Research Article

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

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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 $PM_{2.5}$, PM_{10}, NO_X, O_3, and CO for March–May 2019 and 2020. The study shows a significant increase (rather than decrease) in $PM_{2.5}$ and PM_{10}, increase in O_3 and a decrease in CO and NO_X during the lockdown period. Results are advocating the impact of transported pollution over the study area for maintaining the $PM_{2.5}$ and PM_{10} 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

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other megacities (e.g. [13, 15, 29]). In general, the studies over India reported a decrease in aerosols, NO_X, SO_X, CO and CO_2 and increase in surface ozone (O_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_2, SO_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 ($PM_{2.5}$, PM_{10}), Nitrogen Oxides (NO_X), surface ozone (O_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 India 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,

Fig. 1 Location of study site (Utkal University) marked with a yellow star. Image adopted from Google Earth

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 Pattanaik 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

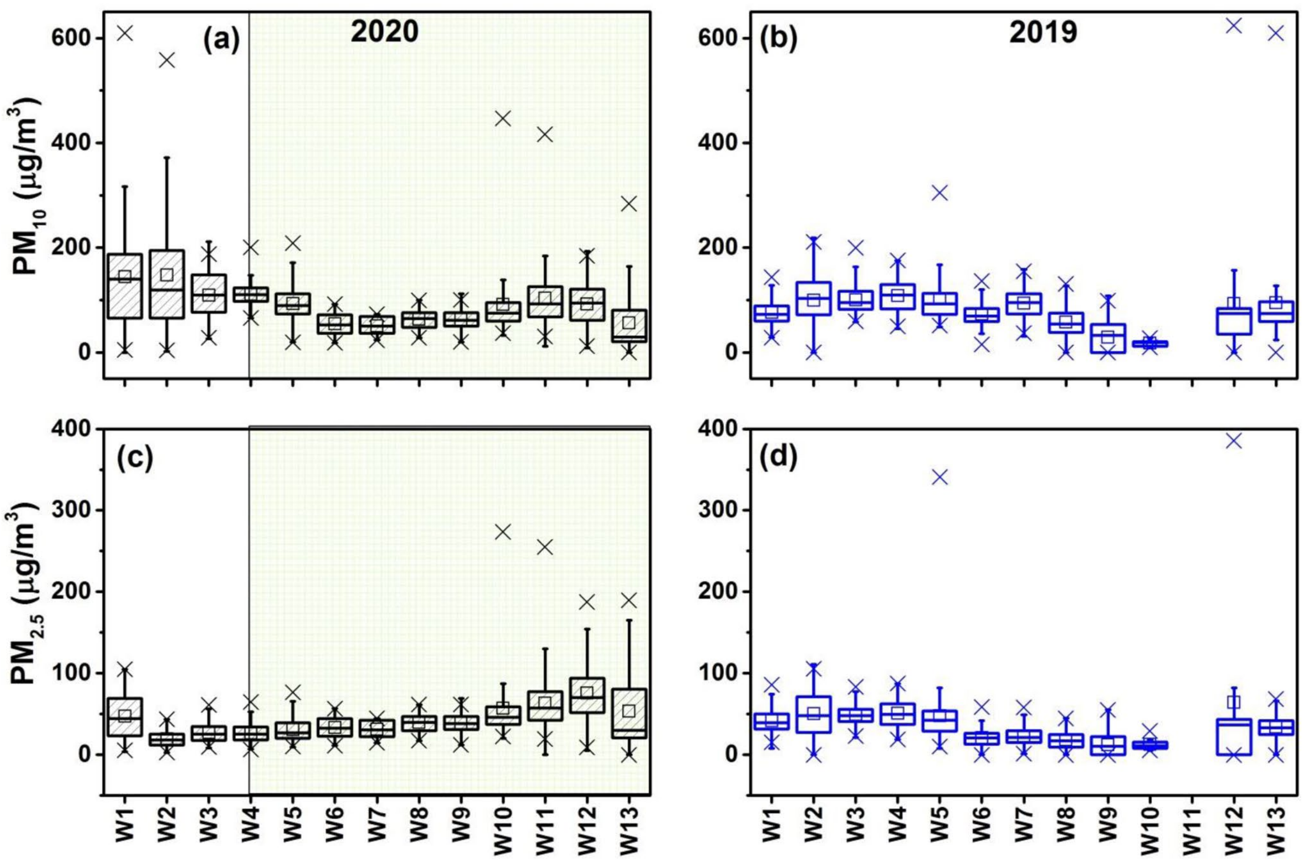

Fig. 2 Variation in **a** PM_{10} from 1 March to 31 May 2020, **b** PM_{10} from 1 March to 31 May 2019, **c** $PM_{2.5}$ from 1 March to 31 May 2020, **d** $PM_{2.5}$ from 1 March to 31 May 2019. The box-whisker represent 1% data limit (lower *X*), 99% data limit (upper *X*), 25, 50 and 75% quartiles 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**) and (**c**), respectively

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

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 (depending on the size of PM, there is a possibility that PM emitted from these power plants and mining region will travel to the study region, and maintains the level of $PM_{2.5}$ and PM_{10}, keeping $PM_{2.5}$ 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 reasons 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 contribution of the power and mining sector in aerosol loading over the area.

Table 2 Average, standard deviation and median values of various pollutants for 24 March–31 May 2020 (lockdown period) and 24 March–31 May 2019, with the percentage change in average values

Parameter	2020		2019		Percentage change
	Avg. (± SD)	Median	Avg. (± SD	Median	
$PM_{2.5}$	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

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

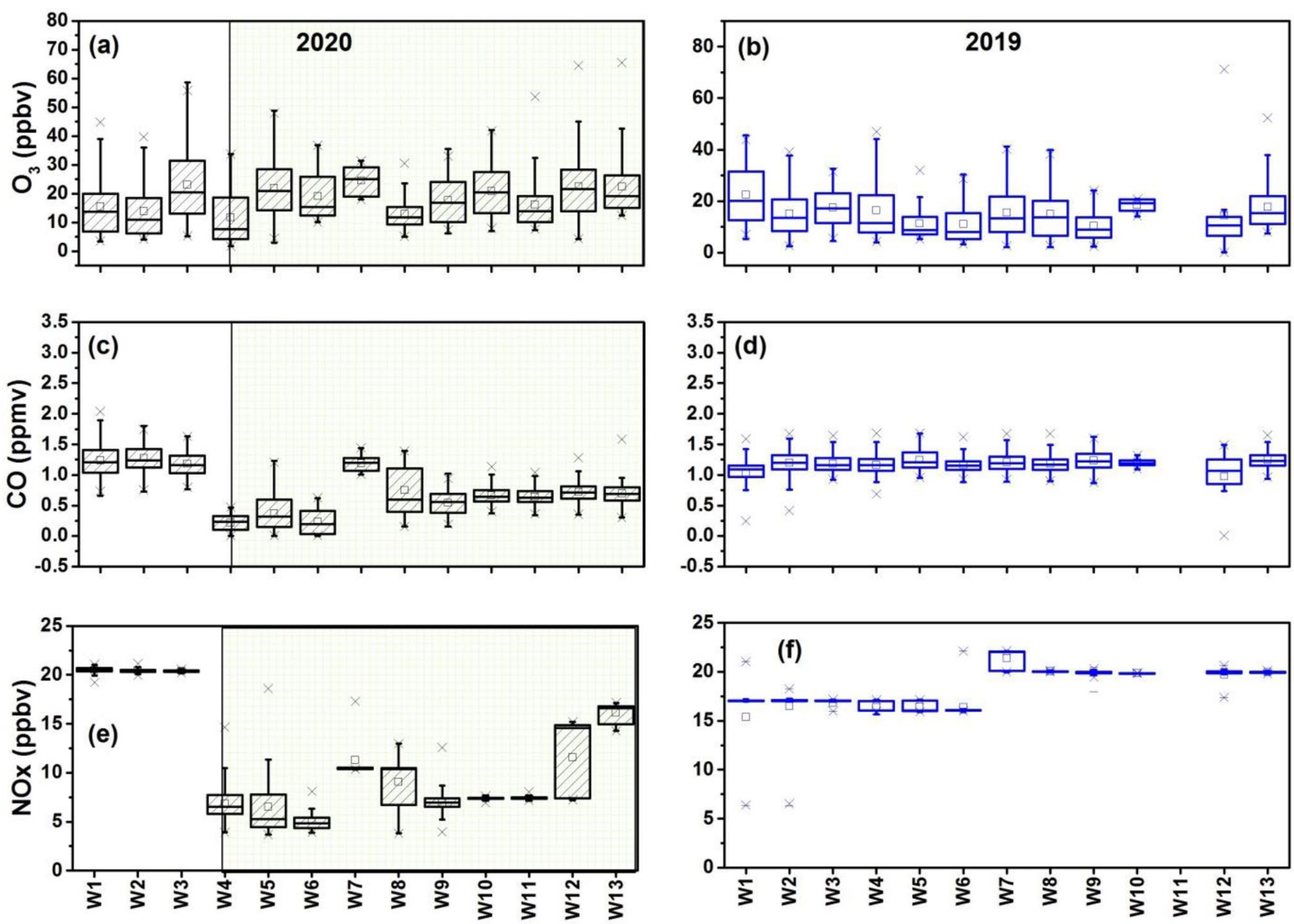

Fig. 3 Variation in **a** O_3 from 1 March–31 May 2020, **b** O_3 from 1 March to 31 May 2019, **c** CO from 1 March to 31 May 2020, **d** CO from 1 March to 31 May 2019, **d** NO_X from 1 March to 31 May 2020, **b** NO_X from 1 March to 31 May 2019, respectively. The box-whisker represent 1% data limit (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 andW8, 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.

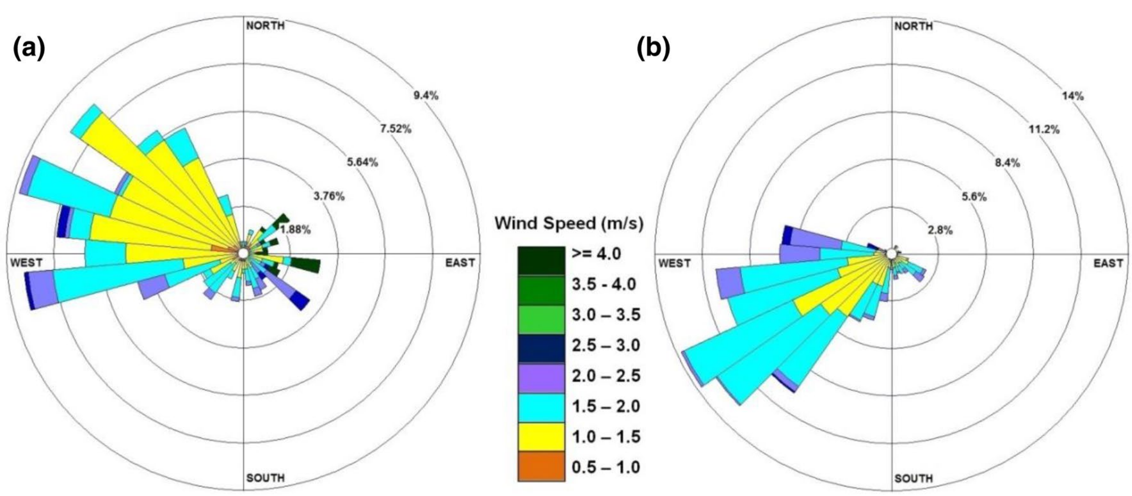

Fig. 4 Wind-Rose diagrams for lockdown period (24 March–31 May) for **a** 2020, **b** 2019

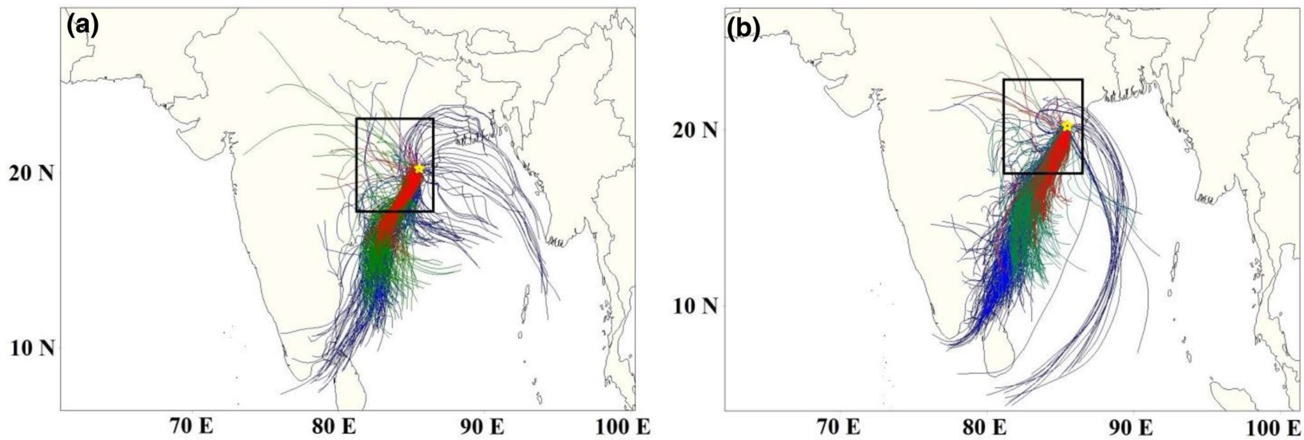

Fig. 5 Back trajectory analysis of $PM_{2.5}$ using two days backward trajectories run at 3-hourly interval for **a** lockdown period of 2020 and **b** same period of 2019. Site location (i.e. Bhubaneswar) is depicted by a yellow star. The black box in both the sub-plots represents the area of high emission following Ranjan et al. [20], Guttikunda and Jawahar [11] and Guttikunda and Jawahar [10]

3.3 Back-trajectory 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 ~ 37–144% (PM2.5) and ~ 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 (~ 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 (~ 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.

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Compliance with ethical standards

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

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