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Effects of Nationwide Lockdown due to COVID-19 on Ambient Air Quality in the State of West Bengal, India

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Abstract

The present study assessed the nationwide lockdown impacts on the air pollution situation across West Bengal, India. Air pollution data was collected from the online monitoring stations of the Central Pollution Control Board across West Bengal. The gradual declining pattern of overall pollution status was observed during the lockdown phase from the pre-lockdown phase. The early unlocking stage found slow and gradual increasing air pollution levels. Siliguri's pre-lockdown 'poor' Air Quality Index (AQI) improved in the lockdown phase to 'satisfactory' level. 'Moderate' level AQI in Asansol of the pre-lockdown stage improved to 'satisfactory' level during the lockdown phase. Pre-lockdown AQI of both Kolkata and Howrah changed from 'moderate' to 'good' level during the lockdown phase. Unlike other pollutants, the ozone level increased in Kolkata, Howrah, and Siliguri in the lockdown phase. The early monsoonal washout possibly caused the changes in the pattern of pollution status of specified periods in the 2019 and 2020. Thus, in the study period of lockdown in 2020, the decrease in pollution level may not only caused by the stoppage of vehicles or industry but also have a possible natural influence.

Keywords: COVID-19; Lockdown; Air pollution trend; Ozone pollution; West Bengal.

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1. Introduction

On 11th Mar 2020, World Health Organization (WHO) announced the SARS-CoV-2 infection outbreak, spreading from the Wuhan City of China as a global pandemic [1-3]. The unprecedented phenomenon forced most countries to implement lockdown to avoid the spread of COVID-19 infection. India saw its first COVID-19 case on 30th Jan 2020 in Kerala, and the first death was recorded on 12th Mar 2020 [4]. West Bengal recorded the first positive case of COVID-19 on 17th Mar and first death on 23rd Mar 2020 [5,6]. To control the spread of the infection, the Government of India first announced the voluntary curfew for a day on 22nd Mar 2020 and then strictly imposed the first lockdown for 21 days from 24th Mar 2020 to 14th Apr 2020 [7]. Subsequently, several phases of lockdown were implemented shutting down all industrial, commercial, and transportation activities to avoid private and public gatherings leaving only the emergency services open [8,9].

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The sudden stoppage of industrial and transportation activities resulted in a gradual decrease in air pollution.

Air pollution is a significant concern in urban India. A wide variety of health complications (allergic rhinitis, sore throat, chronic cough, bronchitis, sinusitis, chest dyspnoea, and bronchial asthma) result from the exposure and inhalation of unhealthy air [10-17]. The health effects are a significant concern due to the high exposure risk of particulate matter in indoor and outdoor environments [18]. Airborne particulate matters (PM) have the potential to affect the respiratory system and cardiovascular systems adversely [19,20]. The respirable particulate matter reduces lung function, aggravate asthma, increases the pneumonia and death rates in new-borns [21]. Air pollutants contain harmful organic and inorganic gases, volatile compounds, and trace metals that directly or indirectly affect the respiratory system. Air pollution caused about 4.9 million deaths (8.7% of global deaths), of which 1.2 million are from India [22]. In West Bengal, 50.9% of the deaths were due to air pollution in people younger than 70 years [23].

Air pollution in West Bengal, the most densely populated state in India, includes industrial sources (zones: Durgapur, Asansol, Haldia, Howrah) and traffic sources (zones: Kolkata, Howrah, Siliguri). Kolkata, the capital city of West Bengal with a dense population, has vast economic activities and heavy traffic-based air pollution. Howrah and Haldia, with industrial activities, produce air pollution in south West Bengal. Durgapur and Asansol are the major industrial cities in eastern India [24,25]. Siliguri, the gateway of northeast India, is an important city in North Bengal. To comprehend the effect of the COVID-19 lockdown on air pollution in the state of West Bengal, the objectives of the present study were to assess the air pollution trends during the lockdown and compare the pollution situation with the pre-lockdown phase. To evaluate how the pollution trend changes with early unlocking stages and compare the pollution trend pattern with the similar time phases in the previous year (2019).

2. Materials and Methods

The air quality data of the state of West Bengal were collected from the online monitoring stations of the Central Pollution Control Board (CPCB), Ministry of Environment, Forest and Climate Change, Government of India. The online stations are selected based on the importance of the place for air pollution from various industrial activities and heavy traffic. The areas chosen initially for the study were Kolkata, Howrah, Haldia, Durgapur, Asansol, and Siliguri based on the accessibility of the online monitoring stations (Fig. 1). But due to the unavailability of the data for the study period of interest, we had to exclude Haldia and Durgapur from the study.

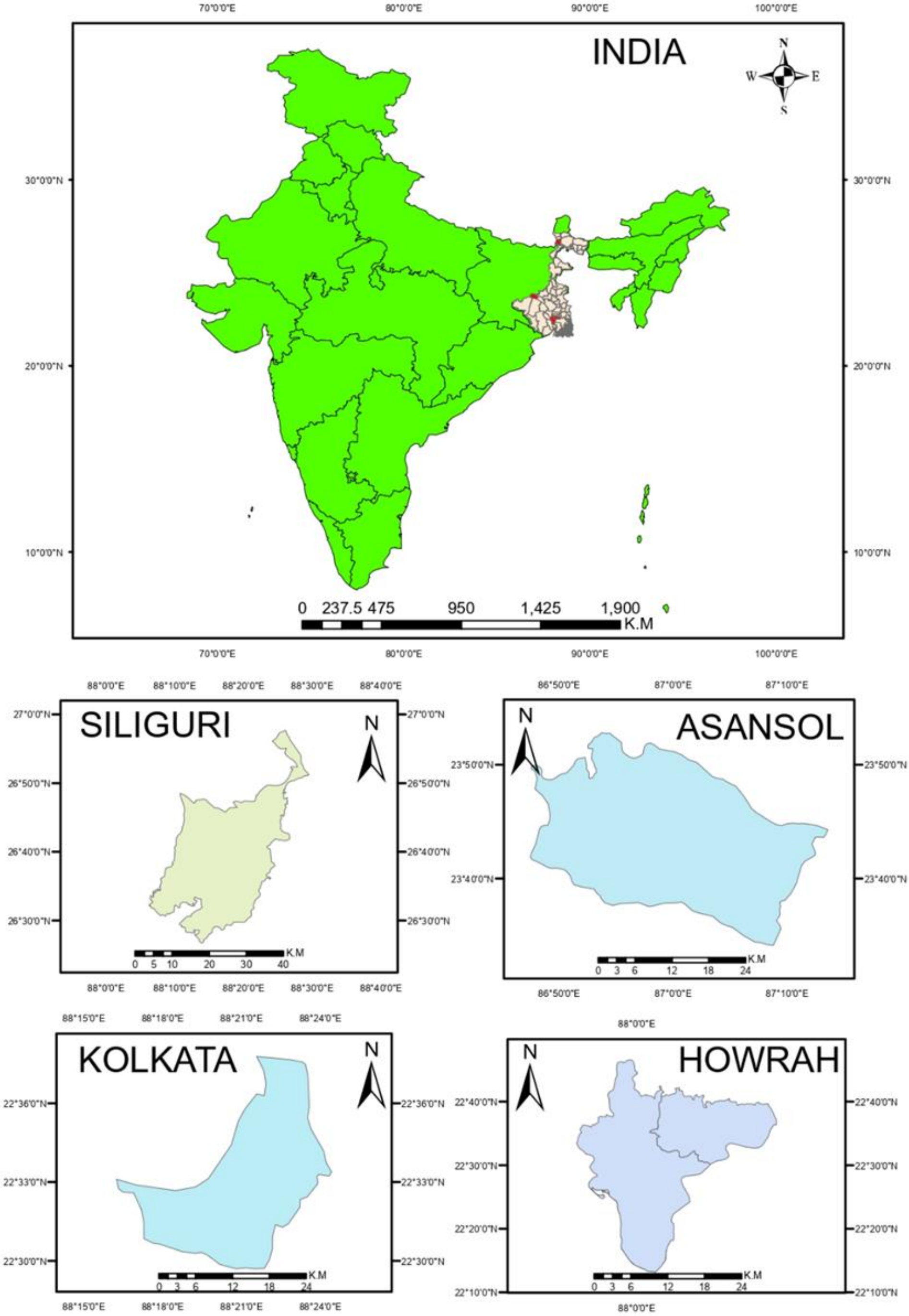

Fig. 1. Study area of Siliguri, Asansol, Kolkata, and Howrah.

The daily (24 or 8 hourly) concentration of seven air pollutants, i.e., particulate matters ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), oxides of nitrogen (NO_x) and ozone (O_3) were obtained from the CPCB online portal for air quality data [26]. The trend was analyzed for the levels of $PM_{2.5}$, PM_{10}, SO_2, NO_2, NO_X, O_3, and CO at different sites for the pre-lockdown (1st Feb to 22nd Mar), lockdown (23rd Mar to31st May), and early unlocking (1st Jun to 4th Aug) phases in West Bengal, India. The above trend of levels of pollutants was compared with the exact times of the previous year (2019) to see the changes in air quality due to the lockdown. The box plot represented the distribution and spread of the data. The radar chart graphically showed the comparative mean pollution magnitude of the cities in pre-lockdown, lockdown, and early unlocking phases and similar periods in 2019. Paired samples t-tests were calculated in search of significant mean differences of pollutants in studied cities for pre-, during, and early unlock phases and similar durations in 2019. Dendrogram by Cluster Analysis specified the relatively similar pollution sites across four cities. Based on the six criteria pollutants by CPCB, AQI was calculated by the AQI calculator of CPCB [27] for the entire phases (pre lockdown, lockdown, and unlocking phase) for 2020, and the same was compared with the similar times of 2019 (Fig. 4B). The indices values were color-coded to indicate the air quality. Satellite data of aerosol optical depth (AOD; Moderate Resolution Imaging Spectrometer- Terra (MODIS-Terra 550 nm, Deep Blue, Land only, MOD08_D3v6.1) NO2 (1/cm2; tropospheric column; 30% cloud screened, daily 0.25°, OMNO2d v003), O3 (DU; total column; DOAS, daily 0.25°, OMDOAO3e v003) and CO (ppbv; surface concentration (ENSEMBLE, MERRA-2 Model, monthly 0.5*0.625° M2TMNXCHM v5.12.4) were collected from Giovanni interface [28] of NASA Goddard Earth Sciences Data Active Archive Centre [29]. Collected data were then processed in ArcGIS10.3 to classify in different color codes to know the spatial pollution difference. The data were analyzed using SPSS (ver.22; IBM, USA), MS-Excel, and ArcGIS (ver. 10.3; ESRI, California).

3. Results

In Kolkata, the mean $PM_{2.5}$ levels in pre, during and post lockdown phases in 2020 were 74.49, 22.08 and 17.13 µg m^{-3}, and have been shown in Table 1, as compared to the similar times during 2019 as 104.32, 45.64 and 29.66 µg m^{-3} respectively (Fig. 2A). Whereas, the mean PM_{10} levels in pre, during and post lockdown phases in 2020 were 157.61, 42.80 and 37.73 µg m^{-3} as compared to the similar times during 2019 as 183.06, 96.88 and 55.66 µg m^{-3} respectively (Fig. 2E). In Howrah, the mean PM_{10} levels in pre, during and post lockdown phases in 2020 were 163.96, 49.22 and 40.37 µgm^{-3} as compared to the similar times during 2019 as 178.09, 87.78 and 71.02 µg m^{-3} respectively (Fig. 2F). The mean $PM_{2.5}$ levels in pre, during and post lockdown phases in 2020 were 77.70, 21.49 and 18.63 µg m^{-3} as compared to the similar time periods in 2019 as 96.66, 42.63 and 34.39 µg m^{-3} respectively (Fig. 2B). In Asansol, the mean PM_{10} levels in pre, during and post lockdown phases in 2020 were 139.31, 71.07 and 49.11 µg m^{-3} as compared to the similar time period in 2019 as 128.33, 95.24 and 53.28 µg m^{-3} respectively (Fig. 2G). The mean $PM_{2.5}$ levels in pre, during, and post lockdown phases in 2020 were 70.54, 31.29, and 26.36 µg m^{-3} as compared to the similar periods in 2019 as 79.77, 51.73, and 32.90 µg m^{-3}, respectively (Fig. 2C). In Siliguri, the mean PM_{10} levels in pre, during and post lockdown phases in 2020 were found to be 163.01, 59.14 and 34.12 µg m^{-3} as compared to the similar periods during the year 2019 as 160.26, 79.38 and 41.76 µg m^{-3} respectively (Fig. 2H). The mean $PM_{2.5}$ levels in pre, during, and post lockdown phases in 2020 were 98.14, 36.85, and 18.79 µ gm^{-3} as compared to the similar times of the year 2019 as 79.30, 41.89, and 21.39 µg $m^{-3,}$ respectively (Fig. 2D). In Kolkata, the NOx levels were observed to be 94.77, 17.07 and 21.13 µg m^{-3} for pre lockdown, lockdown and unlocking phases in 2020 as compared to 117.63, 34.49 and 25.06 µg m^{-3} respectively for the similar times in 2019 (Fig. 3M). In Howrah, the NOx levels were found to be 80.64, 17.07, and 25.96 µg m^{-3} respectively for pre-lockdown, lockdown, and unlocking phases in 2020 as compared to 70.77, 32.82, and 33.05 µg m^{-3} respectively for the similar periods in 2019 (Fig. 3N). In Asansol, the NOx levels were found to be 46.14, 31.74, and 17.87 µg m^{-3}, respectively, for pre-lockdown, lockdown, and unlocking phases in 2020 as compared to 67.13, 24.68, and 24.62 µg m^{-3} respectively for the similar times of the year 2019 (Fig. 3O). In Siliguri, the NOx levels were observed to be 85.04, 32.50, and 31.04 µg m^{-3}, respectively, for pre-lockdown, lockdown, and unlocking phases in 2020 as compared to 50.47, 36.60, and 24.82 µg m^{-3} respectively for similar times in the year 2019 (Fig. 3P). In Kolkata, the CO concentrations in 2020 were 0.82, 0.36, and 0.37 mgm^{-3}, respectively, for pre-lockdown, lockdown, and unlocking phases as compared to 0.80, 0.31 and 0.31 mgm^{-3}, respectively, during the similar times in 2019 (Fig. 4U). In Howrah, the CO concentrations in 2020 were 0.80, 0.35, and 0.38 mg m^{-3} respectively for pre-lockdown, lockdown, and unlocking phases as compared to 0.92, 0.54, and 0.45 mg m^{-3} respectively for similar periods in 2019 (Fig. 4V). In Asansol, the CO concentrations in 2020 were 0.74, 0.47, and 0.44 mg m^{-3} respectively for pre-lockdown, lockdown, and unlocking phases as compared to 0.66, 0.44, and 0.41 mg m^{-3} respectively for similar periods during 2019 (Fig. 4W). In Siliguri, the CO concentrations in 2020 were 0.77, 0.52, and 0.48 mg m^{-3} respectively for pre-lockdown, lockdown, and unlocking phases compared to the 0.98, 1.02, and 0.84 mgm^{-3} respectively for similar times during 2019 (Fig. 4X). In Kolkata, the mean ozone levels in 2020 were 44.23, 43.16, and 34.47 $µgm^{-3}$ respectively for pre-lockdown, lockdown, and post-lockdown phases as compared to 32.09, 28.99, and 29.13 µg m^{-3} for the similar periods during 2019 (Fig. 4Q). Overall, the levels of ozone were higher in the year 2020 than 2019. In Howrah, the mean ozone levels in 2020 were 34.17, 42.31, and 30.86 µg m^{-3} respectively for pre-lockdown, lockdown, and post-lockdown phases as compared to 30.98, 27.77, and 27.85 µg m^{-3} for the similar times in 2019 (Fig. 4R). In Asansol, the mean ozone concentrations in 2020 were 25.05, 21.72, and 11.03 $µgm^{-3,}$ respectively, for pre-lockdown, lockdown, and post-lockdown phases as compared to 15.88, 36.44, and 12.25 µg m^{-3} for the similar times in 2019 (Fig. 4S). In Siliguri, the mean ozone levels in 2020 were 23.80, 29.06, and 18.17 µg m^{-3} respectively for pre-lockdown, lockdown, and post-lockdown phases as compared to

41.44, 43.90, and 21.27 µg m^{-3} for the similar times in 2019 (Fig. 4T). The SO_2 levels were observed to be 14.39, 8.54, and 7.88 µg m^{-3} respectively for pre-lockdown, lockdown, and unlocking phases in 2020 as compared to 13.64, 4.94, and 3.62 µg m^{-3} respectively for the respective periods of the year during 2019 in the metropolitan city of Kolkata (Fig. 5Y). In Howrah, the levels of SO_2 in 2020 were 21.10, 9.91, and 8.35 µg m^{-3}, respectively, for pre-lockdown, lockdown, and unlocking phases compared to 26.63, 12.12, and 6.68 µgm^{-3} respectively for the respective periods of the year during 2019 (Fig. 5Z). In Asansol, the SO_2 levels in 2020 were 19.63, 9.52, and 3.07 µg m^{-3} respectively for pre-lockdown, lockdown, and unlocking phases as compared to the 13.65, 4.51, and 3.73 µg m^{-3} respectively for the respective periods of the year 2019 (Fig. 5a). In Siliguri, the SO_2 levels in 2020 were 5.46, 4.28 and 3.11 µg m^{-3} respectively for pre-lockdown, lockdown and unlocking phases as compared to 1.61, 4.60 and 3.23 µg m^{-3} respectively for the respective periods of the year during 2019 (Fig. 5b).

Table 1. Pollutants level (µg m^{-3}) in pre-lockdown, lockdown, and unlocking phases in different cities of West Bengal.

	Pollutants	Pre-lockdown		Lockdown		Unlocking	
		2020	2019	2020	2019	2020	2019
Kolkata	PM_{10}	157.61	183.06	42.80*	96.88*	37.73	55.66
	$PM_{2.5}$	74.49	104.32	22.08*	45.64*	17.13	29.66
	NO_2	56.84	84.79	12.71*	28.43*	16.88	20.30
	NO_X	94.77	117.63	17.07*	34.49*	21.13	25.06
	SO_2	14.39	13.64	14.39	4.94	7.88	3.62
	CO	0.82	0.80	0.36	0.31	0.37	0.31
	O_3	44.23	32.09	43.16**	28.99**	34.47	29.13
Howrah	PM_{10}	163.96	178.09	49.22*	87.78*	40.37	71.02
	$PM_{2.5}$	77.70	96.66	21.49*	42.63*	18.63	34.39
	NO_2	55.52	57.56	14.52*	27.50*	19.53	27.54
	NO_X	80.64	70.77	17.70*	32.82*	25.96	33.05
	SO_2	21.10	26.63	9.91	12.12	8.35	6.68
	CO	0.80	0.92	0.35	0.54	0.38	0.45
	O_3	34.17	30.98	42.31**	27.77**	30.86	27.85
Asansol	PM_{10}	139.31	128.33	71.07*	95.24*	49.11	53.28
	$PM_{2.5}$	70.54	79.77	31.29*	51.73*	26.36	32.90
	NO_2	28.85	46.42	13.57*	22.78*	7.76	19.82
	NO_X	46.14	67.13	31.74	24.68	17.87	24.62
	SO_2	19.63	13.65	9.52	4.51	3.07	3.73
	CO	0.74	0.66	0.47	0.44	0.44	0.41
	O_3	25.05	15.88	21.72	36.44	11.03	12.25
Siliguri	PM_{10}	163.01	160.26	59.14*	79.38*	34.12	41.76
	$PM_{2.5}$	98.14	79.30	36.85*	41.89*	18.79	21.39
	NO_2	51.19	37.44	26.94*	30.35*	21.97	19.70
	NO_X	85.04	50.47	32.50*	36.60*	31.04	24.82
	SO_2	5.46	11.61	4.28	4.60	3.11	3.23
	CO	0.77	0.98	0.52	1.02	0.48	0.84
	O_3	23.80	41.44	29.06	43.90	18.37	21.27

*PM_{10}, $PM_{2.5}$, NO_2, and NO_X significantly decreased in all cities except NO_X in Asansol during the lockdown phase.

**O_3 significantly increased in Kolkata and Howrah during the lockdown phase.

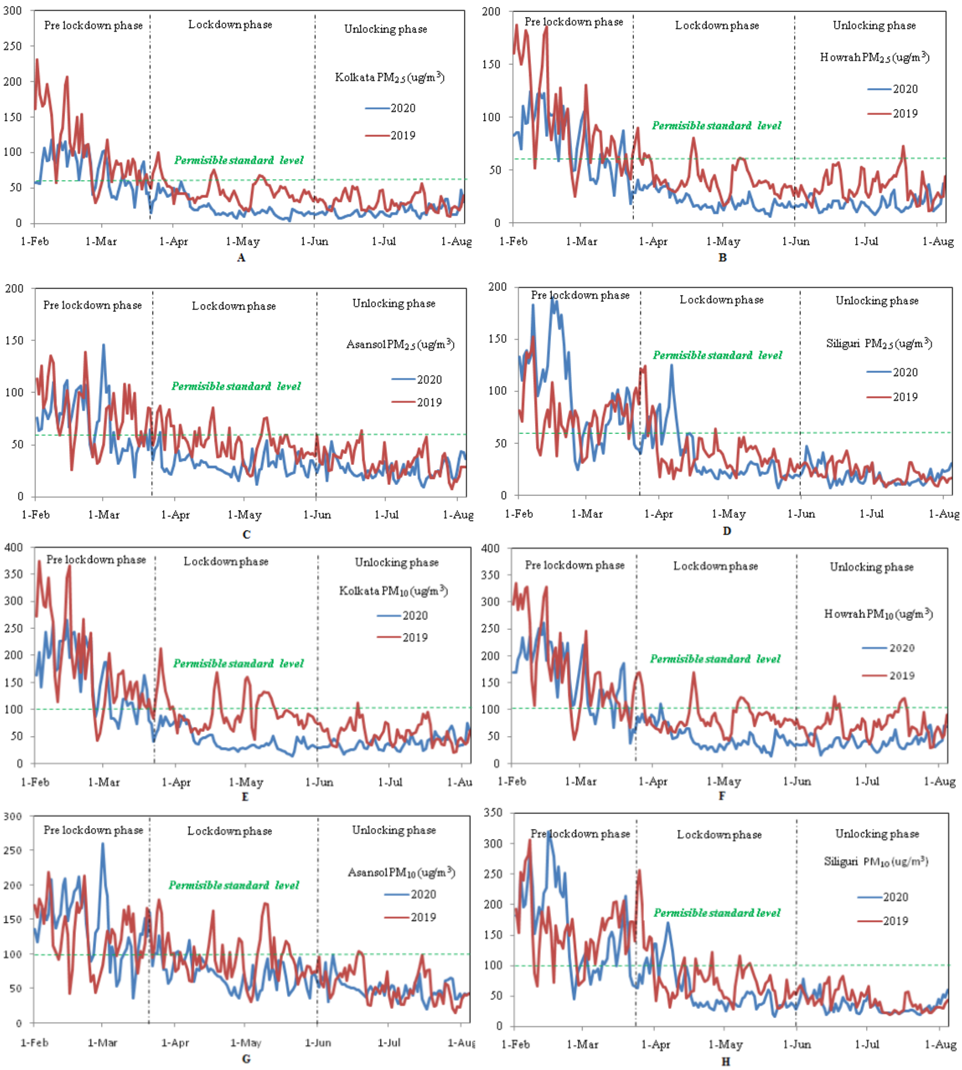

Fig. 2 (A-H). Trend of particulate matter (PM_{10} and $PM_{2.5}$) concentration across West Bengal.

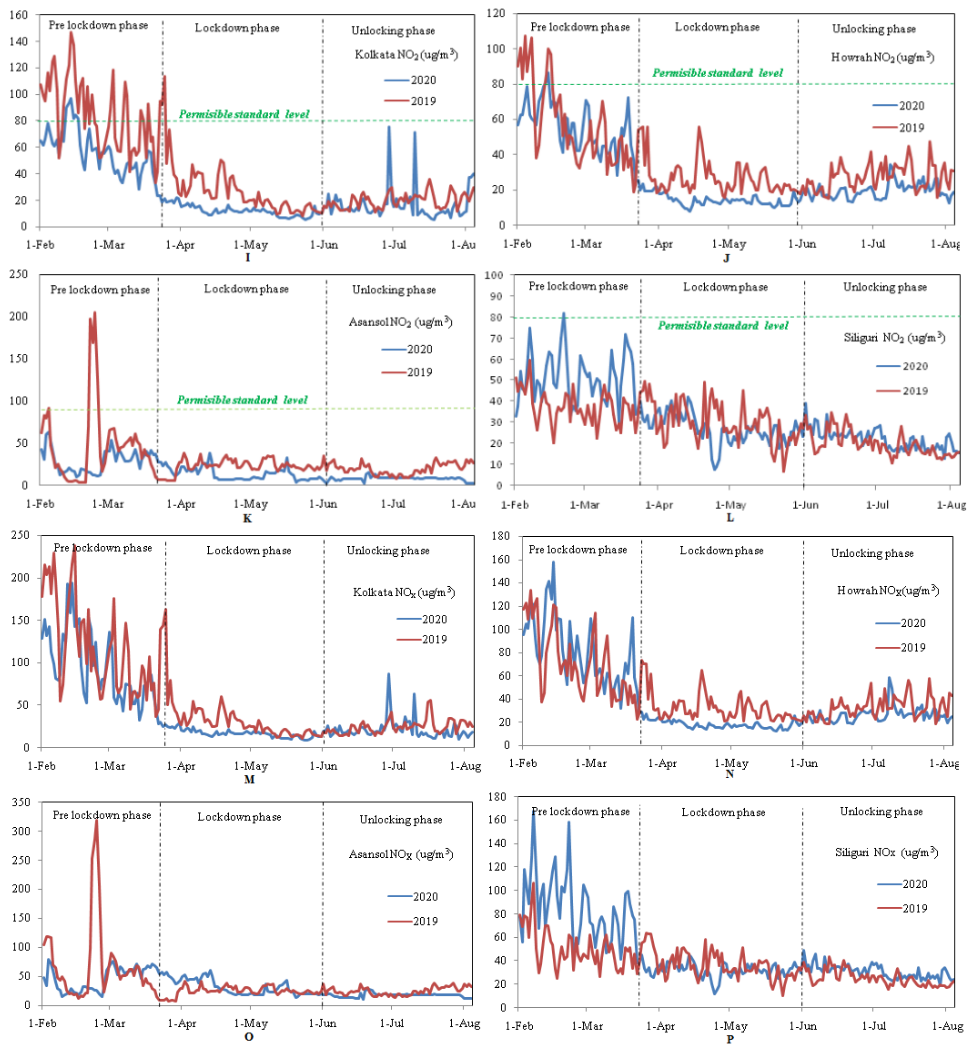

Fig. 3 (I-P). Trend of NO_2 and NO_x concentrations across West Bengal.

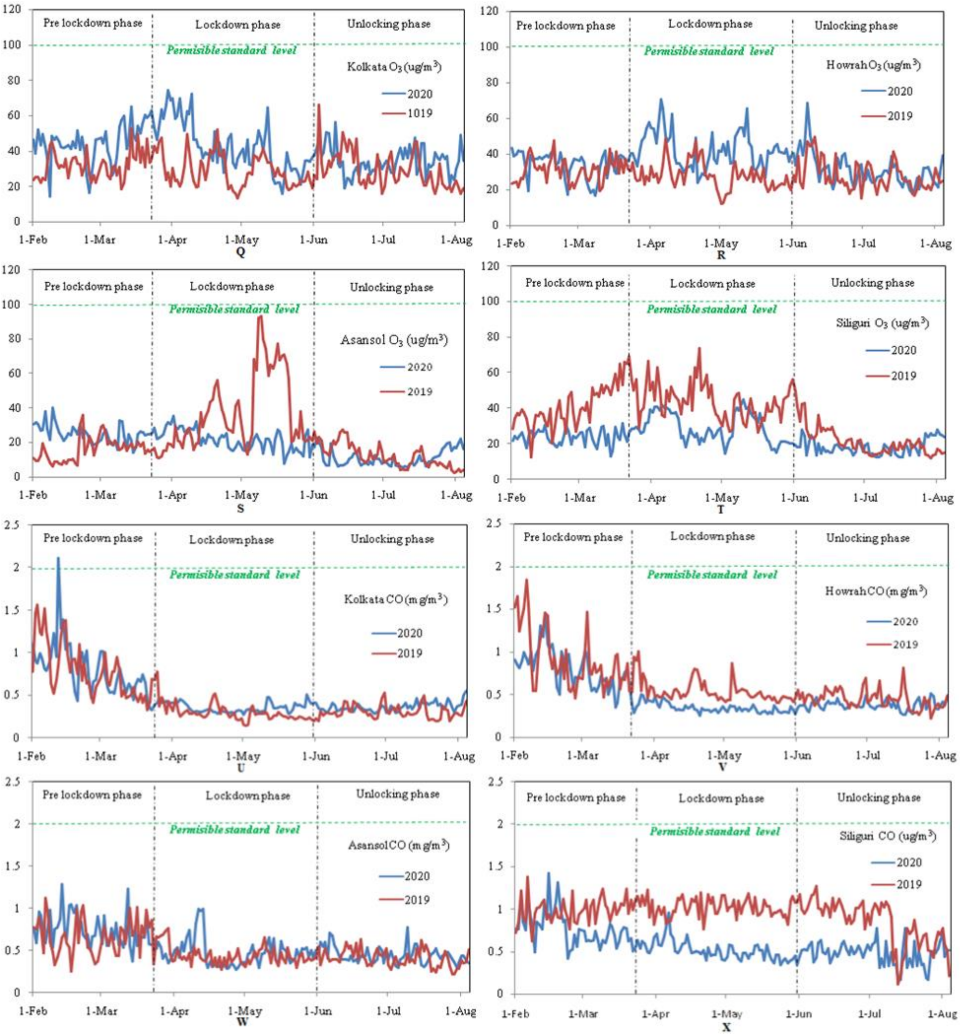

Fig. 4 (Q-X). Trend of O_3 and CO concentrations across West Bengal.

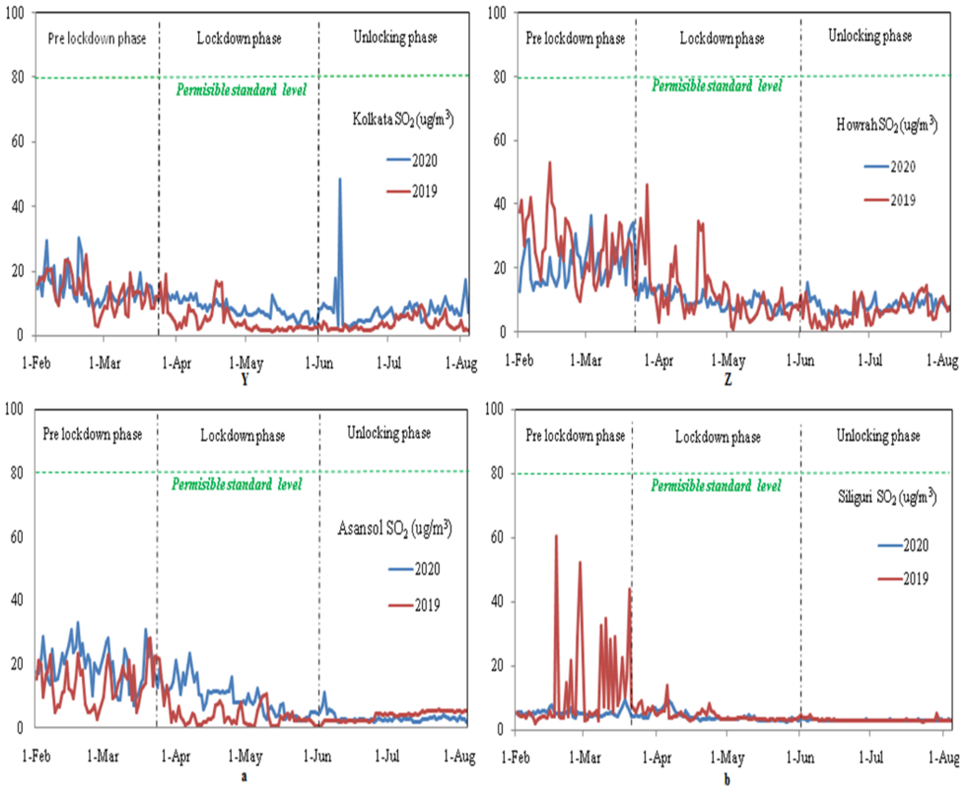

Fig. 5(X-b). Trend of SO_2 concentrations across West Bengal.

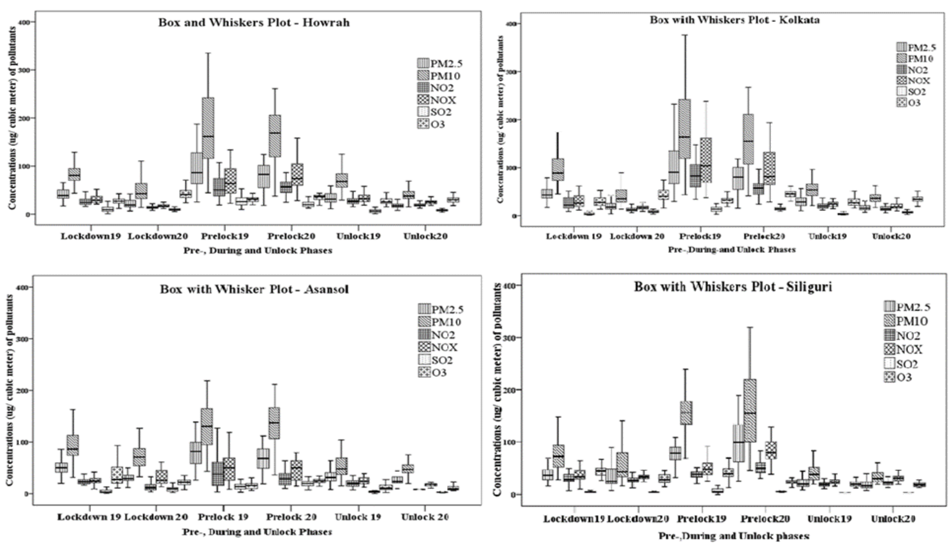

Fig. 6. Boxplot showing pollution distribution and their spread.

4. Discussion

The overall trend of PM_{10} and $PM_{2.5}$ from 1st Feb 2020 in pre lockdown phase showed consistent declining levels in the current year as compared to a similar period in 2019 [30]. The trend of both years indicates a decreasing pattern of PM_{10} and $PM_{2.5}$ levels from the 1st Feb 2020 till the end of July, with intermittent peaks in the 2019 trend. In pre-lockdown or specifically from early February to the end of March, the trend of particulate matters (PM_{10} and $PM_{2.5}$) showed a two-step declining pattern but mostly above the standard prescribed levels in both 2019 and 2020 [31]. In 2020, the pre-lockdown particulate pollution from the month of February to till 21st Mar 2020 was generally lower than the 2019 levels. Then after, the decline was consistent in the lockdown phase till the end of July 2020 and always was below the standard prescribed value of CPCB-NAAQS, India. Whereas, in 2019, the declining trend with intermittent spikes beyond the prescribed standard was seen. The consistent decreasing pattern of NOx levels in Kolkata and Howrah was found in the years 2019 and 2020 from early February to the end of June. More pollution variation was seen in pre lockdown phase as compared to the lockdown and unlocking phases. The NOx levels in 2020 were always less compared to the 2019 values in similar times [32]. In Asansol, unlike others, there was a dip in the trend of NOx levels between February and March. In Siliguri, large variations of NOx levels were found between March and April. The trend of NO_2 levels was similar to NOx in all the phases and years (Figs. 3I, J, K, L). The pre-lockdown NOx levels of 2020 gradually decreased from above to below recommended standard values as compared to 2019, above recommended standard. The trend of SO_2 levels for both 2019 and 2020 started declining slowly from early February and continued through the lockdown phase until the second half of June. Thereafter, it started slowly to increase. The trend line of the 2019 data fluctuates more variation than the 2020 data. In Kolkata and Asansol, the overall SO_2 levels were higher in 2020 than in 2019. In Howrah, the SO_2 levels in 2020 and 2019 were almost similar. In Siliguri, there were some large fluctuations in SO_2 levels in 2019 from February to the end of March. CO levels in Kolkata gradually decreased, both in 2020 and 2019, from 1st Feb to 1st Apr thereafter started to increase. From 1st Apr to the end of July, CO levels in 2020 were more as compared to the 2019 levels. In Howrah, after lockdown, the CO level in 2020 dropped as compared to the levels in 2019. In Asansol, CO levels in 2020 and 2019 were almost the same. In Siliguri, the CO level in 2020 dropped as compared to the CO levels in 2019. In Kolkata, overall ozone levels during the entire study tenure in 2020 were greater than the levels in 2019. In Howrah, the ozone level in the lockdown phase in 2020 was more than that of a similar time in 2019 [33,34]. In Asansol, O_3 gradually decreased from 1st Feb to mid-July in 2020, and then it increased. In Siliguri, the O_3 levels increased marginally from the pre-lockdown trend but were always below the ozone levels in 2019. Boxplot revealed the maximum data variation in the pre-lockdown phase in 2020 and the corresponding time in 2019. The variations were more in particulate matters PM_{10}/$PM_{2.5}$ followed by NOx (Fig. 6). Pairwise comparison of the pollution situation revealed that there was no significant difference in O_3 levels of lockdown (2020) and pre-lockdown (2020) in Kolkata. In Asansol, the difference in levels of CO during lockdown (2020) and the same time in 2019 was non-significant. There was no significant difference in mean $PM_{2.5}$ concentrations between the lockdown phase (2020) and a similar time in 2019. Unlike the general trends of pollution reduction, ozone levels increased in the lockdown phase than pre-lockdown or similar times in the previous year in Kolkata and Howrah, which necessitates special attention for an explanation. The trend was in line with other studies for major urban areas in India and abroad [35,36]. The explanation lies in the basic ground-level ozone formation chemistry. Ozone, a secondary air pollutant formation, starts with the availability of precursor- nitrogenous oxide and bright sunlight. While NO_2 stimulates ozone formation, NO depletes it in the presence of sunlight (Eq. 1).

$$NO_2 + h\nu \longrightarrow NO + O^* \quad (1)$$

$$O_2 + O \longrightarrow O_3 \quad (2)$$

$$O_3 + NO \longrightarrow NO_2 + O_2 \quad (3)$$

Because of the almost absence of vehicular emission of fresh unstable NO, which directly degrades the O_3 in the lockdown period, and the presence of stable $NO_{2,}$ which promote O_3 formation, ultimately leads to ozone accumulation at ground level. The pre-lockdown phase (1st Feb 2020 to 22nd Mar 2020) data indicate Siliguri has poor air quality as compared to moderate air quality for Asansol, Howrah, and Kolkata. Pre-lockdown air qualities improved in the lockdown phase [37] and remained more or less the same in the unlocking phase. In pre lockdown phase, the pollution situation in Jadavpur, Rabindrasarobar, Asansol Court, and Padmapukur were similar and closely related, whereas Fort William and Belurmath were closely similar but distantly related. Based on the pollution situation in the lockdown phase, Fort William, Jadavpur, Victoria, Padmapukur, Bidhannagar, and Rabindra Sarovar areas were similar and closely related. In the unlocking phase, pollution conditions in Victoria, Padmapukur, Ballygunge, Bidhannagar, Fort William, Jadavpur, and Rabindra Sarovar were similar; where Victoria and Padmapukur were closely related, others were distantly related (Fig. 7A-C). In 2019 similar times, Howrah and Kolkata AQI were poor as compared to Asansol and Siliguri as moderate air quality, which subsequently improved and remained almost the same during the unlocking time. Pre-lockdown ‘poor’ AQI in Siliguri improved in the lockdown phase as ‘satisfactory.’ ‘Moderate’ AQI in Asansol of the pre-lockdown phase improved to ‘satisfactory’ during the lockdown phase. Pre-lockdown AQI of both Kolkata and Howrah changed from ‘moderate’ to ‘good’ during the lockdown phase (Fig. 7D). Radar chart graphically presented the relative ranking of the studied cities based on the individual pollutant levels. Pollution load during the lockdown phase were Asansol > Siliguri > Howrah > Kolkata for PM_{10}, Siliguri > Asansol > Kolkata > Howrah for $PM_{2.5}$, Siliguri > Asansol > Howrah > Kolkata for NO_x, Kolkata > Howrah > Asansol >Siliguri for SO_2, Siliguri > Asansol > Kolkata > Howrah for CO and Kolkata > Howrah > Siliguri > Asansol for O_3 (Fig. 8). Satellite images also supports the finding of the lockdown effect for lowering the air pollution load in West Bengal as compared to the pollution status of the similar period during the previous year (2019) (Fig. 9). From June 2020, unlocking (unlocking 1: 1–30 June; unlocking 2: 1–31 July) started nationwide and thereby, the resumption of public transportation and industries lead to increase in pollution levels gradually, but in study tenure (till 4th Aug 2020) of unlocking phase, mean levels of PM_{10}, SO_2, CO in Kolkata, CO levels in Asansol and NOx levels in Siliguri were insignificant as compared to the lockdown phase levels.

Studies across the world showed drastic changes in pollution levels, especially in the air except ozone and its associated health benefits in the form of less mortality, morbidity, premature deaths, chronic obstructive pulmonary disease (COPD), disability-adjusted life years (DALY), etc. in lockdown periods [37-39]. The trend pattern of decreasing air pollution during the study period, 2020, was comparable to the similar period in 2019, but the magnitude of the decrease was more in 2020. The early monsoonal washout possibly causes the underlying cause pattern. Thus, during the study period of lockdown in 2020, the decrement in pollution was not only caused by the stoppage of vehicles or industry but also had a possible natural influence. Studies [40-43] have presented the data only for 2020 and showed huge pollution reduction during lockdown from pre-lockdown status. Unlike them, we assessed 2019 pollution data also and found a comparable similar trend pattern for 2020, indicating an annual recurrence influence (early monsoonal rain washout) other than the exceptional lockdown, which coincided incidentally.

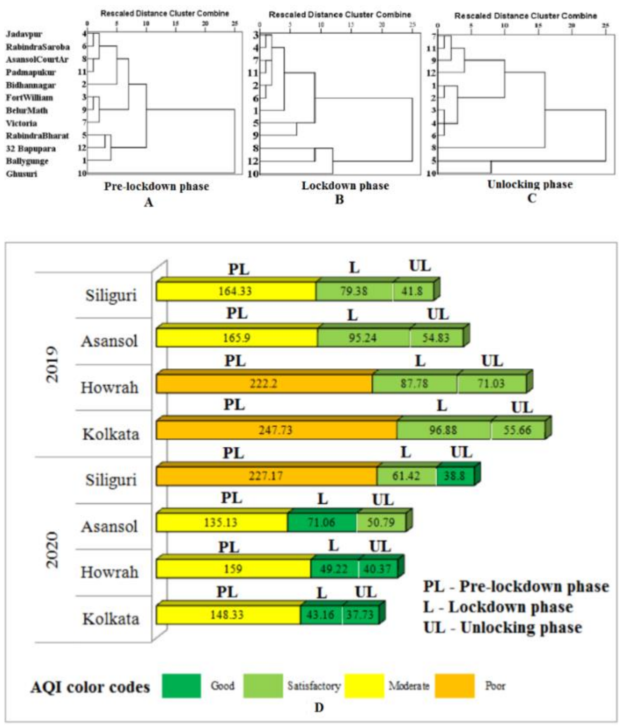

Fig. 7(A-C). The dendrogram shows the relative similarity of the pollution of different monitoring sites, and D represents AQI across studied cities.

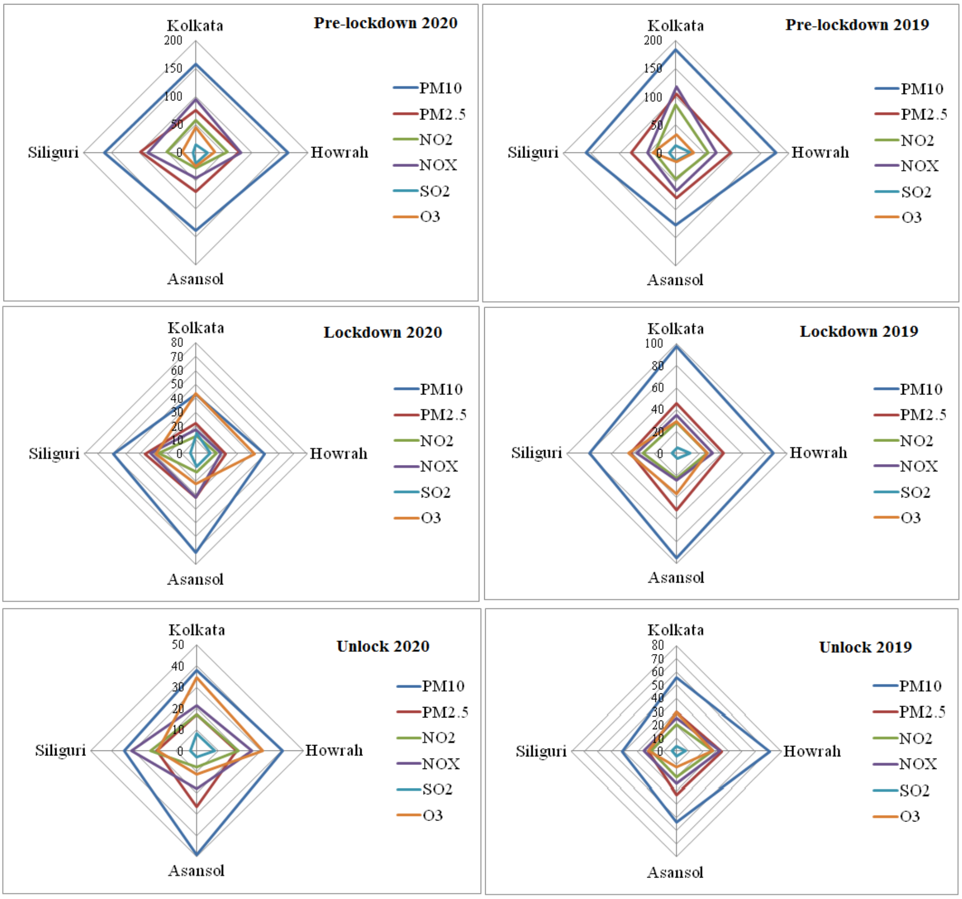

Fig. 8. Radar chart representing relative pollution concentrations in the studied cities.

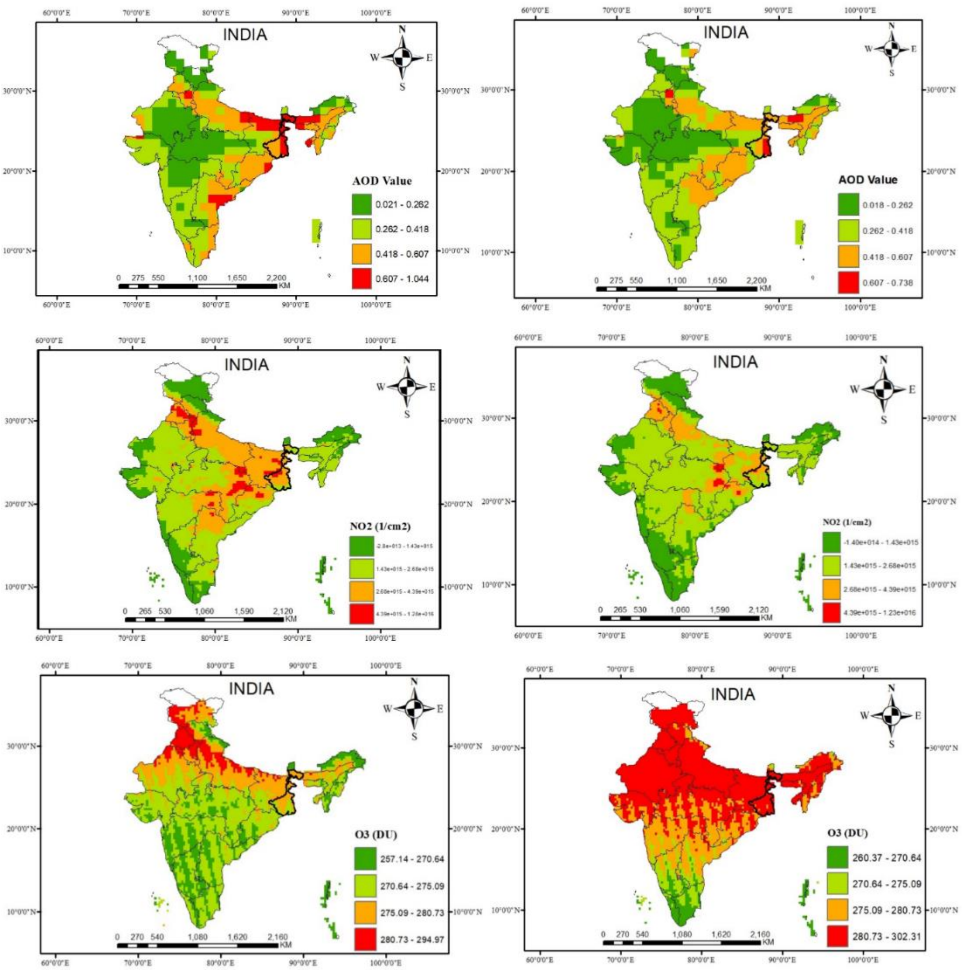

Fig. 9. Satellite imageries show the spatial pollution status across India.

5. Conclusion

A gradual declining pattern of overall pollution status was found in the lockdown phase from the pre-lockdown phase. A comparable air pollution trend pattern but lesser in magnitude was found at a similar time in 2019. The early unlocking phase found slow and gradual increasing air pollution levels. Pre-lockdown 'poor' Air Quality Index (AQI) in Siliguri improved in the lockdown phase to 'satisfactory'. 'moderate' AQI in Asansol of the pre-lockdown phase improved to 'satisfactory' during the lockdown phase. Pre-lockdown AQI of both Kolkata and Howrah changed from 'moderate' to 'good' during the lockdown phase. Unlike other pollutants, the ozone pollution level increased in

Kolkata, Howrah, and Siliguri in the lockdown phase. The early monsoonal washout possibly caused the pattern of pollution status of specified periods in 2019 and 2020. Thus, in the study period of lockdown in 2020, the decrement in pollution may not only be caused by the stoppage of vehicles or industry but also had a possible natural influence.

Limitation of the study

This study was mainly based on the data availability of the online monitoring stations for the specified period across West Bengal, India. There were seven monitoring stations in Kolkata, three in Howrah, one in Asansol, and one in Siliguri. Thus, data from Kolkata and Howrah were more representative than the Asansol and Siliguri.

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