Environment, Development and Sustainability (2021) 23:9581–9608
https://doi.org/10.1007/s10668-020-01034-z

CASE STUDY

Improvement in ambient-air-quality reduced temperature during the COVID-19 lockdown period in India

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Received: 11 July 2020 / Accepted: 1 October 2020 / Published online: 22 October 2020

Abstract

The COVID-19 pandemic forced India as a whole to lockdown from 24 March 2020 to 14 April 2020 (first phase), extended to 3 May 2020 (second phase) and further extended to 17 May 2020 (third phase) and 31 May 2020 (fourth phase) with only some limited relaxation in non-hot spot areas. This lockdown has strictly controlled human activities in the entire India. Although this long lockdown has had a serious impact on the social and economic fronts, it has many positive impacts on environment. During this lockdown phase, a drastic fall in emissions of major pollutants has been observed throughout all the parts of India. Therefore, in this research study we have tried to establish a relationship among the fall in emission of pollutants and their impact on reducing regional temperature. This analysis was tested through the application of Mann–Kendall and Sen's slope statistical index with air quality index and temperature data for several stations across the country, during the lockdown period. After the analysis, it has been observed that daily emissions of pollutants (PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2 and NH_3) decreased by − 1– − 2%, allowing to reduce the average daily temperature by 0.3 °C compared with the year of 2019. Moreover, this lockdown period reduces overall emissions of pollutants by − 51– − 72% on an average and hence decreases the average monthly temperature by 2 °C. The same findings have been found in the four megacities in India, i.e., Delhi, Kolkata, Mumbai and Chennai; the rate of temperature fall in the aforementioned megacities is close to 3 °C, 2.5 °C, 2 °C and 2 °C, respectively. It is a clear indicator that a major change occurs in air quality, and as a result it reduced lower atmospheric temperature due to the effect of lockdown. It is also a clear indicator that a major change in air quality and favorable temperature can be expected if the strict implementations of several pollution management measures have been implemented by the concern authority in the coming years.

Keywords COVID-19 · Air quality index · Air pollutant · Climate

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1 Introduction

The new emergence of COVID-19 was first identified in Wuhan, China, in late December 2019 and on 30th January 2020, the World Health Organization (WHO) declared it a global public health emergency (Sohrabi et al. 2020). After the outbreak of COVID-19 in Iran, Italy, France, USA and other western countries, on 11th March the Wuhan epidemic became the world's largest pandemic in 2020 (Muhammad et al. 2020). This COVID-19 pandemic also well-known as coronavirus pandemic, and yet it is an ongoing epidemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), stated by WHO. People with low immunity are more vulnerable with SARS-CoV-2, basically novel coronavirus mostly prone to the people of pregnant women, elderly people and patients influenced by chronic diseases. Some of the basic symptoms such as fever, cough, fatigue, loss of smell and taste are found among the COVID-19 affected people. There are yet no such verified vaccines or proper treatment facilities for COVID-19. The disease spreads very easily among the people during the time of their close proximity. Therefore, in order to stop the rapid spread of the COVID-19 infection, strict measures have been implemented by the government of (Nussbaumer-Streit et al. 2020) different countries. Thus, several kinds of prevention measures have been incorporated such as recurrent hand washing, maintain social distancing, home isolation, always wearing a mask, etc. (Nussbaumer-Streit et al. 2020). Initially, the transmission of the virus from people to the community and after slowing down the number of COVID-19 cases, the government bans the mass gathering in different social and economic places such as school, universities, industries, public transport, market and religious sites and strains people's social distance and home prison methods. Recent data indicate that until 21 September 2020, 30.9 million people have been affected by COVID-19 in 188 countries around the world. As a result of the COVID-19 pandemic, global social and economic disturbances have taken place. Beside this, the social distancing and home confinement of people has led to a drastic change in gas and pollutant emissions worldwide (Le Quéré et al. 2020).

Nowadays, climate change is happening and has a global impact, such as rising temperatures, changing precipitation patterns and extreme weather conditions etc. (Djalante 2019). According to the latest report of the Inter-Governmental Panel on Climate Change (IPCC) (2018), the global temperatures rose by about 1 °C from the pre-industrial levels and are likely to reach 1.5 °C between 2030 and 2052. And the rising temperatures and global warming have an impact on rising sea-levels, increasing drought and floods, heat waves and cyclones around the world. World air pollution has a greenhouse effect, and the average temperature in the world is changing, which means temperatures are rising (Didenko et al. 2017). The IPCC reports showed that temperature increases are due to the radiative forcing, and this force is primarily caused by the high concentration of atmospheric pollutants (CO_2, CO, NO_2, SO_2 and O_3) (Figueres et al. 2018; Stips et al. 2016).

The real-time observation of various air pollutants asserts that the different gas emission rate drastically falls during the month of April and May 2020 caused by COVID-19 lockdown. The fossil fuels burning have been recorded low consumptions, and daily global CO_2 emissions in April decreased by -17 per cent compared to the average of 2019 (Le Quéré et al. 2020). The others countrywide research shows the major air pollutants have drastically fallen during the COVID-19 lockdown improving the air and water quality (Mahato et al. 2020; Sharma et al. 2020; Yunus et al. 2020). There is a strong relationship between ambient air pollutant and the meteorological attribute like temperature, humidity, wind speed, thunderstorm, etc., in an urban area (Akpinar et al. 2008; Hu et al. 2018). The research study also found that, due to the long lockdown period, the prevention of social distances has had a significant impact on the climate of several micro regions by improving air quality and as a result of this significant decrease in lighting activity in India (Chowdhuri et al. 2020).

In India, the nationwide lockdown was implemented one day after the government of India announced Janata Curfew on 22nd March 2020.[1] Following a lockdown of 68th days (24th March to 31st May 2020) in four different phases, the government has declared unlocking phase, with the exception of the high alert of COVID-19 containment zones. Due to low energy consumption, India has witnessed a significant decline in major air pollutants monitored during the lockdown period (Mahato et al. 2020; Sharma et al. 2020).

The study therefore focused on reducing air pollutants ($PM_{2.5}$, PM_{10}, NO_2, SO_2, CO and O_3) with a view to improving air quality and impacting regional temperatures (minimum, maximum and average temperatures) as well as India's climate during the lockdown period (April and May 2020) compared to previous years. Basically, this study emphasized on temporary reduction of the concentration of several air pollutants in the lower atmosphere, and as a result it significantly affects the climate of micro regions. Our study has given particular importance to the four megacity temperature reductions in India due to dramatic changes in air pollutants over a period of time. Further research can be carried out on several climatic parameters, such as the relationship between low air pollutants and wind speed, pressure, lighting activities, etc., and finally influence the climate of the micro region on the basis of the relationship between the above criteria, i.e., the reduction of air pollutants also significantly reduced temperatures. The study has indeed added new knowledge in literature broadly in earth science and particularly in temperature and atmospheric study. Apart from this, current study would add new information in our understanding of dynamics of air pollution and pollutants in the lower atmosphere or air controlling strategy of pollution.

2 Database and methodology

2.1 Data availability

The major pollutants data such as $PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, CO and O_3 are available at https://app.cpcbccr.com/AQI_India/, https://safar.tropmet.res.in/index.php, and https://app.cpcbccr.com/ccr/. The daily maximum, minimum and average temperature data are available at https://www.iari.res.in/. Monthly temperature data for the month of May during the period of 1980–2019 are available at https://www.indiawaterportal.org/.

[1] Janata Curfew is a curfew by the people and for the people to fight against coronavirus. To control the spread of coronavirus in India, the prime minister of India requested all the citizens make a curfew on March 22 from 7 am till 9 pm. During the Janata Curfew, people are requested to avoid public spaces and stay at home for 14 h in the view of coronavirus outbreak.

3 Methods

AQI is an index through which the air quality of the lower atmosphere is reported on a daily basis. It is generally measured to know how local air quality affects human health and how it affects the regional climate. The measurement of AQI is based on the particulate matters (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), Ozone (O_3) and ammonia (NH_3). Several countries have their own air quality indices, so India also has its own national AQI categories. In India, the National Air Monitoring Program (NAMP) has been operated by the Central Pollution Control Board (CPCB) in cooperation with the Satellite Pollution Control Boards, covering more than 342 monitoring stations across the country. AQI values have been measured using the sub-index values for 223 stations across the country. The sub-index value was determined using the following equation (Gupta and Dhir 2019; Kumar and Goyal 2011).

$$q = 100\left({}^{V}\!/_{V_s} \right) \tag{1}$$

where, q = Quality Rating, V = Observed values of the parameter, and Vs = Standard value recommended for the parameter. Thus, one of the pollutant's sub-indexes has the highest value, and it is responsible for air quality in a station. Alongside the highest sub-index's pollutant concentration value is the AQI. The value of AQI ranges from 0 to 500, and it is categorized into six categories, i.e., good, satisfactory, moderately polluted, poor, very poor and severe with their AQI ranges from 0–50, 51–100, 101–200, 201–300, 301–400 and 401–500, respectively.

The Mann–Kendall test is a method of nonparametric statistical technique to identify data series patterns (Kendall 1975). The principal advantages of this test are that no outer data properties or non-normal data sequence influence this test (Kendall 1975). The most famous test used by Man-Kendall is to grasp the hydrological, weather-related phenomena. However, this measure has been primarily used in this analysis to assess the direction of the air quality index. The monotone air quality pattern of the time series data was observed here. This method has generally been used to prove the hypothesis where the null hypothesis (H0) indicates that there is no such pattern of air quality and temperature over time. However, the alternative hypothesis (H1) indicates that there is a clear pattern in the air quality and temperature (increase or decrease) over time. A rank-based nonparametric technique is used to measure this test that can be used with skewed variables. The method used to measure Mann–Kendall tests has been shown. The Mann–Kendall statistical S test is calculated (Kendall 1975; Mann 1945) as follows

$$S = \sum_{i<j} a_{ij} \tag{2}$$

$$a_{ij} = \mathrm{sign}\left(X_j - X_i\right) = \mathrm{sign}\left(R_j - R_i\right) = \left\{ \begin{matrix} 1 & X_i < X_j \\ 0 & X_i = X_j \\ 1 & X_i > X_j \end{matrix} \right\} \tag{3}$$

Here, R_i and R_j are rank of observation in X_i and X_i time series. The Mann and Kendall have reported that statistics S, with the mean and variance, and the variance is computed (Kendall, 1975; Mann, 1945) as

$$E(s) = 0 \tag{4}$$

$$V_0(S) = \frac{n(n-1)(2n+5)}{18} \tag{5}$$

$$V_0^*(S) = \frac{n(n-1)(2n+5)}{18} - \frac{\sum_{j=1}^{m} t_j\left(t_j - 1\right)\left(2_{tj} + 5\right)}{18} \tag{6}$$

where n is the number of observations, m is the number of groups of tied ranks, each with t_j tied observations. When the number of observation became large, the significance of trend can be computed comparing the standardized variable u as followed.

$$u = \begin{Bmatrix} (S-1)/\sqrt{V_0(S)} & S > 0 \\ 0 & S = 0 \\ (S+1)/\sqrt{V_0(S)} & S < 0 \end{Bmatrix} \tag{7}$$

The positive u value in the Mann–Kendall test shows a growing trend in the data series and a negative downward trend in the data series. The emission and the temperature parameters of the research region concerned were therefore determined on the basis of the u meaning. The estimate of the value u is then compared to the tabulated value to show the conclusion. The probability is contrasted with the one-to-one percent, which means the standard. In this case, if the measured value of u is greater than $|u| \geq |\mathrm{u}1 - \alpha/2\alpha|$, the null hypothesis (H0) is rejected.

Sen's slope showed a pattern of intensity, where there is also a nonparametric approach to median utilization (Gilbert 1987). In this process, the data were sorted in an ascending manner (Gilbert1987). The first sub-series will be placed on the X-axis, while the Cartesian coordinate system will cover about half of the subseries on the Y-axis. The 45° straight line shows no data patterns, but the patterns below show a declining pattern beyond trends (Gilbert 1987). The slope estimates of N datasets were computed by the following equation.

$$Q_i = \frac{x_j - x_k}{j - k} \text{for} i = 1, 2, \dots, N \tag{8}$$

where $x_j, \ldots, x_k$ are the value of data at the time j and k ($j > k$), respectively. The median of slope or Sen's slope estimator of odd and even data is computed as

$$Q_{\mathrm{m}} = Q_{[(N+1)/2]} \tag{9}$$

$$Q_{\mathrm{m}} = \frac{1}{2}\left[Q_{(N/2)} + Q_{\{(N+2)/2\}}\right] \tag{10}$$

where Q_{m} is median of data trend. Equation (5) applied if N is odd data, and if N is even Eq. (6) is used. When the median slope is statistically different than zero, the confidence interval of Q_{m} at specific probability (Da Silva et al. 2015; Gilbert, 1987) is estimated as

$$C_{\alpha} = Z_{1-\alpha/2}\sqrt{\mathrm{Var}(S)} \tag{11}$$

where Var (S) is calculated from Eq. (6) and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution.

It is also a well-known fact that every statistical technique has some limitations in its applied side. Therefore, the Man–Kendall test also has some limitations, which give a negative result in shorter datasets and periodicity data, i.e., seasonal variations. On the other hand, Sen's slope also produces a negative result in a short dataset. Therefore, in both of cases longer the time series data give much more effective result in trend analysis. Thus, here we used a long-term climatic data to meet our objective with special emphasis on, during and after lockdown period. Moreover, the AQI and the Mann–Kendall statistical method both will be suitable to understand the trend and internal dynamics of temporary improvement in ambient-air-quality reduced temperature during the COVID-19 lockdown period in India.

4 Results

Throughout this study, data on pollutants were used to show the improvement in air quality available from February 2016 to 20 May 2020 to estimate changes in daily emissions during the forced closure of the COVID-19 pandemic and its impact on the regional climate during the pandemic phase (2020) compared to previous years. This change in pollutants and air quality was compared with the average daily pollutants of previous available years (2016–2019 across the country) in order to provide a quantitative study of relative improvement compared to pre-lockdown conditions. Changes in daily atmospheric pollutants and temperatures have been estimated at five different types of forced lockdown phases (Table 1) across the country due to improved levels of pollutants and temperatures in accordance with strict government regulations and their impact on the regional climate and environment [Eqs. (1)–(11) in Methods]. The study is carried out across India as a whole, with 4 most polluted mega-cities (Delhi, Mumbai, Kolkata and Chennai) accounting for 1.4 billion people worldwide (18.5%), 15% of pollution and 12.5% of global deaths (Gurjar et al. 2016). The strict lockdown form of government intervention is specified on a scale of 1–5 and specifies the degree to which a negligible relaxation of 1.4 billion people has been permitted (Table 1). Scale 1 indicates that all kinds of activities are strictly prohibited throughout the country, e.g., 'Janata Curfew' from 7 a.m. To 9:00 p.m. Sunday 22 March 2020 to control the outbreak of COVID-19. Scale 2 shows that, despite the opening of the market, almost all services and factories have been declared suspended, the consequences of nationwide arrests for violating the lockdown regulation have been witnessed, but daily emissions have dropped substantially (5%). Scale 3 reflects that the relaxation has been introduced to agricultural businesses, livestock, aquaculture and forestry, and to shops selling agricultural goods, etc., which has boosted the daily level of emissions by 2%. However, the lockdown has also been extended to 3 May 2020. Scale 4 reveals the continuation of the enforced lockdown duration until 17 May 2020, where the red zones will remain under strict lockdown; however, then the orange zones would allow only private and hired vehicles with no public transport while, as usual, bus travel is permitted in green zones with a limited capacity of 50%. Scale 5 demonstrates extended relaxation and lockdown until 31 May 2020 in the red hot spot zones. This shows a gradual improvement in daily pollutants and air quality, resulting in a declining temperature trend across the country.

Table 1 Lockdown types, its Prohibition and relaxation

Scale	Lockdown type	Duration	Prohibition	Relaxation
Scale 1	Janata Curfew	22 March, 2020 (14-h)	Restriction on people stepping out from their homes; Road, air and rail transport services; educational institution; industrial establishments and hospitality services were suspended	Transportation services such as essential goods, fire, police along with emergency services, i.e., food shops, petrol pumps, ATMs were exempted
Scale 2	Phase-I	25 March–14 April, 2020	Nearly all services and factories were suspended	Special parcel trains were allowed to transport essential goods
Scale 3	Phase-II	15 April–3 May, 2020	Transports such as rail, Metro services, air, buses; inter-district and inter-state movements; educational institution; religious places, cinema halls, bars, shopping complexes; sports; industrial activities; etc.	Medical services with specific permitted, agricultural activities, online teaching, data and call centers for government activities only
Scale 4	Phase-III	4 May–17 May 2020	Railway and Metro services, educational institutions, cinema halls, malls, places of worship, non-essential movement between 7 P. M.–7 A.M., inter/intra-district buses with 50% capacity	Shops/e-commerce dealing essential goods, private offices with 33%capacity, two-wheelers without pillion rider, four-wheelers with 1 driver and 2 passengers, inter-states movement of goods
Scale 5	Phase-IV	18 May–31 May 2020	Metro, air and rail services remain suspended, religious and political gatherings prohibited; vulnerable groups such as those above 65 years, pregnant women and children below 10 to remain at home; schools, colleges, malls to remain shut	Buses, auto-rickshaws, cabs can operate; barber shops and salons can open; restaurants can function, but only for take-away; weddings cannot have more than 50 guests and funerals not more than 20; delivery of essential and non-essential items allowed through online shopping platforms; Cap on 33% strength in offices done away with, work from home to be encouraged; social distancing and staggered work hours to be followed in offices

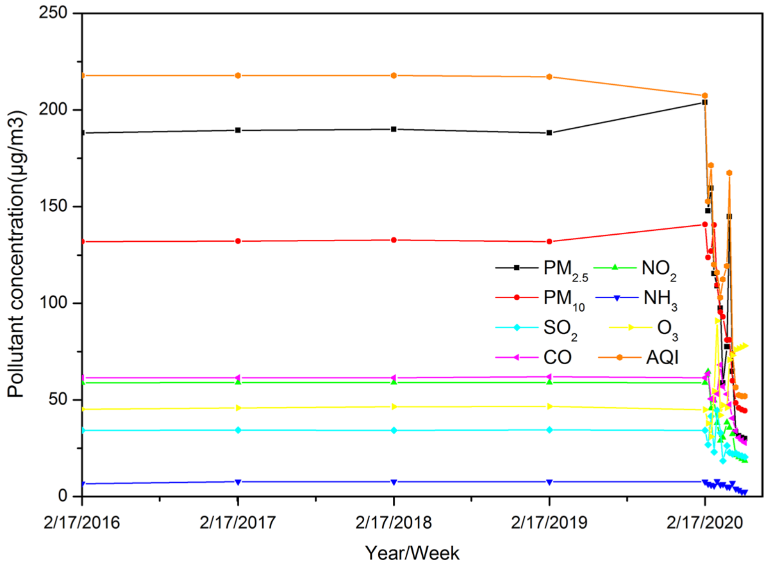

Fig. 1 Trend of major pollutants during pre-lockdown (2016–2020) and lockdown period

4.1 Daily changes in pollutants levels and air quality

The strict lockdown policy was introduced by the Government of India to mitigate and monitor the Covid-19 pandemic. It was a common consensus to develop a policy of social distancing and to avoid a public meeting. In addition to the above policies, strict measures have been taken to put an end to the transport networks (air, rail and road) and the closure of major factories. As a result of this drastic improvement in air quality, especially among vital pollutants such as PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, NH_3 and O_3 have been observed (Fig. 1). The result of the strict lockdown was to decrease emissions of pollutants by − 12% (− 8–− 16%) per day across the nation by 22 March 2020 onwards compared to the average amount of pollution in 2019 (Fig. 2). The 21 March 2020 change in pollutants was the maximum daily average change from 1 January to 20 May 2020. In particular, the quantity of pollutants decreased from 'Janata Curfew' to lockdown (22 March 2020 to 31 March 2020) just below the permitted limit within one week, whereas the concentration of O_3 increased in the manufacturing and transport areas (Fig. 3). Atmospheric pollution emissions such as PM_{10} and $PM_{2.5}$ were decreased by − 48.56% and − 57.09%, respectively (Figs. 4 and 5). Other pollutants that showed significant improvements during pre-lockdown and lockdown are NO_2 (− 46.95%), SO_2 (− 32.11%), while CO (− 22.82%) and NH_3 (− 30.61%) showed very small reductions compared to other pollutants (Fig. 6, 7, 8, 9 and Table 2). This resulted in a significant improvement in air quality (− 42.90% with a net decrease of − 65.85) during the lockdown period from 'Janata Curfew' to lockdown phase 4 (22 March–31 May 2020) (Fig. 10 and Table 2). It has been observed that the level of emissions has indeed improved in metropolitan areas. PM_{10} and $PM_{2.5}$ decreased by − 43.91% and − 61.35% in Delhi (Table 3), while PM_{10} and $PM_{2.5}$ decreased by − 58.04% and − 71.56%, respectively, in Mumbai (Table 4). PM_{10} and $PM_{2.5}$ concentrations in Kolkata decreased by − 71.72% and − 81.25%, respectively (Table 5), while PM_{10} and $PM_{2.5}$ concentrations in Chennai decreased by − 47.08% and -59.26%, respectively (Table 6),

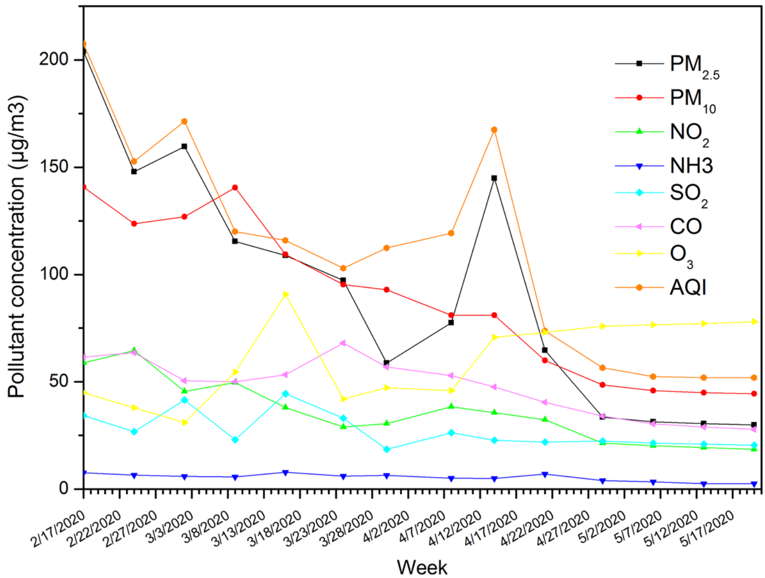

Fig. 2 Trend of major pollutants during pre-lockdown (17 February–21 march, 2020) and lockdown period

owing to the COVID-19 pandemic. Other pollutants with notable changes during the pandemic period are SO_2 (−32.10%) and NO_2 (−31.14%), though CO (−25.17%) shows a rather slight decrease compared to other contaminants in Delhi (Table 3). Besides this, in Mumbai, CO (−29.55%) and NO_2 (−77.56%) were the pollutants that showed substantial improvements, whereas SO_2 (−19.62%) saw a rather slight decrease relative to other pollutants (Table 4). Similarity, CO (−59.83%) and NO_2 (−62.64%) are contaminants in Kolkata, which has seen a significant decrease in the pre-locking and lockdown period (Table 5). Similarity, CO (−48.31%) and NO_2 (−33.43%) are contaminants in Chennai, which has seen a sharp decline during these phases (Table 6). This is due to a different pollution challenge in Chennai than the other megacities in India. Basically, this megacity has a unique coastal location, sea breeze is being developed, and all pollutants will disappear from the city and move inland. However, motorization in public transport is very high compared to many other megacities and therefore adds enormous pollution to the lower atmosphere, basically CO and NO_2. However, due to a strict lockdown, the public transport system, i.e., road motorization, has been totally stopped. As a result, a sharp decrease in the level of CO and NO2 pollutants in the Chennai megacity has been observed.

4.2 Changes in daily temperature

A significant decrease in temperature was noted when the COVID-19 lockdown minimized human activity and the movements of vehicles, thus decreasing concentrations of pollutants in the atmosphere, which eventually led to a considerable decrease in temperature (Figs. 11 and 12). The daily temperature trend during the Covid-19 pandemic lockout for maximum, minimum and average (Table 7) are 0.099 °C, 0.109 °C and 0.102 °C, while in 2019 these daily temperature trends were 0.102 °C, 0.119 °C and 0.111 °C per day. Similarly, in 2018 these daily temperature trends were also found increasing (0.110 °C,

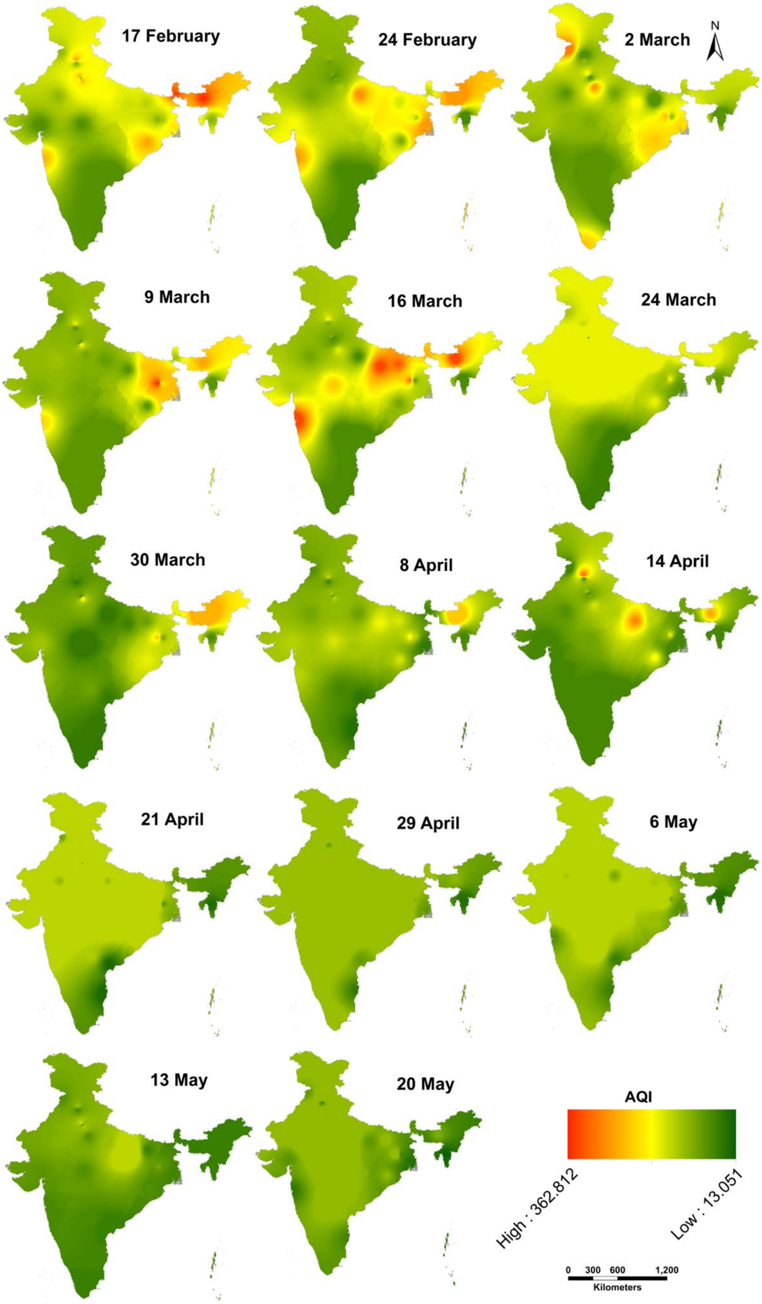

Fig. 3 Spatial distribution of O_3 in before (17th February–16th March) and during lockdown (24th March–20th May) period

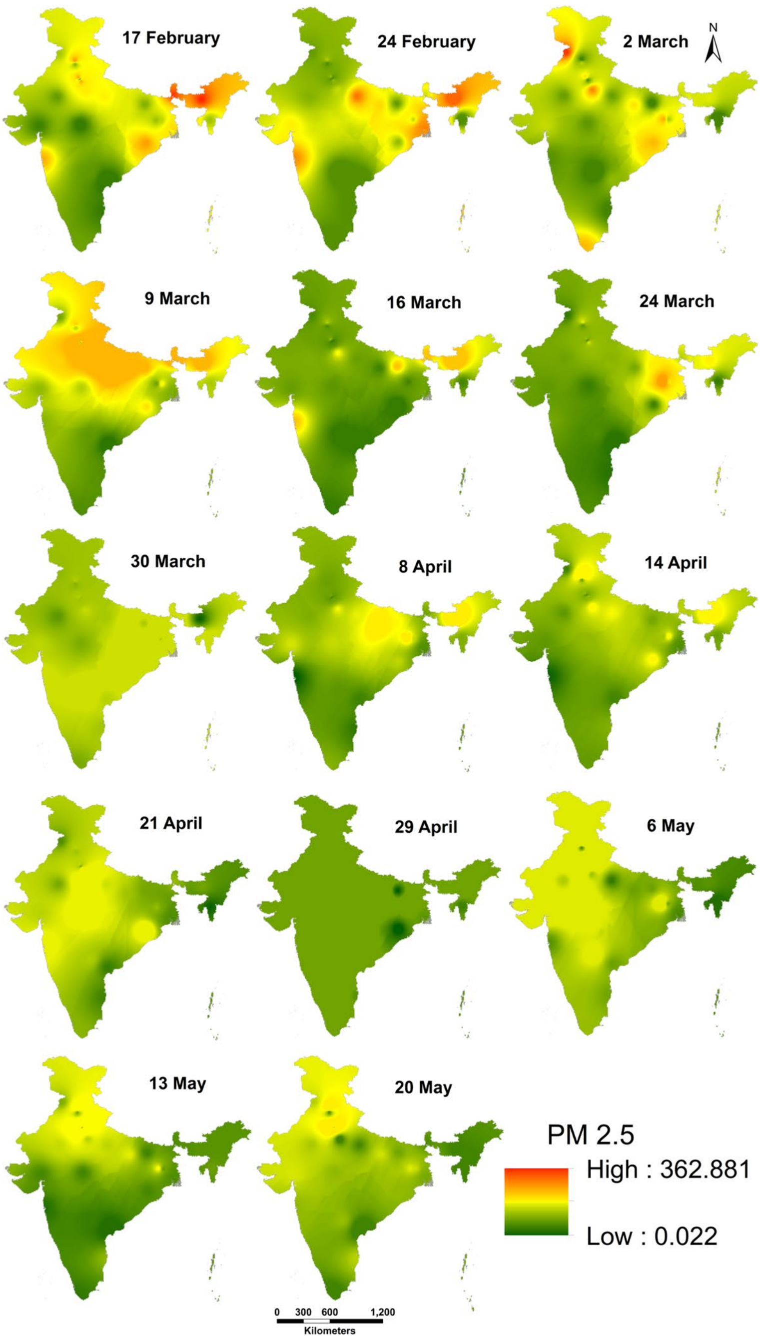

Fig. 4 Spatial distribution of $PM_{2.5}$ in before (17th February–16th March) and during lockdown (24th March–20th May) period

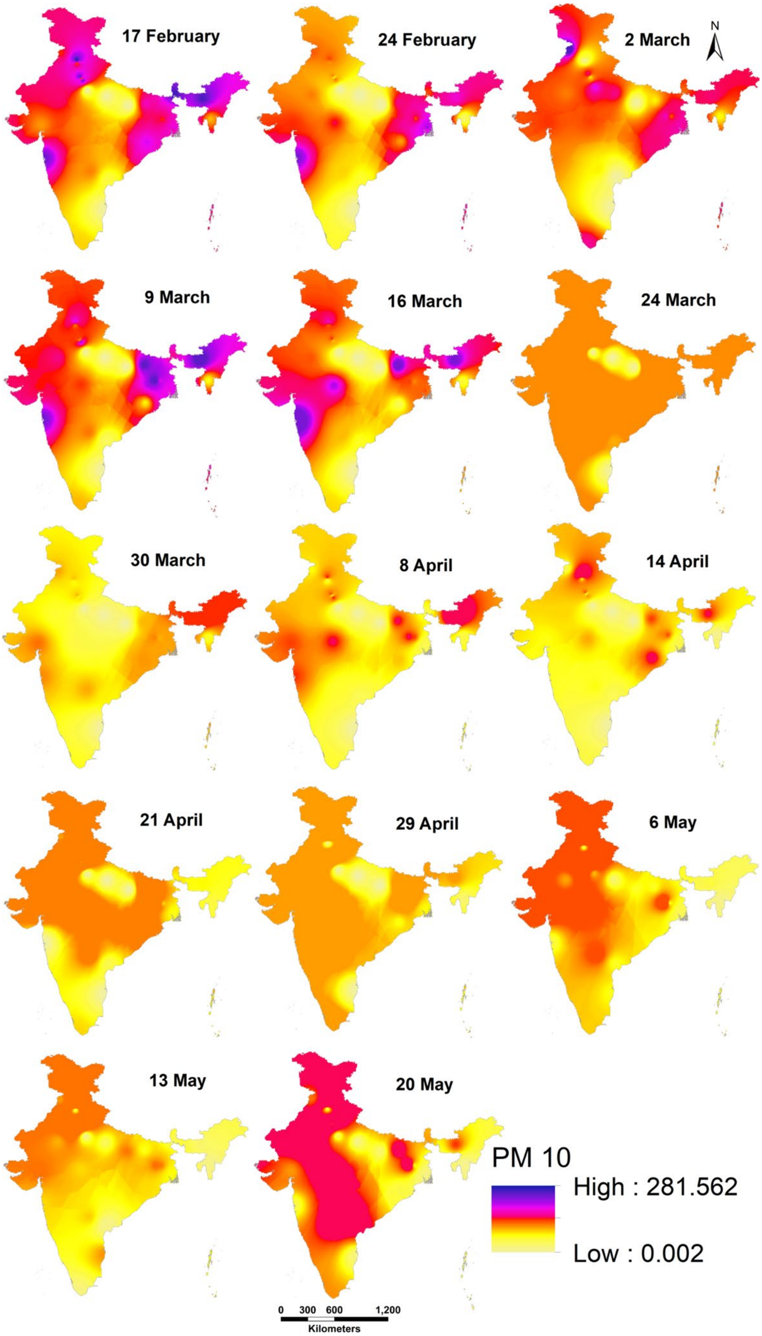

Fig. 5 Spatial distribution of PM_{10} in before (17th February–16th March) and during lockdown (24th March–20th May) period

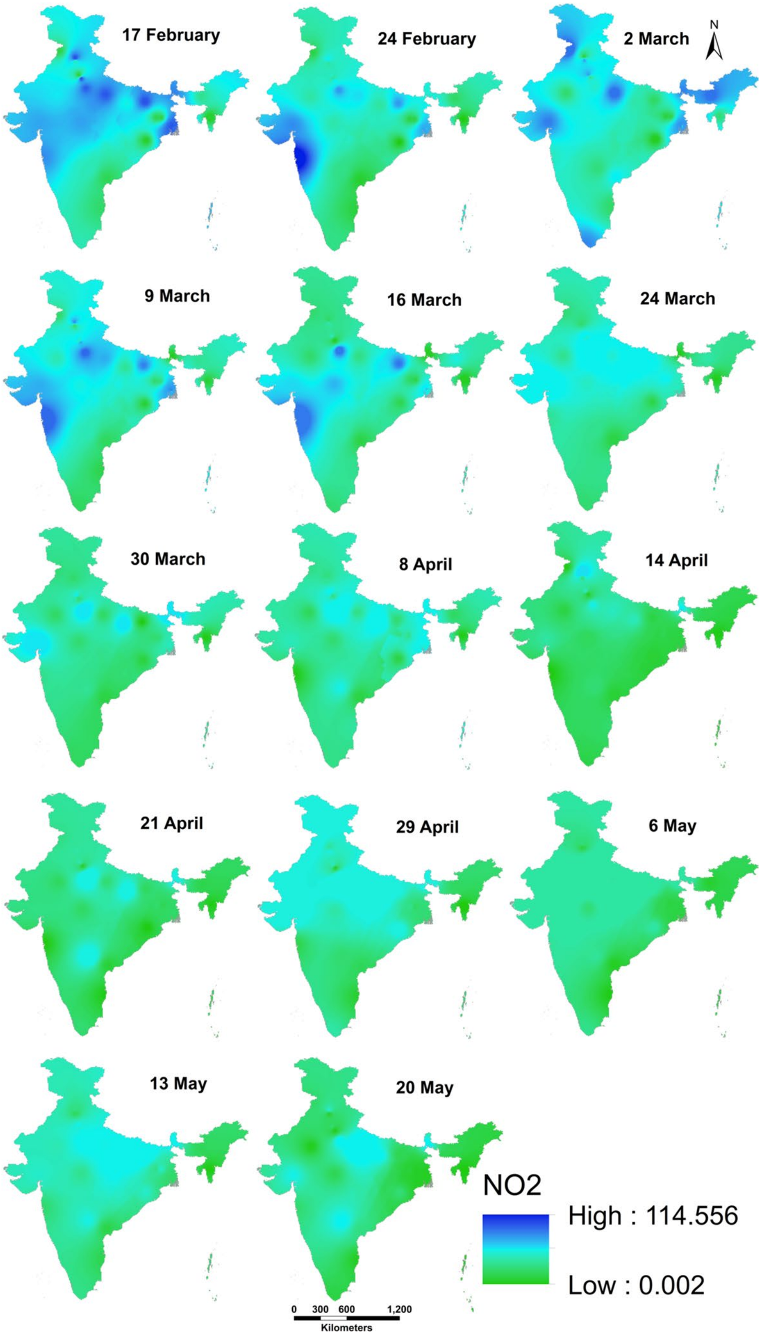

Fig. 6 Spatial distribution of NO_2 in before (17th February–16th March) and during lockdown (24th March–20th May) period

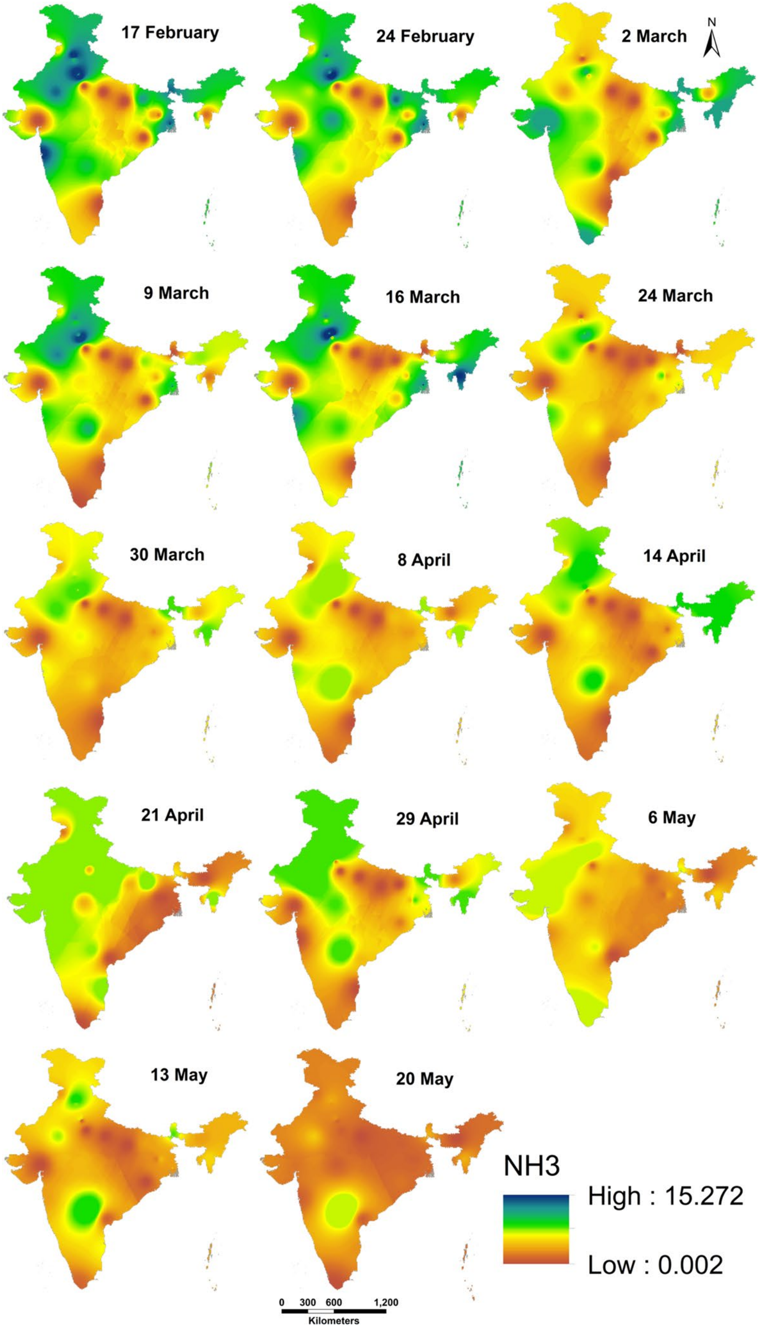

Fig. 7 Spatial distribution of NH_3 in before (17th February–16th March) and during lockdown (24th March–20th May) period

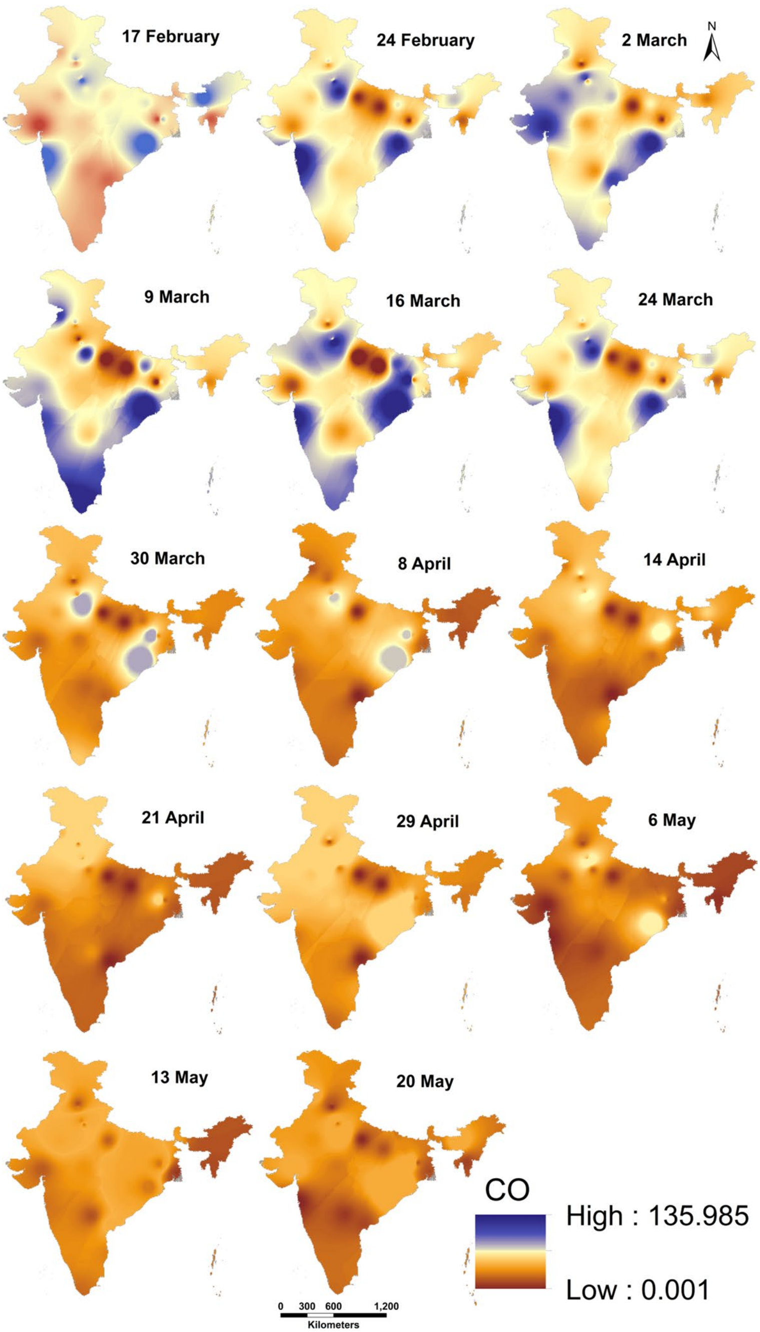

Fig. 8 Spatial distribution of CO in before (17th February–16th March) and during lockdown (24th March–20th May) period

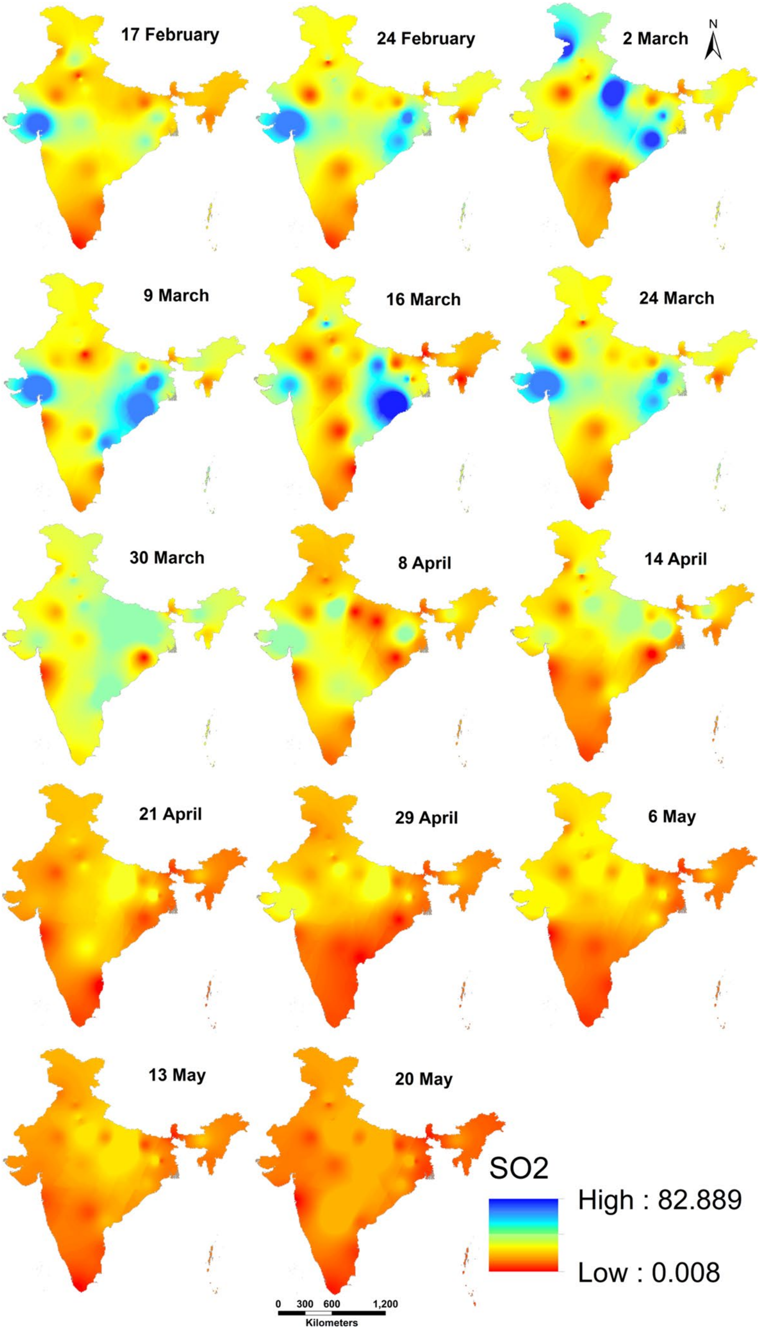

Fig. 9 Spatial distribution of SO_2 in before (17th February–16th March) and during lockdown (24th March–20th May) period

Table 2 Pollutant matter and gases before and after lockdown in India, 2020

Types of pollutants	Before lockdown									
	17-Feb-2020		24-Feb-2020		02-Mar-2020		09-Mar-2020		16-Mar-2020	
	High	Low	High	Low	High	Low	High	Low	High	Low
$PM_{2.5}$	362.811	45.004	250.869	44.89	281.917	37.285	209.849	21.002	185.852	32.064
PM_{10}	281.562	0.02	247.435	0.017	253.908	0.004	281.057	0.012	218.757	0.013
NO_2	114.556	3.151	122.967	6.091	85.977	5.078	99.252	0.087	75.98	0.074
NH_3	15.272	0.009	13.001	0.007	11.95	0.002	11.253	0.005	15.745	0.006
SO_2	66.946	1.586	52.958	0.62	82.917	0.008	45.954	0.124	82.889	6.003
CO	106.885	16.043	127.022	0.001	100.888	0.131	99.856	0.001	106.526	0.001
O_3	82.752	7.133	75.695	0.01	57.94	4.068	104.955	4.004	180.57	1.007
AQI	362.812	52.004	257.106	48.376	281.918	60.753	210.122	30.002	185.956	46.002

Types of pollutants	After lockdown																		Overall variation	
	24-Mar-2020		30-Mar-2020		08-Apr-2020		14-Apr-2020		21-Apr-2020		29-Apr-2020		6-May-2020		13-May-2020		20-May-2020		Net	%
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low		
$PM_{2.5}$	163.655	31.001	117.316	0.085	154.839	0.022	289.776	0.029	129.258	0.055	66.972	0.029	62.789	0.027	60.89	0.025	59.798	0.024	−84.0104	−57.09
PM_{10}	190.831	0.011	185.95	0.013	161.907	0.011	161.907	0.011	119.696	0.008	96.943	0.008	91.69	0.005	89.89	0.002	88.79	0.002	−62.2966	−48.5635
NO_2	57.729	0.052	60.903	0.056	76.627	0.008	70.983	0.087	64.506	0.008	42.726	0.026	40.521	0.021	38.789	0.002	36.988	0.002	−24.0972	−46.9536
NH_3	12.168	0.006	12.764	0.005	10.159	0.006	9.968	0.005	13.985	0.003	7.995	0.004	6.889	0.002	5.01	0.004	5.02	0.005	−2.05844	−30.6088
SO_2	65.94	0.023	36.935	0.03	52.605	0.025	45.482	0.027	43.908	0.003	44.891	0.003	42.907	0.002	41.89	0.005	40.79	0.005	−10.9188	−32.1136
CO	135.985	0.069	113.814	0.051	105.86	0.001	94.971	0.051	80.917	0.001	67.923	0.027	60.789	0.025	57.937	0.002	55.789	0.003	−12.7235	−22.8283
O_3	78.993	5.064	88.126	6.253	91.789	0.029	141.282	0.045	145.89	0.058	151.789	0.071	152.369	0.659	153.789	0.5	155.89	0.002	32.91671	63.52934
AQI	163.885	42.001	190.852	34.058	218.76	20.006	289.997	45.002	129.509	18.005	99.895	13.051	92.889	12.01	90.79	13.01	90.89	13.05	−65.8573	−42.9024

Source: National Air quality Index portal, Central Pollution Control Board, Govt. of India, 2020

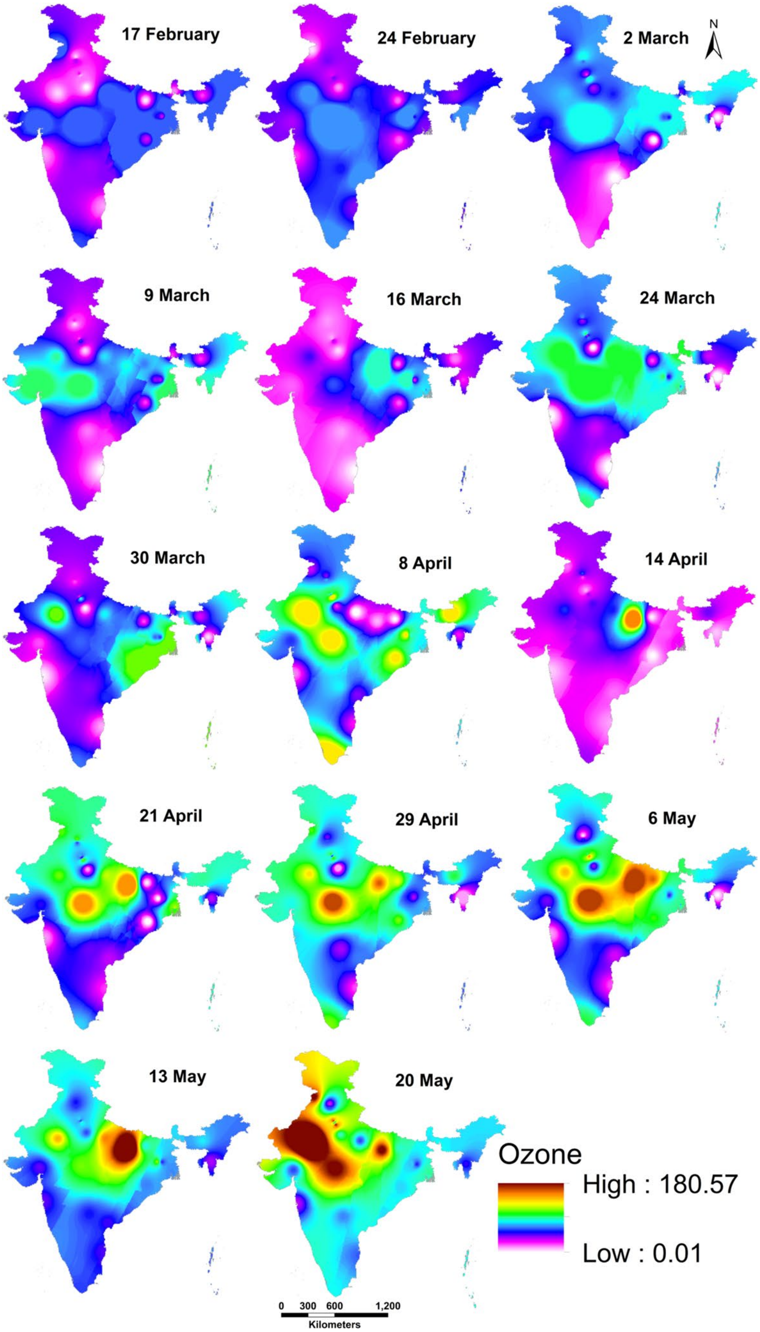

Fig. 10 Spatial distribution of Air Quality Index (AQI) in before (17th February–16th March) and during lockdown (24th March–20th May) period

Table 3 Pollutant matter and gases before and after lockdown in Delhi, 2020

Types of pollutants	Before lockdown									
	17-Feb-2020		24-Feb-2020		02-Mar-2020		09-Mar-2020		16-Mar-2020	
	High	Low	High	Low	High	Low	High	Low	High	Low
$PM_{2.5}$	360.998	237.014	206.997	83.0983	246.746	100.014	185.979	7.085	245.963	8.089
PM_{10}	330.997	46.044	197.977	85.004	260.124	11.1415	218.968	50.1346	204.978	88.044
NO_2	120.932	6.015	78.976	28.057	85.9892	8.81	76.9671	6.04546	69.974	22.021
NH_3	12.994	0.015	12.999	3.006	11.999	4.005	9.999	2.004	13.994	1.002
SO_2	41.981	5.28	29.999	1.002	36.995	6.014	45.9934	6.012	33.792	7.001
CO	123.928	31.006	108.908	19.041	104.972	14.012	96.9816	5.006	103.948	12.008
O_3	42.999	30	65.987	8.008	28.849	5.013	73.97	3.016	42.968	4.019
AQI	361.998	42.59	364.89	45.32	355.489	52.13	312.35	40.89	319.89	42.39

Types of pollutants	After lockdown																		Overall variation	
	24-Mar-2020		30-Mar-2020		08-Apr-2020		14-Apr-2020		21-Apr-2020		29-Apr-2020		06-May-2020		13-May-2020		20-May-2020			
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Net	%
$PM_{2.5}$	163.652	10.068	98.998	40.0045	90.998	29.025	118.98	35.002	107.789	32.001	110.23	38.8475	97.32	1.0078	96.89	1.198	95.98	2.02	−103.198	−61.3548
PM_{10}	142.985	53.037	90.999	45.02	118.999	68.0165	182.997	0.033	118.998	44.002	146.999	51.0328	123.989	33.008	112.59	32.09	109.89	33.08	−65.5765	−43.9105
NO_2	55.977	2.023	78.947	4.002	63.961	3.001	78.956	13.023	78.9491	6.002	78.948	10.001	41.999	9.001	42.58	8.02	41.39	7.59	−15.6914	−31.147
NH_3	11.39	3.001	9.993	2.001	5.999	2.014	10.99	3	10.94	0.0014	8.98	1.001	7.89	4.009	5.89	1.01	5.69	1.012	−1.9344	−26.8603
SO_2	40.73	9.001	29.98	1.003	24.98	4.00218	28.98	7.0004	21.999	1.008	20.89	1.009	19.89	9.0013	19.01	2.01	20.12	1.02	−6.87172	−32.1005
CO	100.23	2	74.813	7.026	75.89	9.053	76.89	20	77.78	16.007	75.89	16.9307	76.89	25.759	76.23	14.25	75.89	13.24	−15.605	−25.1771
O_3	46.996	5.019	55.958	5.023	73.944	5.031	157.985	5.0534	52.999	6.04	168.985	17.0367	66.9553	14.029	66.89	12.39	65.98	12.98	16.14457	52.9627
AQI	218.59	21.89	210.58	22.89	201.89	22.69	200.79	21.69	189.89	22.89	169.87	18.98	152.39	18.79	132.89	18.29	112.59	18.01	−95.1493	−49.0982

Table 4 Pollutant matter and gases before and after lockdown in Mumbai, 2020

Types of pollutants	Before lockdown									
	17-Feb-2020		24-Feb-2020		02-Mar-2020		09-Mar-2020		16-Mar-2020	
	High	Low	High	Low	High	Low	High	Low	High	Low
$PM_{2.5}$	292.98	133.028	224.98	71.027	168.992	58.0096	65.9991	37.0005	131.997	48.0012
PM_{10}	301.988	118.022	238.99	13.0162	195.992	41.0102	156.996	12.0027	240.991	41.0144
NO_2	108.993	1.0012	122.997	11.0017	81.9965	21.0048	70.9981	4.0009	116.983	8.0012
NH_3	8.9996	1.0004	11.9976	2.0003	56.9928	1.0024	8.9981	1.0001	10.9994	0.0013
SO_2	41.9953	4.0002	3.997	1.0008	89.9913	4.0004	54.9935	3.0006	58.9936	5.0005
CO	92.9973	24.0117	106.989	2.0016	91.9966	19.0008	75.9933	9.0065	114.982	24.0008
O_3	57.9958	13.0002	83.917	0.0009	36.9991	3.0037	45.9992	9.0003	57.9903	8.0054
AQI	301.993	133.028	238.994	110.018	195.995	79.006	156.996	76.0061	240.991	48.0023

Types of pollutants	After lockdown																		Overall variation	
	24-Mar-2020		30-Mar-2020		08-Apr-2020		14-Apr-2020		21-Apr-2020		29-Apr-2020		06-May-2020		13-May-2020		20-May-2020			
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Net	%
$PM_{2.5}$	63.9949	32.0005	53.9995	24.0029	64.9976	20.0021	51.99	13.0053	52.9983	26.0016	37.9998	19.0002	36.9987	19.0001	38.49	19.01	37.19	20.01	−88.163	−71.5601
PM_{10}	98.9978	41.0048	92.9965	4.0065	115.997	41.0054	92.9827	5.0166	95.9966	38.0032	77.9979	27.009	75.0001	26.0098	74.89	27.01	72.189	21.01	−78.9399	−58.0431
NO_2	30.9944	1.0011	21.9989	4.0002	16.999	2.0001	15.9992	3.0001	30.9968	3.0012	21.9998	2.00297	20.9998	2.0001	20.89	2.01	19.89	1.09	−42.427	−77.5662
NH_3	6.9998	1.0001	4.9998	1.0005	4.4998	1.0003	2.9999	1.0001	7.9994	1.0001	3.9998	1.0003	3.9998	1.0001	4.01	1.0001	3.98	1.012	−7.38243	−71.6796
SO_2	51.47	2.0008	54.79	1.0008	42.89	1.0009	28.9937	3.0006	28.9943	2.0011	79.9823	2.0025	28.3339	1.9998	27.49	1.59	27.69	1.01	−5.2395	−19.6256
CO	74.9926	12.0006	81.9914	11.0013	83.9906	6.0018	88.9795	12.0003	94.9792	7.0031	57.9945	5.00177	54.9998	4.0001	54.01	4.49	53.89	4.0001	−16.5798	−29.5551
O_3	62.9892	6.0002	81.9845	7.001	18.9991	2.0017	21.9996	4.0014	38.9924	7.0027	162.984	1.0028	89.0027	2.9998	87.59	2.01	88.59	2.0001	6.583877	20.84086
AQI	98.9979	55.0029	92.9978	56.0021	115.998	78.0003	92.994	62.0059	95.9977	42.0006	79.9981	38.0108	78.89	37.01	68.01	35.89	66.59	34.0001	−89.8587	−56.8356

Table 5 Pollutant matter and gases before and after lockdown in Kolkata, 2020

Types of Pollutants	Before lockdown									
	17-Feb-2020		24-Feb-2020		02-Mar-2020		09-Mar-2020		16-Mar-2020	
	High	Low	High	Low	High	Low	High	Low	High	Low
$PM_{2.5}$	294.815	145.278	289.808	137.249	289.836	148.305	170.968	71.2055	94.919	21.1054
PM_{10}	286.527	133.145	272.601	115.089	253.942	136.049	180.949	73.049	102.969	34.1038
NO_2	122.907	55.047	92.934	52.1404	93.967	47.036	71.9765	11.129	67.9675	5.07228
NH_3	17.949	2.025	14.963	1.03	13.964	2.019	10.9744	3.003	10.9769	1.00784
SO_2	25.9558	10.0092	65.9652	7.018	60.9709	10.0111	35.986	5.012	29.9753	5.03107
CO	175.746	16.039	61.9864	26.044	89.8923	18.1206	47.9403	10.098	77.886	10.0436
O_3	153.89	17.0524	125.89	10.011	155.541	12.0856	224.832	12.051	172.776	52.0712
AQI	341.988	41.59	324.746	42.32	331.13	42.13	302.59	39.89	317.89	41.39

Types of pollutants	After lockdown																		Overall variation	
	24-Mar-2020		30-Mar-2020		08-Apr-2020		14-Apr-2020		21-Apr-2020		29-Apr-2020		06-May-2020		13-May-2020		20-May-2020			
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Net	%
$PM_{2.5}$	92.896	10.0494	87.927	1.0265	34.9943	21.0177	50.9949	38.0031	49.78	1.0072	39.59	5.01859	30.997	20.005	30.29	4.02	38.79	5.01	−135.159	−81.2504
PM_{10}	97.901	50.0352	97.977	50.0208	44.988	24.0394	72.9821	45.0229	47.986	23.0255	43.9583	16.0316	48.989	28.025	42.38	16.32	41.89	16.89	−113.928	−71.7238
NO_2	62.8981	9.038	35.9857	10.0205	153.903	5.0199	17.9627	4.0093	22.9611	5.01257	18.9698	4.01197	18.969	5.009	17.23	4.05	16.89	5.01	−38.8537	−62.6495
NH_3	9.981	2.005	7.99074	2.00448	5.9969	1.0036	7.98165	1.0035	6.98506	1.00278	5.991	1.002	4.997	1.002	5.89	1.01	5.39	1.002	−3.77795	−48.4899
SO_2	19.9856	9.006	24.9874	9.00669	8.9987	6.0024	13.9823	3.00922	14.9726	2.00961	8.999	4.0004	9.995	2.009	8.39	4.01	7.89	4.012	−16.6342	−64.9941
CO	65.9023	13.041	51.9112	3.147	28.959	7.064	31.9605	10.0659	21.9756	8.04294	31.953	7.0712	29.955	6.031	28.89	6.01	27.955	6.01	−31.9383	−59.8323
O_3	84.8868	14.018	167.815	62.0623	154.69	20.0084	153.48	14.033	164.89	15.0362	136.57	21.0121	123.69	13.009	123.78	13.01	122.89	14.09	−14.7883	−15.7961
AQI	210.69	21.57	201.69	21.47	198.89	21.59	198.79	20.89	190.29	21.79	168.98	18.9	151.39	18.69	133.59	17.89	110.39	17.89	−85.6008	−46.8875

Table 6 Pollutant matter and gases before and after lockdown in Chennai, 2020

Types of pollutants	Before lockdown									
	17-Feb-2020		24-Feb-2020		02-Mar-2020		09-Mar-2020		16-Mar-2020	
	High	Low	High	Low	High	Low	High	Low	High	Low
$PM_{2.5}$	72.9998	40.0023	68.9998	37.0023	110.993	18.0015	91.997	18.015	75.9998	35.0001
PM_{10}	52.9983	22.0005	58.995	21.0007	54.321	20.993	27.9988	9.0041	50.0001	20.6312
NO_2	22.9995	5.0012	18.9996	5.0005	23.01	3.01	19.9994	3.0051	21.9901	1.0013
NH_3	11.9999	7.002	38.996	11.0002	12.99	5.893	90.9991	9.0031	11.9998	0.9998
SO_2	55.9982	7.0006	47.9985	6.0005	48.7	4.003	7.991	4.003	38.0001	5.0124
CO	68.9991	31.0001	96.998	21.002	88.327	15.0019	69.9983	15.0015	77.0001	16.0001
O_3	21.9997	13.001	24.9998	19.0001	13.63	5.983	39.321	4.002	41.0001	0.9998
AQI	198.47	40.28	187.59	41.01	195.48	39.19	189.59	38.79	187.89	40.13

Types of pollutants	After lockdown																		Overall variation	
	24-Mar-2020		30-Mar-2020		08-Apr-2020		14-Apr-2020		21-Apr-2020		29-Apr-2020		6-May-2020		13-May-2020		20-May-2020			
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Net	%
$PM_{2.5}$	58.3249	30.0001	63.001	27.9998	42.9998	10.0001	54.9998	0.998	35.0001	4.0001	16.0018	7.0001	14.9998	9.0001	13.69	7.01	13.59	8.59	− 33.723	− 59.266
PM_{10}	30.9998	14.0001	38.001	11.214	31.0001	18.0098	18.9998	11.001	20.9998	16.0001	22.0001	11.0019	16.9998	7.001	20.59	10.59	16.49	7.01	− 15.9105	− 47.0804
NO_2	20.0001	1.0001	21.001	2.998	16.0001	1.998	26.9998	1.998	8.0001	0.998	12.9998	3.0098	9.9998	1.0001	9.49	1.01	8.89	1.19	− 4.14708	− 33.4397
NH_3	14.0001	7.9998	10.001	5.0012	11.9998	5.0019	12.001	6.001	9.0001	5.0001	10.9998	2.0018	10.0018	1.0009	10.01	1.01	9.89	1.0009	− 12.7593	− 63.5163
SO_2	9.0009	5.0001	11.0001	3.9287	8.019	3.9998	20.0001	3.998	8.0001	3.998	8.9998	2.00019	8.9998	2.0001	8.49	1.59	8.01	1.01	− 15.9127	− 70.8152
CO	48.9998	1.0001	38.9998	0.0998	37.0001	19.0002	41.0001	17.001	37.0019	17.0001	45.0011	19.9998	36.0001	14.0018	32.49	14.01	31.89	14.01	− 24.1269	− 48.3188
O_3	40.9998	5.9998	65.889	6.0001	66.89	9.0019	78.49	11.001	120.998	10.0098	101.998	19.9998	124.0018	13.9909	124.01	12.59	123.01	13.01	34.2669	186.2974
AQI	185.79	20.57	145.79	20.49	152.69	20.59	150.589	19.89	123.69	20.78	101.29	17.89	89.789	17.79	88.79	17.01	79.89	16.89	− 44.1638	− 38.1241

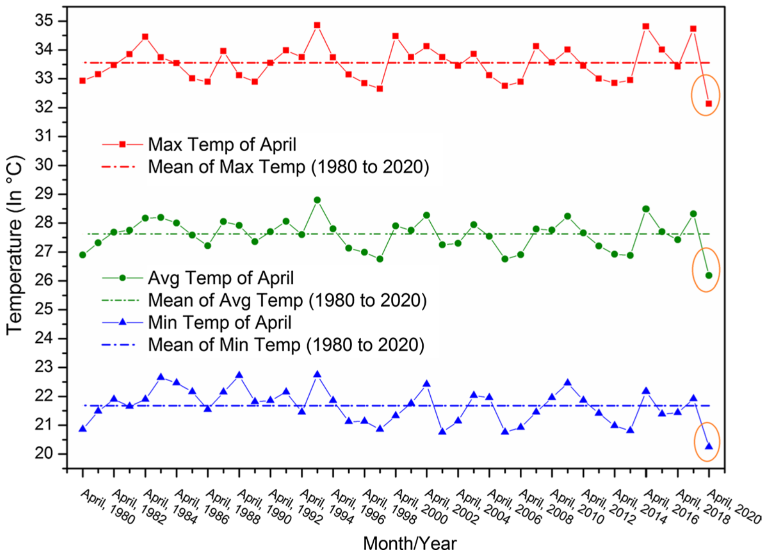

Fig. 11 Trend in maximum, minimum and average temperature of April month from 1980 to 2020

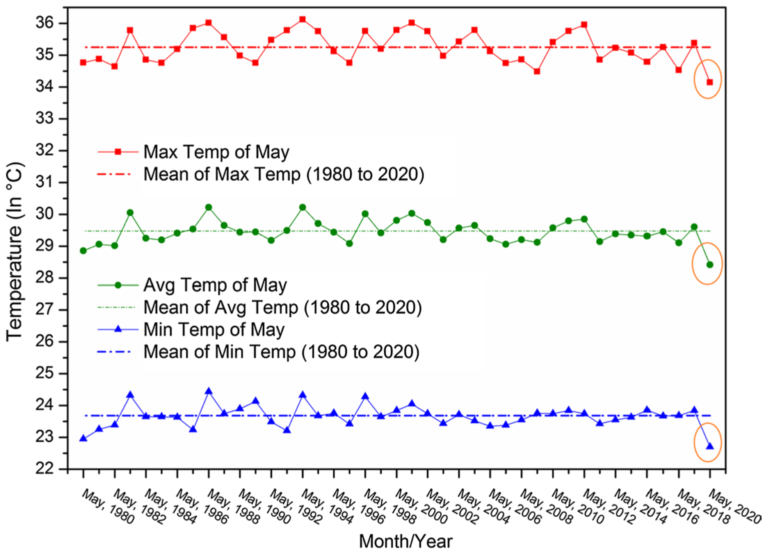

Fig. 12 Trend in maximum, minimum and average temperature of May month from 1980 to 2020

0.124 °C and 0.129 °C). The same rising temperature trend was observed for the rest of the years (1980–2020). The findings of the Mann-Kendal and Sen slope rank tests indicate that the maximum, minimum and average temperatures for May 2020 (lockdown period) decreased by 2 °C, 1 °C and 1.5 °C, respectively, compared to the previous year, i.e., 1980–2019 which eventually had a considerable impact on the regional climate (Table 7). In the case of the metropolitan cities of India, the same findings have been found that

Table 7 Daily trend of temperature (°C) in India and its four megacities for the year of 2018, 2019, 2020

Mega city and Country	Year	Daily temperature					
		Mann–Kendal Z			Sen's slope		
		Maximum	Minimum	Average	Maximum	Minimum	Average
Delhi	2020	8.88***	8.76***	8.69***	0.99	0.121	0.118
	2019	9.21***	9.89***	9.77***	0.102	0.133	0.129
	2018	9.56***	10.09***	10.06***	0.124	0.129	0.131
Mumbai	2020	8.46***	8.78***	8.66***	0.96	0.105	0.116
	2019	8.98***	9.06***	9.43***	0.106	0.109	0.123
	2018	9.01***	9.54***	9.72***	0.113	0.126	0.129
Kolkata	2020	8.01***	8.25***	8.45***	0.092	0.119	0.106
	2019	8.84***	9.23***	9.48***	0.106	0.132	0.118
	2018	9.43***	9.96***	10.03***	0.121	0.126	0.128
Chennai	2020	7.58***	7.23***	7.55***	0.079	0.092	0.087
	2019	7.34***	7.49***	7.45***	0.089	0.101	0.099
	2018	8.44***	8.91***	8.36***	0.099	0.102	0.109
India	2020	8.61***	8.23***	8.01***	0.099	0.109	0.102
	2019	8.31***	9.21***	9.01***	0.102	0.119	0.111
	2018	9.25***	9.89***	9.76***	0.11	0.124	0.129

***, **, and * are the significant at the 1%, 5%, and 10% level of significance respectively

temperatures in Delhi are falling close to 3 °C due to a significant reduction in air pollution, while temperatures in Kolkata are falling by 2.5 °C, while temperatures in Mumbai and Chennai are falling by 2 °C.

5 Discussion

India ranks fifth among the most polluted nations in the world and is home to the 21 most polluted cities in the world based on $PM_{2.5}$ and PM_{10} concentrations. In the last 10 years, a number of suggestive measures across Indian cities have failed to maintain standard air quality. However, the COVID-19 pandemic has changed and significantly improved the quality of the environment and air. As a result of the tight lockdown, emissions of pollutants have been reduced by − 12% (− 8– − 16%) per day across the country by 22 March 2020, compared to the average volume of pollution in 2019, with a substantial and definitely unimaginable height. As a result, the maximum, minimum and average temperatures for May 2020 (lockdown period) decreased by 2 °C, 1 °C and 1.5 °C, respectively, compared to the previous year, i.e., 1980–2019, which therefore had a significant impact on the regional climate. However, plenty of the improvements seen during the lockdown phase in 2020 are likely to be temporary, as they do not suggest any weaknesses in the regional environment and transport policy measures. The social discomfort of restrictions and related adjustments could alter the potential course of action in complex ways, but social reactions alone, as seen here, do not motivate the significant and sustainable reductions needed to achieve an optimum level of emissions. Government initiatives to control the outbreak of COVID-19 pandemic demand for a method such as strict lockdown to manage the regional climate, specifically aimed at balancing air quality with higher well-being, a goal that has not been achieved before but now through compulsory lockdown.

Different micro- and laboratory-based studies from around the world have shown that there are significant effects of air quality on temperature and humidity as well as on micro-climate changes. Fang et al. (Fang et al. 1998) tested in the laboratory for temperature and humidity characteristics in clean air and polluted air and observed a temperature increase of 18–28 °C and a relative humidity of 30–70% in polluted air. Wallace et al. (Wallace et al. 2010) investigated the effect of air quality on the reversal of surface air temperature in the industrial city of Hamilton, Canada, and the most affected air pollutants are NO_2 and $PM_{2.5}$. Strefler et al. (Strefler et al. 2014) investigated the fact that the country that has already implemented air pollution policies has seen a decline in the rate of global temperature changes over the last decade. The study of the pandemic caused by COVID-19 (Le Quéré et al. 2020) showed that the significant global daily greenhouse gas emissions of CO2 decreased by − 11– − 25% in April 2020 compared to April 2019, which could reduce global temperatures.

This study reveals that the study region is well-recognized for its high level of pollution worldwide. As a consequence, the major pollution factors are excessive vehicle numbers, unplanned urbanization and sub-urban regions, and poorly maintained roads. The COVID-19 outbreak effect, strict lockdown, significantly reduces pollutant levels and improves air quality, resulting in a gradual reduction in temperature and impacts on the regional climate. For example, in metropolitan cities such as Delhi, Kolkata, Mumbai and Chennai, temperatures have dropped significantly, ultimately having a significant impact on the regional climate.

Several drivers aim to revive an even higher level of pollution relative to the policy-induced pre-COVID-19 pandemic pathways, including calls by some policy makers and companies to postpone Green New Deal projects and reduce vehicle emissions requirements and to hinder the implementation of renewable energy and supply side work. The degree to which world leaders find the net zero emission reduction targets and the demands of climate change in the preparation of their economic responses to COVID-19 are likely to have an impact on the path of emissions of pollutants in the coming decades.

6 Conclusion

The COVID-9 pandemic has been restricted and confined human activities to avoid the rapid spread of this deadly virus (COVID-19) in India. The pollution from commercial industries has also been decreased significantly during this time period. The impact of much-needed lockdown was analyzed by concentrating on concentrations of seven air contaminants and environment indicators from 17 February to 20 May 2020 at 223 locations in different stations throughout the nation. Among all pollutants, PM_{10} and $PM_{2.5}$ reported the highest reduction followed by NO_2, SO_2, NH_3 and CO. PM_{10} and $PM_{2.5}$ concentrations decreased by approximately − 48.56% and − 57.09%, respectively, compared to the previous four years across the country. Among the four megacities, the Kolkata has noticed the record fall of $PM_{2.5}$ and PM_{10} (− 81.25 and − 71.72%), Mumbai has witnessed the highest fall of NO_2 and NH_3 (− 77.56 and − 71.67%), Chennai has the highest descend of SO_2 and CO (− 70.81 and − 48.31%), and the highest O_3 concentration (− 15.79%) fall down in lockdown period has been observed in Kolkata megacity. The daily increases of the average temperature of March to May 2020 are more than 0.027 °C and 0.009 °C from the same period of 2018 and 2019, respectively, in India. The Sen's Slope result of the daily temperature of four megacities in India also follows the national trend that is 0.002–0.022 °C lower increases than the period of 2018 and 2019. Daily emissions of pollutants that ultimately reduce the maximum, minimum and average temperatures for April and May 2020 (lockdown period) decreased by 2 °C, 1 °C and 1.5 °C, respectively, compared to the previous year, i.e., 1980–2019, which ultimately had a significant impact on the regional climate. In the case of four megacities in India, the same findings have been found that temperatures dropping in Delhi and Kolkata are close to 3 °C and 2.5 °C, and Mumbai and Chennai are falling by 2 °C in each. It is a clear indicator that a major change in air quality and temperature can be expected if the strict implementation of pollution management measures, such as lockdown, has been implemented in the coming years. Therefore, this type of research work can further help to understand and analyze the impact of micro-region climate in a wider sense. However, the study would also provide policy maker and other management authority to make plan for air pollution- and global warming-related issues. The study has enormous importance considering the relation of particulate matter and associated climatic parameters like temperature in lower atmosphere and its regional impact.

Compliance with ethical standards

Conflict of interest There is no conflict of interest among the authors in this research article.

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

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