy [25]. The
results are important for highlighting the relative con-
tribution of the power and mining sector in aerosol loading
over the area.

**Table 1** Percentage change in various pollutants on a weekly basis for 2020 compare to 2019 (W11 data were not adequate for calculating percentage change due to more data gaps)

| Week of the study | PM$_{2.5}$ | PM$_{10}$ | O$_3$ | NO$_x$ | CO |
|-------------------|-----------|-----------|-------|--------|----|
| W1 (1–7 March)    | 13.58     | 76.81     | −30.88| 33.34  | 21.39|
| W2 (8–14 March)   | −61.77    | 48.18     | −8.31 | 24.14  | 5.91 |
| W3 (15–21 March)  | −44.69    | 8.46      | 31.53 | 21.21  | −0.44|
| **Lockdown period** |          |           |       |        |    |
| W4 (22–28 March)  | −46.92    | 2.64      | −28.95| −58.10 | −81.45|
| W5 (29 March–4 April) | −36.30 | −8.69    | 93.30 | −60.37 | −70.44|
| W6 (5–11 April)   | 58.40     | −25.29    | 70.47 | −69.09 | −79.96|
| W7 (12–18 April)  | 37.11     | −45.55    | 57.42 | −47.17 | −1.21|
| W8 (19–25 April)  | 113.94    | 10.65     | −13.80| −54.59 | −36.57|
| W9 (26 April–2 May) | 110.53  | 114.93   | 68.07 | −65.17 | −56.01|
| W10 (3–9 May)     | 144.18    | 219.74    | 13.87 | −62.78 | −44.51|
| W11 (10–16 May)   | −        | −         | −     | −      | −    |
| W12 (17–23 May)   | −11.58    | −21.35    | 55.15 | −41.30 | −42.48|
| W13 (24–31 May)   | 64.21     | −48.73    | 26.98 | −19.25 | −43.37|

Lockdown started on 24 March 2020 and W4–W13 comes under lockdown period.
3.2 Variation in surface ozone ($O_3$), CO and NO$_X$ before and during the lockdown

The non-reduced PM values develop our interests to analyse further the gaseous pollutants, NO$_X$, CO and $O_3$. As we know that CO and NO$_X$ are involved in $O_3$ production/destruction [26, 32], the combined variation of these three parameters will be helpful for getting an insight of pollution change during the lockdown period. Surface $O_3$, as we observe in Fig. 3a, shows no decrease over the site. The values are on the higher side when we compare them with 2019, with more data points going in higher values (top 99% range). The effect of increasing surface $O_3$ starts immediately with the lockdown week, and we observe that from W4 (which is the week after lockdown implementation), the values are going on the higher...

| Parameter | 2020 Avg. (± SD) | Median | 2019 Avg. (± SD) | Median | Percentage change |
|-----------|-----------------|--------|-----------------|--------|------------------|
| PM$_{2.5}$ | 50.73 (± 39.91) | 41.90  | 30.30 (± 36.26) | 25.60  | 40.26            |
| PM$_{10}$  | 83.50 (± 52.04) | 77.90  | 81.89 (± 71.09) | 74.11  | 1.92             |
| $O_3$      | 21.60 (± 10.79) | 20.74  | 19.00 (± 9.67)  | 17.59  | 12.05            |
| NO$_X$     | 8.50 (± 3.47)   | 7.40   | 18.96 (± 2.03)  | 19.92  | −123.07          |
| CO         | 0.57 (± 0.27)   | 0.60   | 1.21 (± 0.25)   | 1.19   | −111.07          |

Fig. 3 Variation in a $O_3$ from 1 March–31 May 2020, b $O_3$ from 1 March to 31 May 2019, c CO from 1 March to 31 May 2020, d CO from 1 March to 31 May 2019, d NO$_X$ from 1 March to 31 May 2020, b NO$_X$ from 1 March to 31 May 2019, respectively. The box-whisker represent 1% data limit (lower X), 99% data limit (upper X), 25, 50 and 75% quartiles with lower upper extreme in the box, and mean values (square) of the weekly data. The X-axis depicts weekly progression with W1 representing 1–7 March, and so on with W13 representing 23–31 May. Lockdown period of 2020 has been masked in (a), (c) and (e), respectively.
side to the comparable 2019 values (Fig. 3b). The CO and NO$_x$ on the other hand, are showing a decrease in values (Fig. 3c, e) after the lockdown was implemented over the region, compared to previous year values (Fig. 3d, f). It can be noticed that last year values were more or less constant, maintaining a higher range of both CO and NO$_x$ over the study region. As observed by box-whisker plots, both NO$_x$ and CO decreased substantially from W4, which is the lockdown start over the site and remains lower in 2020 till W13. As expected, this decrease causes a relative increase in surface O$_3$, except W4 and W8, where the 2019 values were still higher. Surface O$_3$ increases ~13–93%, NO$_x$ decreases ~19–69%, and CO decreases ~19–69%, during the lockdown period at Bhubaneswar (Table 1).

The lockdown period average variations for O$_3$, NO$_x$ and CO are confirming the findings by weekly analysis. Table 2 shows the average, standard deviation and median values for O$_3$, NO$_x$ and CO during lockdown (2020) and same period of 2019 with percentage change for total period based on the average values. It is to be noted here, that O$_3$ has a percentage change of 12.05 (increase) during the lockdown period, which is in support of previous reported studies and the weekly analysis for the present work (Table 1). The NO$_x$ and CO values are decreasing as found in weekly analysis with 123.07% and 111.07% for the lockdown period. Similar increase in O$_3$, and decrease in NO$_x$ and CO are observed for the median values as well, and the standard deviation was higher in 2020 compare to 2019. The lockdown leads to drastic reduction of vehicular emission (~90%) and industrial activities (~56%) [12], and thereby shows a significant reduction in both NO$_x$ and CO over the site. At the same time, there is increase in residential slum burning and cooking activities which account nearly 25% of the total energy consumption. The NO$_x$ values during the lockdown period are reduced to almost half of their values of 2019. It is to be noted that the monitoring station is in close vicinity of national highway and encounters heavy traffic day and night in nearby roads as mentioned in the site description, which causes a visible reduction in values during the lockdown. The reduction of NO emissions causes less removal of O$_3$ through reaction with NO, and allows to build-up higher O$_3$ values. A similar observation of increased surface O$_3$ was also reported by Sicard et al. [30] over European and Chinese cities, Dantas et al. [6] over Rio de Janeiro, Brazil, Nakada and Urban [18] over São Paulo, Brazil, by Collivignarelli et al. [5] over Milan, Italy and by Sharma et al. [29] over twenty cities of India during lockdown periods of respective regions. The analysis shows that the CO, NO$_x$ and O$_3$ are following the reported trends globally during the lockdown, but PM values do not have lockdown effects. To get further clarity of variation in various pollutants, we analysed the percentage change in values of 2020. The results are calculated weekly, and Table 1 summarises the percentage change in various pollutants.

To clarify the role of wind patterns in changing the pollution, we have analysed and compared wind speed and direction along with surface air temperature and relative humidity at the site. Figure 4 depicts the wind rose diagram for 2020 and 2019 during the lockdown period. The surface wind speed and direction certainly changed in 2020 with predominant winds from north-westerly to that of south-westerly in 2019 (Fig. 4b), with a decrease in wind speed in general. Though it is an important observation, we can’t conclude the changing pollution levels in 2020 as the result of changed wind patterns. The transported pollution may travel hundreds of km and indicates the necessity of employing Lagrangian transport modelling in the present study.
3.3 Back-trajetory analysis for identifying possible changes in source regions during lockdown period

We calculated 2 days (48 h) isentropic back trajectories at every three-hour interval using HYSPLIT Lagrangian model for the lockdown period (i.e. 24 March–31 May 2020) and the same period of 2019. The back trajectories are calculated by using GDAS data (mentioned in the data section) with a new trajectory initiated at every 3 h for the study period. The back trajectories are not showing any significant source region change in 2020 to that of 2019 (Fig. 5). As expected, most of the trajectories are coming from coastal regions and Bay of Bengal to the study site with few trajectories approaching from northern and central Indian region [14, 24]. These trajectories reach to the site by crossing high emission regions of coal-fired power plants and coal mining regions of the country [9]. The black box in Fig. 5a and b is similar to box 5 of coal-fired power plants as identified by Guttikunda and Jawahar [10].

Guttikunda and Jawahar [11] proposed the increasing density of number of coal-fired power plants in this region, which may be the cause of higher aerosol concentrations reaching the site even during lockdown. Apart from coal-fired power plants, the box is also encompassing the coal mines region producing higher AOD during lockdown [21]. The results are proposing that there are no apparent changes in source regions bringing higher loads of pollutant to the site during the lockdown period. Though the back trajectories are showing a small difference for the area covered in north–south and east–west expansion in 2019 than 2020, the extents of major contributing areas are same (i.e. eastern and central India regions) in both the years.

4 Conclusions

The present work analyses pollutants (PM$_{2.5}$, PM$_{10}$, O$_3$, CO and NO$_X$) at a tropical coastal station Bhubaneswar during Coronavirus lockdown period in India, and for the same period of the previous year to access the change in pollutants. The results can be summarised as:

- PM$_{2.5}$ and PM$_{10}$ are not decreasing at the site as reported at various other places globally. The variables are showing an increase of $\sim$37–144% (PM$_{2.5}$) and $\sim$2–219% (PM$_{10}$) during the lockdown period. The reason for maintaining high levels can be attributed to the continuous operation of coal-fired thermal power plants and operation of coal-mines in the nearby region, along with coal and woods based biomass burning at residential and slum areas in Bhubaneswar.

- NO$_X$ and CO decrease ($\sim$19–69% and 2–18%) during the lockdown period, showing their direct relation with vehicular and industrial emission over the region. Surface O$_3$ increases ($\sim$13–93%) with this decrease of NO$_X$ and CO.

- Back trajectory analysis shows that there is no change in density or weightage of source regions (mainly power plants and coal mines area) for transporting pollution to the site during the lockdown.

The results are important to understand the baseline pollution over the area and to identify the contribution of power and mining sectors in overall air quality.

Acknowledgements Authors want to acknowledge the Indian Institute of Tropical Meteorology (IITM), Ministry of Earth Science, Govt. of India, for funding the instrumented site under MAPAN program.
Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Arora S, Bhauskhandi KD, Mishra PK (2020) Coronavirus lockdown helped the environment to bounce back. Sci Total Environ 742:140573
2. Bao R, Zhang A (2020) Does lockdown reduce air pollution? Evidence from 44 cities in northern China. Sci Total Environment 731:139052
3. Beig G, Srinivas R, Parkhi NS, Carmichael GR, Singh S, Sahu SK, Rathod A, Maji S (2019) Anatomy of the winter 2017 air quality emergency in Delhi. Sci Total Environment 681:305–315
4. Bherwani H, Nair M, Musugur S, Gupta A, Kapley A, Kumar R (2020) Valuation of air pollution externalities: comparative assessment of economic damage and emission reduction under COVID-19 lockdown. Air Qual Atmos Health 13:1–12
5. Collivignarelli MC, Abbà A, Bertanza G, Pedrazzani R, Ricciardi P, Miino MC (2020) Lockdown for Covid-2019 in Milan: What are the effects on air quality? Sci Total Environment 732:139280
6. Dantas G, Siciliano B, França BB, da Silva CM, Arbilla G (2020) The role of coal technology in redefining India’s climate change agents and other pollutants. Environ Res Lett 12(10):105006
7. Draxler RR, Hess GD (1998) An overview of the HYSPLIT_4 modelling system for trajectories. Aus Meteorol Mag 47(4):295–308
8. Gogikar P, Tyagi B, Gorai AK (2019) Seasonal prediction of particulate matter over the steel city of India using neural network models. Model Earth Syst Environ 5(1):227–243
9. Gogikar P, Tyagi B, Padhan RR, Mahaling M (2018) Particulate matter assessment using in situ observations from 2009 to 2014 over an industrial region of eastern India. Earth Syst Environ 2(2):305–322
10. GuttiKundu SK, Jawahar P (2014) Atmospheric emissions and pollution from the coal-fired thermal power plants in India. Atmos Environ 92:449–460
11. GuttiKundu SK, Jawahar P (2018) Evaluation of particulate pollution and health impacts from planned expansion of coal-fired thermal power plants in India using WRF-CAMx modeling system. Aerosol Air Qual Res 18(12):3187–3202
12. IIP (2020) https://www.busines-standard.com/article/economy-policy/industrial-output-goes-missing-in-april-as-iip-sees-recorde d-fall-of-55-5-120061201189_1.html
13. Jain S, Sharma T (2020) Social and travel lockdown impact considering coronavirus disease (COVID-19) on air quality in megacities of India: present benefits, future challenges and way forward. Aerosol Air Qual Res 20:1222–1236
14. Mahapatra PS, Sinha PR, Boopathi R, Das T, Mohanty S, Sahu SC, Gurjar BR (2018) Seasonal progression of atmospheric particulate matter over an urban coastal region in peninsular India: role of local meteorology and long-range transport. Atmos Res 199:145–158
15. Mahato S, Pal S, Ghosh KG (2020) Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Sci Total Environment 730:139086
16. Marapu P, Cheng Y, Beig G, Sahu SK, Srinivas R, Carmichael GR (2014) Air quality in Delhi during the commonwealth games. Atmos Chem Phys 14(19):10619–10630
17. Mukti A, Ramdhani MW (2020) Lockdown policy as a corona disease (COVID-19) asked from the environmental aspect of life based on law act NO. 32 of 2009 concerning management and protection of environment. Veteran Law Rev 3(1):22–36
18. Nakada LYK, Urban RC (2020) COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil. Sci Total Environment 730:139087
19. Navinya C, Patidar G, Phuleria HC (2020) Examining effects of the COVID-19 national lockdown on ambient air quality across urban India. Aerosol Air Qual Res 20:1759–1771
20. Paital B (2020) Nurture to nature via COVID-19, a self-regenerating environmental strategy of environment in global context. Sci Total Environment 729:139088
21. Ranjan AK, Patra AK, Gorai AK (2020) Effect of lockdown due to SARS COVID-19 on aerosols optical depth (AOD) over urban and mining regions in India. Sci Total Environment 745:141024
22. Sahu RK, Dadich J, Tyagi B, Vlissa NK, Singh J (2020) Evaluating the impact of climate change in threshold values of thermodynamic indices during pre-monsoon thunderstorm season over Eastern India. Nat Hazards 102:1541–1569
23. Sahu SK, Ohara T, Beig G (2017) The role of coal technology in redefining India’s climate change agents and other pollutants. Environ Res Lett 12(10):105006
24. Sahu SK, Tyagi B, Pradhan C, Beig G (2019) Evaluating the variability, transport and periodicity of particulate matter over smart city Bhubaneswar, a tropical coastal station of eastern India. SN Appl Sci 1(5):383
25. Sahu SK, Beig G, Sharma C (2008) Decadal growth of black carbon emissions in India. Geophys Res Lett 35(2):1–5
26. Saraf N, Beig G (2004) Long-term trends in tropospheric ozone over the Indian tropical region. Geophys Res Lett 31(5):1–5
27. Sarfaraz M, Shahzad K, Shah SGM (2020) The impact of COVID-19 as a necessary evil on air pollution in India during the lockdown. Environ Pollut 266:115080
28. Shahzad F, Shahzad U, Fareed Z, Iqbal N, Hashmi SH, Ahmad F (2020) Asymmetric nexus between temperature and COVID-19 in the top ten affected provinces of China: a current application of quantile-on-quantile approach. Sci Total Environment 736:139115
29. Sharma S, Zhang M, Gao J, Zhang H, Kota SH (2020) Effect of restricted emissions during COVID-19 on air quality in India. Sci Total Environment 728:138878
30. Sicard P, De Marco A, Agathokleous E, Feng Z, Xu X, Paolelli E, Rodriguez JJD, Calatayud V (2020) Amplified ozone pollution in cities during the COVID-19 lockdown. Sci Total Environment 745:139542
31. Smart Cities Mission (2017) https://smartcities.gov.in/content/
32. Tyagi B, Singh J, Beig G (2020) Seasonal progression of surface ozone and NOx concentrations over three tropical stations in North-East India. Environ Pollut 258:113662
33. WHO (2020) Rolling updates on coronavirus disease (COVID-19). https://www.who.int/emergencies/diseases/novel-coronaviru s-2019/events-as-they-happen. Retrieved 21 July 2020

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.