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Reduction in air pollution plummets in Delhi-NCR due to lockdown under covid-19 pandemic

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Abstract
The epidemic of Novel COVID-19 was reported in India in January, 2020 and increased day by day due to the movement of people from one place to another place. The COVID-19 became a pandemic because of the mass movement of people from one part of the country to the other. The Government of India announced the nationwide lockdown with effect from the midnight of 24th March because of the COVID-19 pandemic. The various provisions were made to lock down the industries, transportation, etc. if not very essential. The shifting of humans in order to contain the spread of the virus is suspected but for urgent migration, the people are put in quarantine for 14 days. Most of the activities where the people interaction is required and of not very essential were closed. As a result air quality improved significantly in the country. Similar findings have been observed in the Delhi-NCR which further corroborated by Air Quality Index (AQI) data. The mass concentrations of PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO show 37-81%, 11-88%, 25-87%, 29-54% and 68% reduction in PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO concentrations, respectively in the lockdown phase, as compared to the pre-lockdown phase in Delhi-NCR. All of the major cities of Delhi-NCR analysed in this paper, had their AQI, largely within good to satisfactory categories in the lockdown phase as compare to pre-lockdown categories being poor.

Keywords: Particulate matter, COVID-19, lockdown, traffic, industries, CPCB, Janta curfew

Introduction
The deadly pandemics COVID-19 has been observed to spread from Wuhan City of China in the month of December, 2019 and slowly spread across the globe (Travaglio *et al*., 2020; Raibhandari *et al*., 2020; Chauhan and Singh, 2020) [6, 5, 1]. COVID-19 has been produced by a novel coronavirus (SARS-CoV-2) supposed to be originated from another mammal (Travaglio *et al*., 2020). COVID-19 has turned as one of the deadliest pandemics that started affecting the almost entire world with 4,993,470 affected cases as on May 22, 2020 (WHO report, 2020) [10] and having a death toll of 327,738. The Covid-19 positive person, while sneezing, droplets are spread in the air and it influences other nearby people (Wang and Du, 2020; Chauhan and Singh, 2020) [7, 8, 1]. Now, social isolation has become the solution to contain this virus (Long, 2020) [4].

Recognizing the facts, various countries have imposed complete lockdown to stop this virus and migrants if any are put for quarantine for 14 days as the symptoms of the virus normally appear in 14 days. After screening the situation of COVID-19 in India and taking lessons from affected countries, the Indian Government also announced voluntary Janata (People's) Curfew on 22nd March, 2020 in the whole country and canceled all flights, trains, bus services and closed all industrial and commercial activities. After its success, an absolute lockdown was imposed on 25th March 2020 for 21 days to break the chain of COVID-19 (Long, 2020) [4]. Further, the lockdown has been extended in phases 2, 3, and 4 till 17th May 2020 to control the spread of infection through a complete halt on the movement that helped in maintaining the criteria of "social distancing". The total lockdown has raised chaos among people but helped in reducing the pace of spreading the virus among society. However, a very new development in nature's cleanliness has been noticed by everyone as well as the instruments showed a drastic improvement in air quality in the country as well as in Delhi-NCR. This showed that Nature is flourishing during the coronavirus pandemic followed by the lockdown in the larger part of the world forcing the closure of the industries and aviation sector, as well as less traffic on the roads causing lowering of pollution that also gave space for the wildlife to thrive.

Pollution and greenhouse gas emissions have reduced across continents as countries try to contain the spread of the new coronavirus by the lockdown.

Global air pollution is famous for badly impacting human health around the globe. World Health Organization (WHO) reported that around seven million died and one in eight of total global deaths were attributable to air pollution. It has been very obvious to observe the lowering of air pollution concentration in the lockdown period. Hence to quantify the status of air pollution in one of the highly polluted locations of NCR, we have carried out an analysis of PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, and O_3 at various districts in Delhi-NCR, where complete lockdown has been imposed under the lockdown condition of India. Our analysis shows a significant improvement in the air quality of Delhi-NCR due to total lockdown and restrictions imposed on the industries, traffic, etc. due to the COVID-19.

Worldwide, ambient air pollution contributes to 7.6% of all deaths based on the data of 2016 (WHO, 2016) [11]. This positive impact on the environment gave a solution though difficult to implement in normal conditions at the cost of economic breakdown.

Study Area and Methodology

National Capital Region (NCR) consists of the area of Delhi and nearby cities of the adjoining states. As per the notification, the NCR consists of the whole of National Capital Territory-Delhi, 13 districts of Haryana, 8 districts of Uttar Pradesh (8), and 2 districts of Rajasthan making 55,083 sq. km in total area (Fig. 1). NCR region is one of the highly dense inhabited regions and the strong seasonal variability of aerosol optical properties across the NCR is observed. This is under the influence of various pollutants emitted through the various sources and further being governed by the large seasonal variability of the meteorological conditions. The primary contributors to air pollution in the Delhi region are both natural and anthropogenic like industrial units, vehicular emission, road dust, tire pads, construction activities, etc. (CPCB, 2016) [3].

The emission data of various pollutants were collected from continuous ambient air quality monitoring (CAAQM) network, Central Pollution Control Board (CPCB). The data of 51 monitoring stations were analyzed for Delhi and its neighbouring major NCR towns i.e. Noida, Greater Noida, Ghaziabad, Baghpat, Hapur, Bulandshahr, Meerut, Muzaffarnagar, Faridabad, Gurugram, Sonipat, Rohtak, Bhiwani, Panipat, Palwal, Karnal, Mahendergarh, Jind and Alwar for the period from 11 March 2020 to 7 April 2020 which have been studied in two phases: Pre-lockdown phase (11-23 March 2020) and Lockdown phase (24 March- 7 April 2020). AQI values have also been calculated to observe the air quality in the NCR region.

Fig 1: National Capital Region (NCR), showing various districts of Haryana, Uttar Pradesh and Rajasthan under this region

3. Results and Discussion

3.1 Effect of Lockdown in Delhi-NCR

The nationwide lockdown has come in effect since the midnight of 24th March because of COVID-19 pandemic. Under the lockdown, the major sectors responsible for air pollution like transport, industries, power plants, construction activities, biomass and refused burning, road dust re-suspension and residential ctivities were put on halt. In addition, the other activities like diesel generators (DG), restaurant, landfill fires, etc. were not operational and nationwide transportation facilities were postponed with exceptions for essential services. The academic institutions, industries, and hospitality services were also adjourned. Under these circumstances, the improvement in air quality was noticed in the urban and rural areas across the country. The NCR-region, which is the hub of pollution and being counted as number one for most of the time has resulted in a noticeable improvement in air quality. This result has been substantiated while analyzing the data of air pollution and air quality before and after the imposition of lockdown.

3.1.1 Emission of PM_{10} and $PM_{2.5}$

In the NCR-region, the mass concentrations of PM_{10} vary from 67.56 to 230.09 μgm^{-3} with a mean value of 130.01 μgm^{-3} (Fig. 2a) and $PM_{2.5}$ varies from 31.90 to 102.7 μgm^{-3} with a mean value of 59.91 μgm^{-3} (Fig. 2b) during the pre-lockdown phase. However, the mass concentrations of PM_{10} vary from 30.53 to 139.45 μgm^{-3} with a mean value of 67.63 μgm^{-3} and $PM_{2.5}$ varies from 15.23 to 66.23 μgm^{-3} with a mean value of 31.60 μgm^{-3} in the NCR region during the lockdown phase. The largest concentration of PM_{10} and $PM_{2.5}$ were observed in the districts of Uttar Pradesh and followed by Delhi, Haryana, and Rajasthan which were the part of Delhi NCR during the pre-lockdown phase. During the lockdown phase, a 50-55% reduction in PM_{10} and $PM_{2.5}$ concentrations have been observed due to the reduction of transportation activities, the nonfunctioning of essential commercial units, and prevailing weather conditions. The reduction in PM_{10} and $PM_{2.5}$ concentrations were also observed due to a reduction in combustion and industrial sources which are the common sources of both fractions of particulate matter. The daily mean concentration of $PM_{2.5}$ and PM_{10} were also correlated with the national ambient air quality standards (NAAQS) of India (http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php). These exercises helped in understanding that the concentrations were much greater than the threshold limit of $PM_{2.5}$ (60.0 μgm^{-3}) and PM_{10} (100.0 μgm^{-3}) on a daily basis in the study area which is very vulnerable to the health problem. During the pre-lockdown phase, the mass concentration of both PM_{10} and $PM_{2.5}$ were higher than the threshold limit while it became much lower during the lockdown phase.

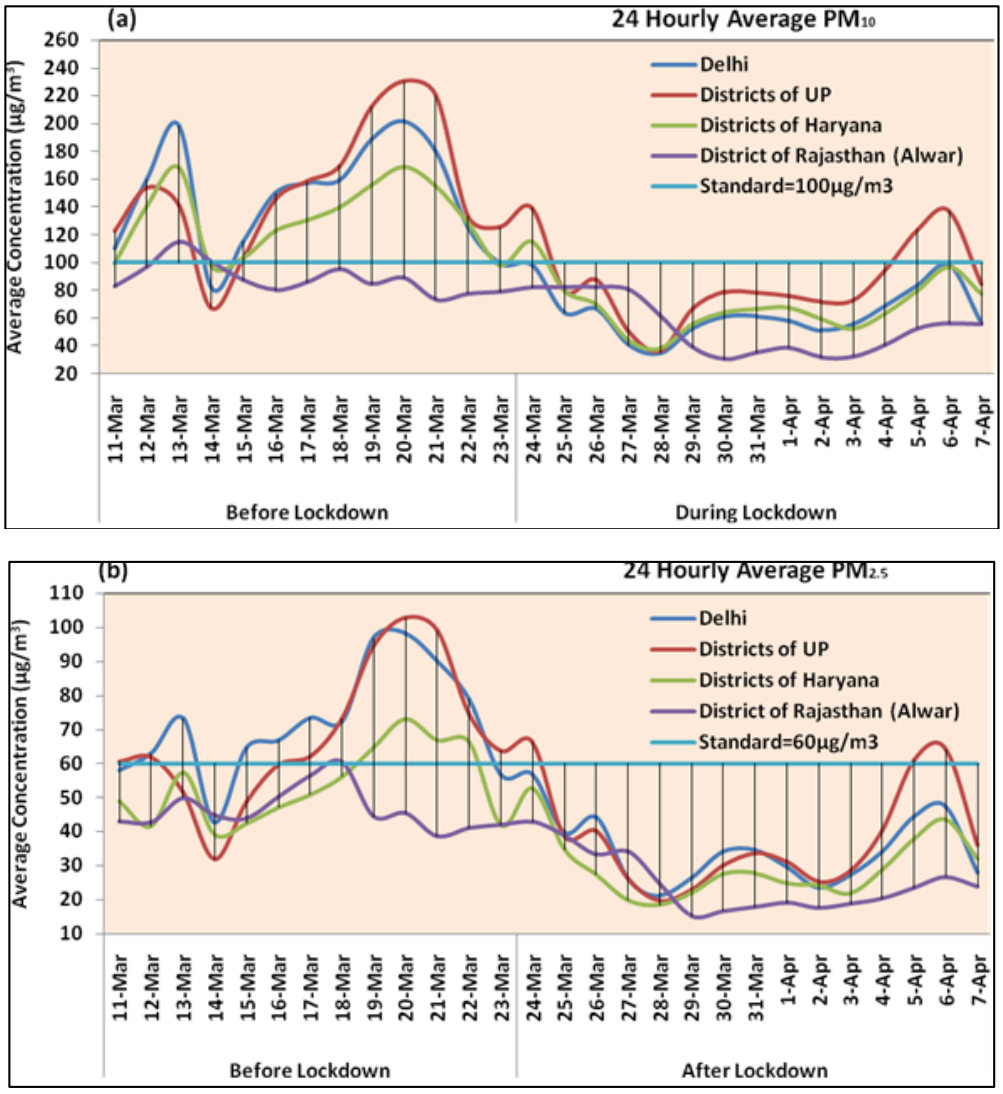


Fig 2: (a) average daily mass concentration of PM_{10} and (b) average daily mass concentration of $PM_{2.5}$ in the NCR from March 11 to April 07, 2020.

3.1.2 Emission of NO_2 and SO_2

The transportation and industrial sectors are the major sources of NOx and SO_x in the NCR. The mass concentrations of NO_2 varied from 23.71 to 75.36 µgm^{-3} with a mean value of 37.13 µgm^{-3} (Fig. 3a) and SO_2 varied from 11.38 to 41.61 µgm^{-3} with a mean value of 19.66 µgm^{-3} (Fig. 3b) in the NCR during the pre-lockdown phase. However, the mass concentrations of NO_2 varied from 12.74 to 35.76 µgm^{-3} with a mean value of 20.38 µgm^{-3} and SO_2 varied from 9.03 to 27.7 µgm^{-3} with a mean value of 16.10 µgm^{-3} in the NCR during the lockdown phase. During the lockdown phase, a 56% reduction in NO_2 and 30-35% reduction in SO_2 was observed in the NCR due to the reduction of transportation and industrial activities. The daily mean concentrations of both NO_2 and SO_2 were observed within the threshold limit of NAAQS during the pre-lockdown and lockdown phase but during the lockdown phases the values are much lower (Fig. 3).

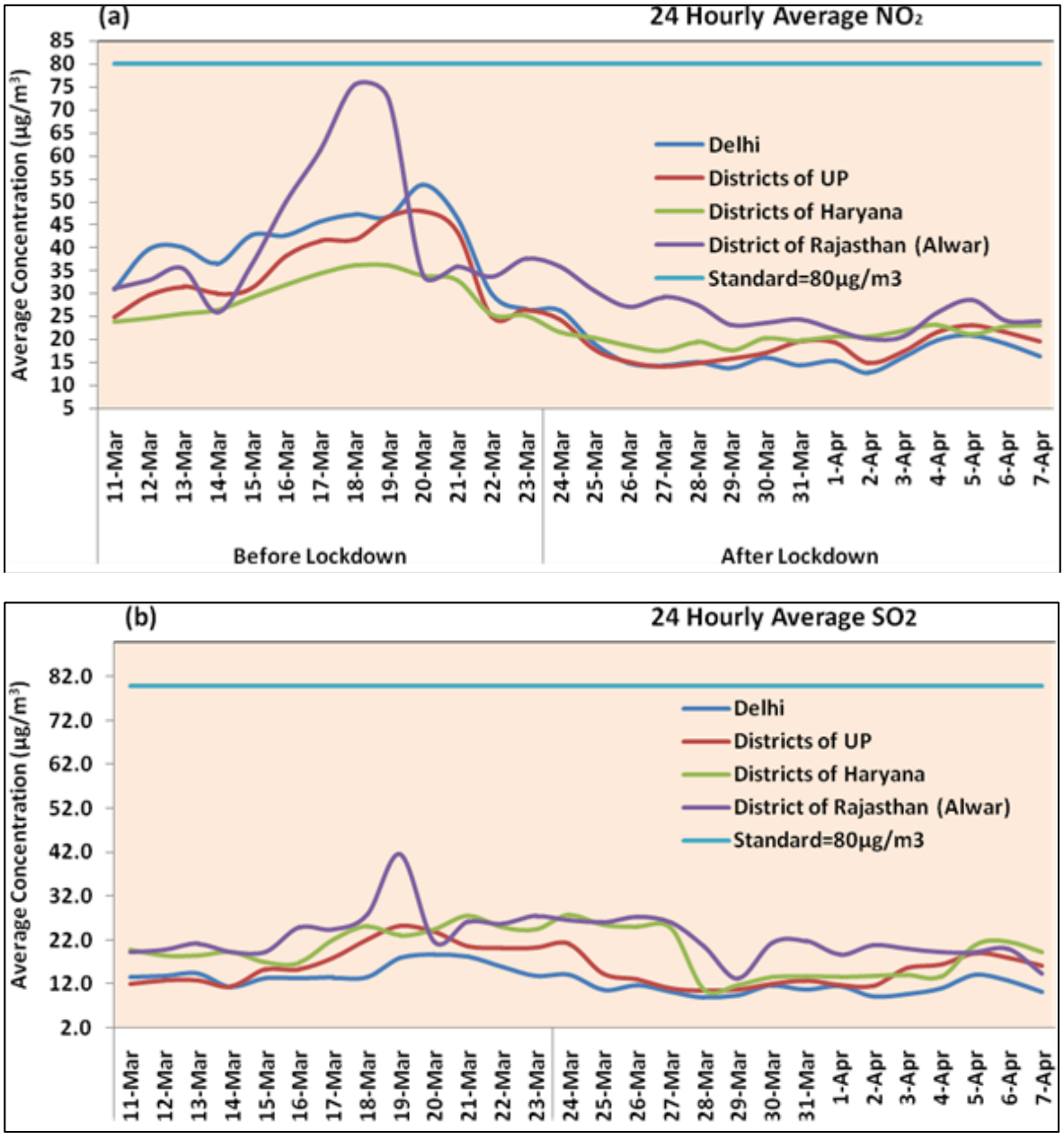


Fig 3: (a) Average daily mass concentration of NO_2 and (b) Average daily mass concentration of SO_2 in the NCR during March to April, 2020.

3.1.3 Emission of CO and O_3

The mass concentrations of CO varied from 0.56 to 1.95 µg m^{-3} with a mean value of 1.01 mg m^{-3} (Fig. 4a) and O_3 varies from 19.77 to 65.20 µg m^{-3} with a mean value of 38.95 µgm^{-3} (Fig. 4b) in the NCR during the pre-lockdown phase. However, the mass concentrations of CO varied from 0.37 to 1.94 µg m^{-3} with a mean value of 0.80 µg m^{-3} and O_3 varied from 17.66 to 51.04 µg m^{-3} with a mean value of 36.14 µg m^{-3} in the NCR during the lockdown phase. During the lockdown phase, 5-8% of reduction in CO and SO_2 was observed in the NCR due to the non-operation of industries. The daily mean concentrations of both CO and O_3 were observed within the threshold limit of NAAQS during the pre-lockdown and lockdown phase (Fig. 4).

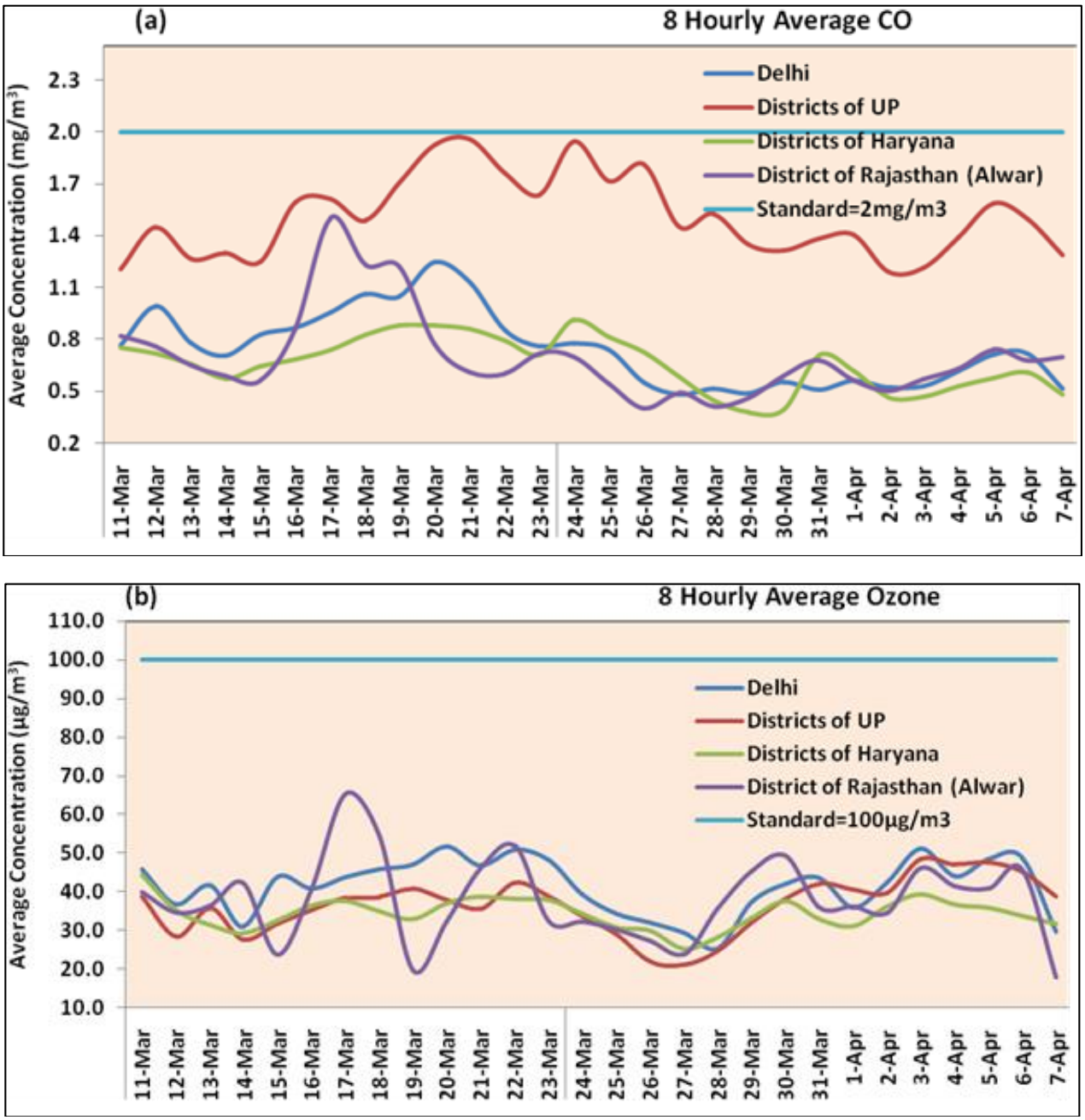
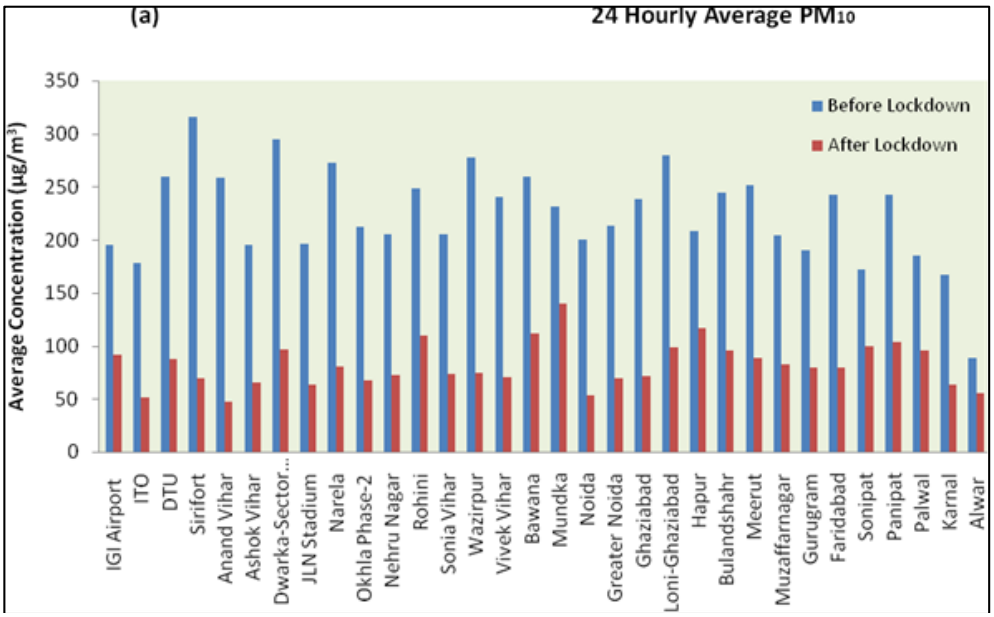


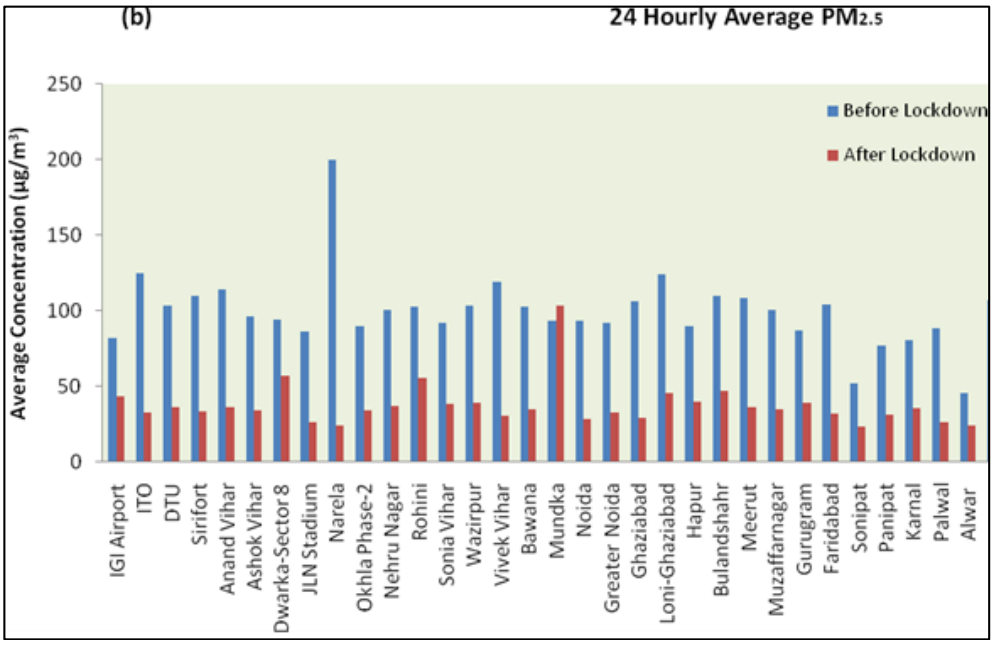
Fig 4: (a) average daily mass concentration of CO and (b) average daily mass concentration of O_3 in the NCR from March 11 to April 07, 2020.

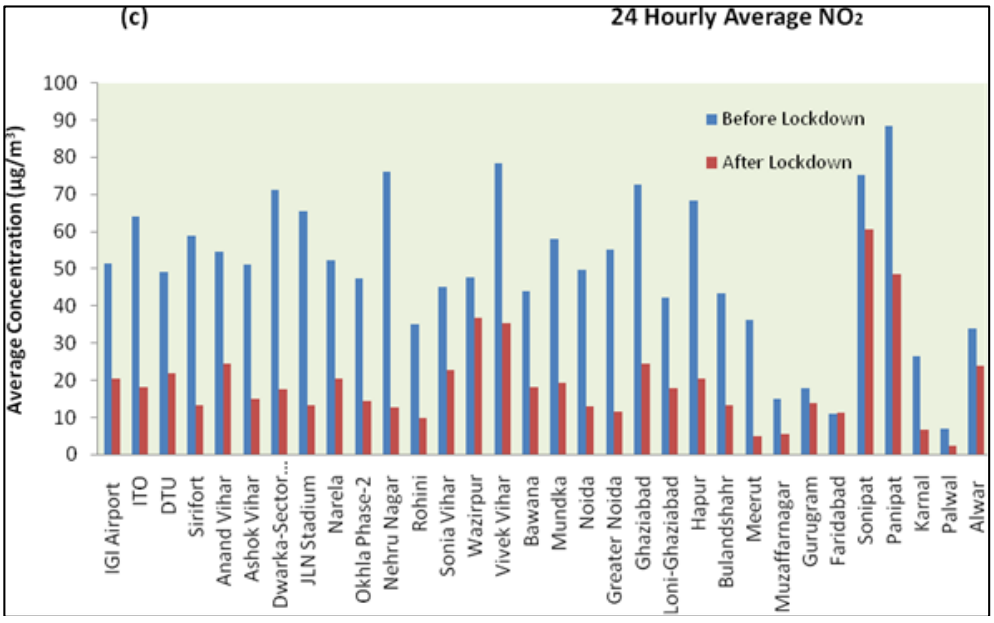
3.2 Air Pollution Hotspots in Delhi-NCR

The data analysis of the 32 hotspots of Delhi-NCR reveals that Sirifort area recorded 78%, 69%, 77%, 44%, 76% and 40% reduction in PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, and O_3 levels respectively during the lockdown phase, as compared to the pre-lockdown phase. Anand Vihar which is an interstate bus stand and a major traffic hub, saw 82%, 69%, 55%, 65%, and 41% reduction in PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO concentrations. Similarly, 73%, 63%, 23%, 51%, and 41% reduction were observed in PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO levels respectively at Wazipur area. The plots given below depict average PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, and O_3 concentrations in the 32 hotspots in the pre-lockdown phase and during the lockdown phase (Fig. 5).

Income Tax Office (ITO) traffic junction is a major hub for the pollution due to vehicular emission since long in the Delhi, saw 71%, 74%, 72%, 43% and 68% reduction in PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO concentrations respectively during the lockdown phase, as compared to the pre-lockdown phase. Similarly, 71% and 88% reduction was observed in PM_{10} and $PM_{2.5}$ levels respectively at Vivek Vihar and Narela. The 71%, 72%, 68%, 21%, and 45% reduction was observed in PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO levels respectively at Noida and Ghaziabad which are major hotspots in the NCR. Further, Gurugram and Faridabad have recorded 62%, 63%, 20%, 15%, and 53% reduction in PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO levels respectively. It is to be noted that these areas are a major transport and industrial hub in the NCR, thus sharp decline in pollution levels affirm that traffic and industrial operation restrictions were instrumental in improving air quality. The research on air pollution concentration during lockdown due to COVID 19 has also been performed for PM2.5 data in Beijing, Shanghai, Guangzhou, and Wuhan cities which showed a drastic reduction in atmospheric pollution (Wang *et al*., 2020) [7, 8]. These profound reduction of emissions were related to the reduction of traffic activities and closure of the industries.


(a)
24 Hourly Average PM10
Average Concentration (µg/m³)
Before Lockdown
After Lockdown
IGI Airport
ITO
DTU
Sirifort
Anand Vihar
Ashok Vihar
Dwarka-Sector...
JLN Stadium
Narela
Okhla Phase-2
Nehru Nagar
Rohini
Sonia Vihar
Wazirpur
Vivek Vihar
Bawana
Mundka
Noida
Greater Noida
Ghaziabad
Loni-Ghaziabad
Hapur
Bulandshahr
Meerut
Muzaffarnagar
Gurugram
Faridabad
Sonipat
Panipat
Palwal
Karnal
Alwar


(b)
24 Hourly Average PM2.5
Average Concentration (µg/m³)
Before Lockdown
After Lockdown
IGI Airport
ITO
DTU
Sirifort
Anand Vihar
Ashok Vihar
Dwarka-Sector 8
JLN Stadium
Narela
Okhla Phase-2
Nehru Nagar
Rohini
Sonia Vihar
Wazirpur
Vivek Vihar
Bawana
Mundka
Noida
Greater Noida
Ghaziabad
Loni-Ghaziabad
Hapur
Bulandshahr
Meerut
Muzaffarnagar
Gurugram
Faridabad
Sonipat
Panipat
Karnal
Palwal
Alwar


(c)
24 Hourly Average NO2
Average Concentration (µg/m³)
Before Lockdown
After Lockdown
IGI Airport
ITO
DTU
Sirifort
Anand Vihar
Ashok Vihar
Dwarka-Sector...
JLN Stadium
Narela
Okhla Phase-2
Nehru Nagar
Rohini
Sonia Vihar
Wazirpur
Vivek Vihar
Bawana
Mundka
Noida
Greater Noida
Ghaziabad
Loni-Ghaziabad
Hapur
Bulandshahr
Meerut
Muzaffarnagar
Gurugram
Faridabad
Sonipat
Panipat
Karnal
Palwal
Alwar

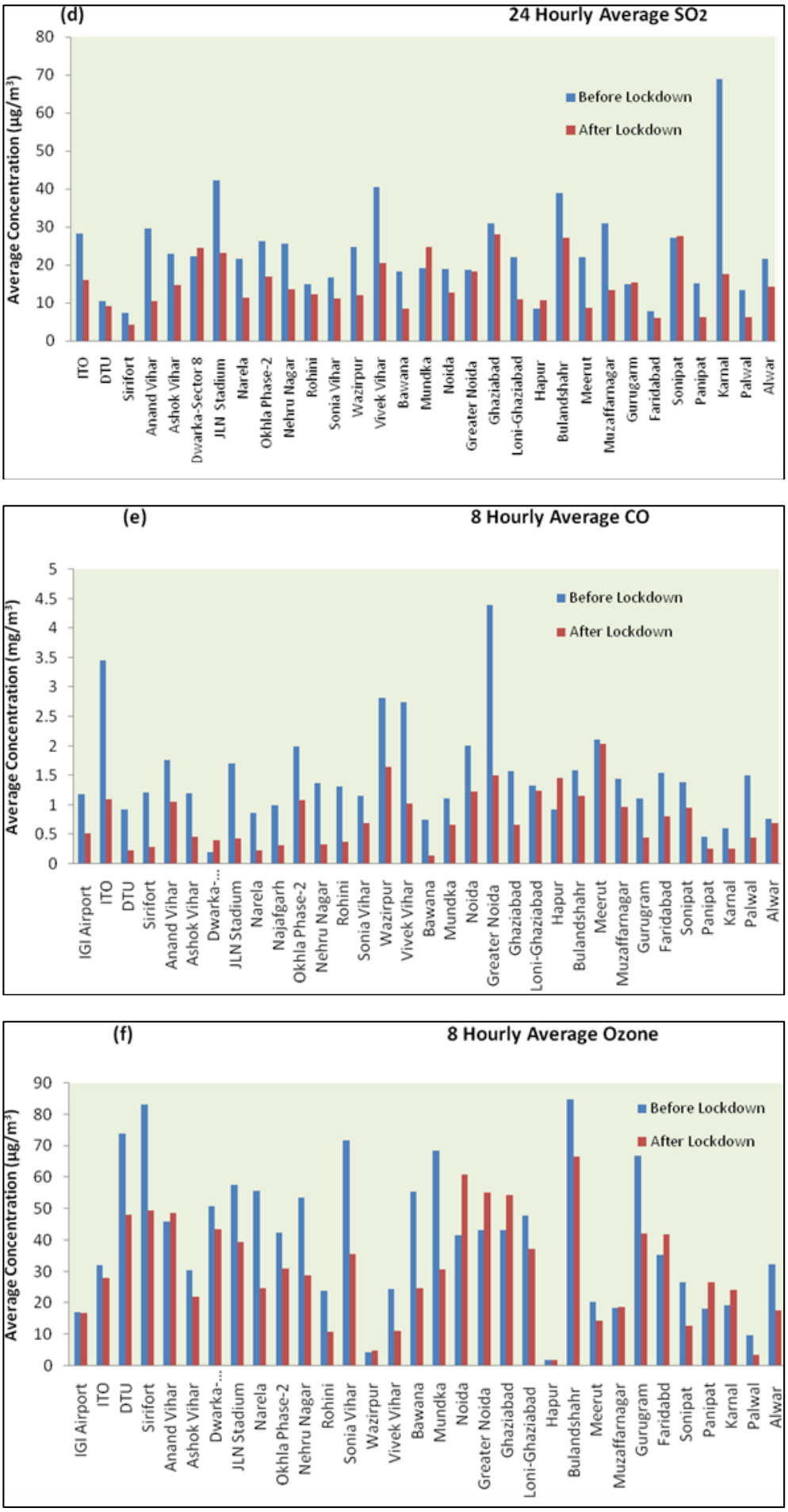


Fig 5: (a) Average daily mass concentration of PM_{10}, (b) $PM_{2.5}$, (c) NO_2, (d) SO_2, (e) CO, and (f) O_3 in the NCR during pre-lockdown and lockdown phase.

3.3 Air Quality Index

The significant enhancement in the air quality of Delhi NCR is observed in the lockdown phase because the source of major pollutants of particulate matters and NO_2 has been suspended under the lockdown. The Air Quality Index (AQI) in Delhi-NCR was mostly reported as 'Poor' in the pre-lockdown period (Table-1). In the lockdown stage, the limited movement of vehicles, nonoperational industries, and commercial units as well as increased mixing height has changed the status of AQI to the 'satisfactory' category. On March 26, 2020, high surface winds (25 kmph) further maintained AQI even though mixing height dropped to 1100 m. The next day, though wind speed and mixing height were reduced to half value, the AQI value improved further and Gurugram recorded the 'Good' AQI category. Scattered rains in Delhi NCR on 27th March and during March 28- 29, 2020 along with increased wind speed and mixing height further helped in improving the AQI, with Delhi, Ghaziabad and Noida recording 'Good' AQI on March 28, 2020. Favourable conditions ensued, leading to AQI remaining in 'Good' and 'Satisfactory' AQI categories. However, after 4th April due to a change in temperature and onset of dry conditions, high winds led to the lifting of local dust resulting in slight deterioration of air quality to the 'moderate' category.

Table 1: Air Quality Index in the NCR during pre-lockdown and lockdown phase

Sr. No.	Locations	Air Quality Index		Sr. No.	Locations	Air Quality Index	
		Before Lockdown	Lockdown			Before Lockdown	Lockdown
1	IGI Airport	173	91	17	Mundka	213	244
2	Income Tax Office	304	52	18	Noida	213	53
3	Delhi Technical University	244	88	19	Greater Noida	233	70
4	Sirifort	266	69	20	Ghaziabad	256	72
5	Anand Vihar	280	59	21	Loni-Ghaziabad	303	98
6	Ashok Vihar	220	65	22	Hapur	198	111
7	Dwarka-Sector 8	245	96	23	Bulandshahr	264	95
8	Jawaharlal Nehru Stadium	186	63	24	Meerut	260	89
9	Narela	362	65	25	Muzaffarnagar	234	83
10	Okhla Phase-2	198	68	26	Gurugram	189	80
11	Nehru Nagar	235	70	27	Faridabad	274	80
12	Rohini	241	106	28	Sonipat	148	100
13	Sonia Vihar	205	74	29	Panipat	195	102
14	Wazirpur	243	74	30	Palwal	168	95
15	Vivek Vihar	297	80	31	Karnal	193	63
16	Bawana	241	108	32	Alwar	126	55
	Legends						
	Good	Minimal Impact			Poor	Breathing discomfort to people on prolonged exposure	
	(0–50)				(201–300)		
	Satisfactory	Minor breathing discomfort to sensitive people			Very Poor	Respiratory illness to the people on prolonged exposure	
	(51–100)				(301–400)		
	Moderate	Breathing discomfort to the people with lung, heart disease, children and older adults			Severe	Respiratory effects even on healthy people	
	(101–200)				(>401)		

4. Conclusion

During the lockdown period, there has been a general improvement in air quality in the Delhi-NCR as a result of the restrictions imposed during the lockdown, which is corroborated by both Air Quality Index data.

The mass concentrations of PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO showed 37-81%, 11-88%, 25-87%, 29-54% and 68% of reduction in PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO concentrations, respectively during the lockdown phase, as compared to the pre-lockdown phase in Delhi-NCR.

The Sirifort, Anand Vihar, Wazipur, ITO, Vivek Vihar, Narela, Okhla, Dwarka, Noida, Ghaziabad, Faridabad, and Gurugram were the major hotspots in the Delhi-NCR. Hence not only these areas but the other parts of the NCR region also found to have their AQI largely within good to satisfactory levels in the lockdown phase which largely lied to the poor air quality in the pre-lockdown periods.

This highlighted the impact of anthropogenic activities on the air quality index which affects human health very badly.

The Covid-19 lockdown situation in almost the entire world has shown the importance of nature in our day to day life. The noticeable enhancement in nature has empowered the believe that by reducing the anthropogenic activities that retard the well being of nature, the Earth can be saved.

We are largely dependent on Mother Nature and become ignorant while care of Earth is needed. The preservation of natural resources and sustainable development remains largely in our thought or on the paper discussion but not implemented properly.

During the period of lockdown under COVID 19, it has opened our eyes that our actions are responsible and impacting the Earth's sustainability.

The availability of pure air for breathing, the enhanced greenery, clean sky, better visibility of stars, the movement of various wildlife into the cities are few examples of rejuvenation of nature due to the coronavirus lockdown in India.

4.1 Data statement

All the data used in the present study are freely available, if needed we will provide data used in the present study to anyone.

4.2 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5. Acknowledgments
The authors are grateful to CPCB for providing data for the various locations of Delhi-NCR.

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