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ASSESSING THE IMMEDIATE EFFECT OF COVID-19 LOCKDOWN ON AIR QUALITY: A CASE STUDY OF DELHI, INDIA

Ankit Sikarwar[1]*, Ritu Rani[1]

[1]Department of Development Studies, International Institute for Population Sciences, Mumbai, Maharashtra 400088, India
*Corresponding author, e-mail: anks.sik@gmail.com

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Abstract

In India, a nationwide lockdown due to COVID-19 has been implemented on 25 March 2020. The lockdown restrictions on more than 1.3 billion people have brought exceptional changes in the air quality all over the country. This study aims to analyze the levels of three major pollutants: particulate matter sized 2.5 μm ($PM_{2.5}$) and 10 μm (PM_{10}), and nitrogen dioxide (NO_2) before and during the lockdown in Delhi, one of the world's most polluted cities. The data for $PM_{2.5}$, PM_{10}, and NO_2 concentrations are derived from 38 ground stations dispersed within the city. The spatial interpolation maps of pollutants for two times are generated using Inverse Distance Weighting (IDW) model. The results indicate decreasing levels of $PM_{2.5}$, PM_{10}, and NO_2 concentrations in the city by 93%, 83%, and 70% from 25 February 2020 to 21 April 2020 respectively. It is found that one month before the lockdown the levels of air pollution in Delhi were critical and much higher than the guideline values set by the World Health Organization. The levels of air pollution became historically low after the lockdown. Considering the critically degraded air quality for decades and higher morbidity and mortality rate due to unhealthy air in Delhi, the improvement in air quality due to lockdown may result as a boon for the better health of the city's population.

Keywords: COVID-19, Lockdown, Air pollution, Delhi, Spatial interpolation

INTRODUCTION

The world is facing unforeseen challenges to cope up with the unprecedented growth of Coronavirus Disease (COVID-19). The exponential widespread of the COVID-19 has become a global pandemic that has led to pernicious consequences in various parts of the world. COVID-19 was first identified in December 2019 in the province of Wuhan, China (Kucharski et al., 2020; Zhu et al., 2020), and around four months later it has adversely affected life and economy in more than a hundred countries (WHO, 2020). To curb the spread of this highly contagious disease and minimize the fatality, different countries have adopted drastic yet important measures to reduce the interaction among individuals such as banning large-scale public and private gatherings, imposing a curfew, restraining transportation, promoting social distancing, creating strict quarantine instructions, and locking down countries, states and cities, depending on the country-specific situation.

On the one hand, the cost of enacting the preventive measures against COVID-19 is immense, but on the brighter side, it could have some significant benefits on society too. For example, locking down the country might do contribution to the improvement of overall environmental conditions. This improvement may partially equilibrate the cost of these counter COVID-19 measures. For example, according to Singh and Chakraborty (2020) cities across India, which were the 14 most polluted cities during the last year in the world out of 20, are breathing some of the cleanest air after the nationwide implementation of lockdown. Recently, many researchers have attempted to study the effect of COVID-19 lockdown on air pollution at different levels (Dutheil et al., 2020; Li et al., 2020; Muhammad et al., 2020; Sharma et al., 2020; Wang et al., 2020).

Since the 1990s, Delhi has been ranked as one of the most polluted cities among the world's developing countries (Gujrar et al., 2004; WHO, 2016). Particularly, air pollution caused by onsite burning of agricultural crop residue is one of the many causes of critical levels of air pollution in the northern part of India (Satyendra et al., 2013). The higher level of air pollution in the overcrowded Delhi cause significant public health problems (Dholakia et al., 2013; Rizwan et al., 2013). Due to severely degraded air quality, in 2017, a community health emergency was declared in Delhi by the Indian Council of Medical Research (Chowdhury et al., 2019). A study by Goyal (2003) points out that vehicular emission has shown a decreasing trend due to the CNG (Compressed Natural Gas) implementation. But, the overall particulate matter concentration has seen a consistent rise (Kumar and Goyal, 2014; Gujrar et al., 2016; Nagpure et al., 2016). Moreover, air pollution also has severe implications on society, economy, and the environment including climate change. Therefore, it has become a paramount concern of public health, environment, and development (Kampa and Castanas, 2008).

However, the extent of lockdown varies across different countries and cities around the globe depending on the number of cases. Undoubtedly, the lockdown has put a temporary rest to a significant number of social and economic activities in the countries and their people (Alvarez et al., 2020; Inoue and Todo, 2020). Overall, the significance and impacts of lockdown are yet not well understood and likely to have a significant role in the restoration of air quality (Mahato et al., 2020). Therefore, to analyze and to understand the temporary improvement in air quality due to COVID-19 lockdown is important in Delhi, which is one of the most polluted cities in the world. Moreover, it could be considered as an effective alternative measure to combat air pollution issues.

India first announced a public curfew on 22 March 2020, and later imposed a nationwide lockdown from 25 March 2020 till 15 April, and extended it further until 3 May 2020 to block the spread of the virus. Looking at the severity of increasing numbers of infections, the third phase of lockdown was extended till 17 May 2020 with the classification of districts into three severity zones (i.e. red, orange, and green). Nationwide lockdown amid the COVID-19 outbreak has created a unique scope for researchers to work in this direction and to suggest future policy measures to control air pollution in cities with degraded air quality. Addressing the above-mentioned points, the present study aims to understand the impact of COVID-19 lockdown on the air quality of Delhi by comparing the levels of air pollutants ($PM_{2.5}$, PM_{10}, and NO_2) before and during the lockdown. When most of the recent studies have dealt with national level measurement of air pollution based on satellite estimates (Dutheil et al., 2020; Li et al., 2020; Muhammad et al., 2020; Sharma et al., 2020; Wang et al., 2020), this study attempts to analyze the data from 38 ground monitoring stations to study the lockdown effect on Delhi's air quality.

STUDY AREA

Delhi, officially the National Capital Territory of Delhi, is a city and a union territory of India located at 28.61°N and 77.23°E (Fig. 1). This city is the administrative center and the second financial capital of India. With the geographical area of 1485 km2, Delhi holds the second position in the list of leading megacities of the world (United Nations, 2018). It stands as India's largest urban agglomeration with more than 15 million people with a population density of 11297 people per km2 (Chandramouli and General, 2011). Two prominent features of the geography of Delhi are the Yamuna flood-plains and the Delhi Ridge. This type of location provides favourable conditions for the accumulation of polluted air masses. The Yamuna River was the historical boundary between the states of Punjab and Uttar Pradesh, and its flood plains provide fertile alluvial soil suitable for agriculture but are prone to recurrent floods. Delhi has been continuously inhabited since the 6th century BC (Asher, 2000). Through most of its history, Delhi has served as a capital of various kingdoms and empires. It has been captured, ransacked, and rebuilt several times, particularly during the medieval period, and modern Delhi is a cluster of many cities spread across the metropolitan region (Sikarwar and Chattopadhyay, 2020).

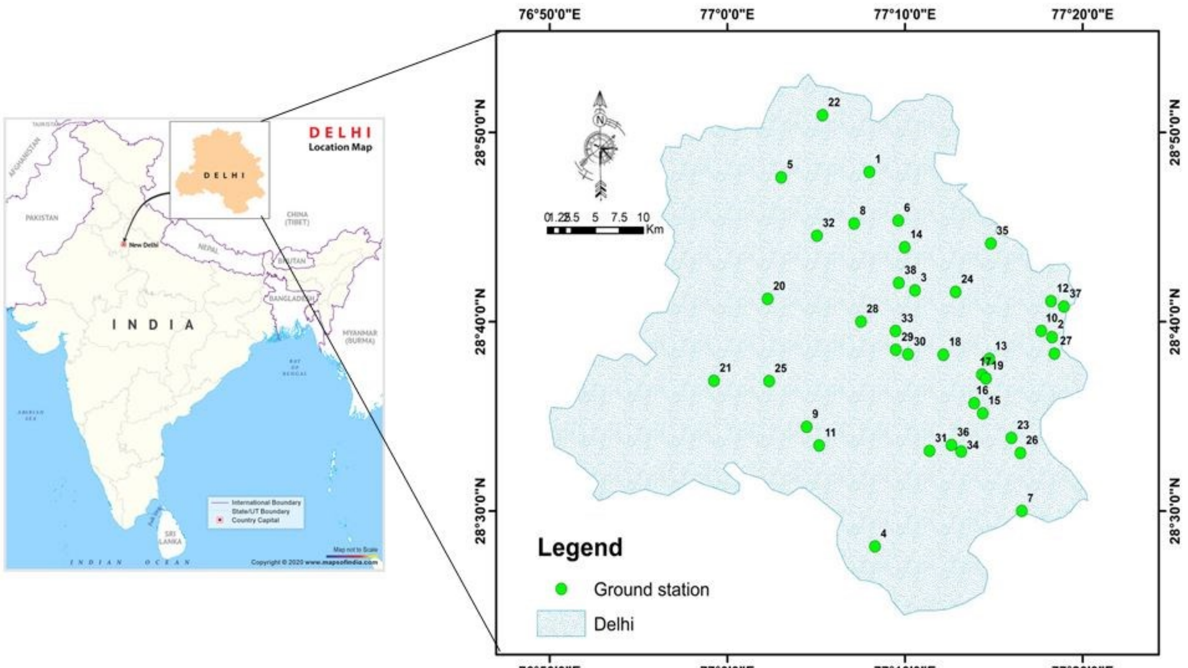

Fig. 1 The study was performed in the city of Delhi. The map shows the administrative extent of the city and ground- based air-monitoring stations considered in the study

DATA AND METHODS

To assess the air quality status of Delhi before and during the lockdown period, data from 38 air quality monitoring stations situated at various parts of the city has been taken into consideration (Table 1). These ground monitoring stations are managed under the authority of three main organizations namely CPCB (Central Pollution Control Board), DPCC (Delhi Pollution Control Committee), and IMD (Indian Meteorological Department). The 24-hour average concentration of three major pollutants including Particulate Matter 2.5 ($PM_{2.5}$), Particulate Matter 10 (PM_{10}), and Nitrogen Dioxide (NO_2) have been obtained from the CPCB online dashboard for air quality data dissemination (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/) running by the Central Control Room for Air Quality Management. As described by the Environmental Protection Agency (2020) particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Particles less than 10 µm in diameter (PM_{10}) can get deep into the lungs and some may even get into the bloodstream. Particles less than 2.5 µm in diameter ($PM_{2.5}$), also known as fine particles, pose the greatest risk to health. Whereas NO_2 is one of a group of highly reactive gases and adversely affects the human respiratory system.

The analysis is divided into two sections. In the first section, the trend of daily average (24-hour) concentrations of $PM_{2.5}$, PM_{10}, and NO_2 are studied before and during the lockdown. Considering 25 March (start of the lockdown) as a baseline, the average concentrations of air pollutants were studied from 25 February to 21 April to understand the temporal changes. The second section deals with the mapping of spatial changes in the levels of air pollution before and during the lockdown. The spatially interpolated maps of concentrations of air pollutants on 25 February and 21 April have been generated to estimate the spatial changes in air quality in the city.

Interpolation methods, in general, share the same basic mathematical foundation. They all estimate the value at an unmeasured location as a weighted average of the measurements at surrounding monitoring stations. They differ in their choice of sample weights and the surrounding stations (Xie et al., 2017). This study has used the Inverse Distance Weighting (IDW) method of spatial interpolation of air pollutants. In air pollution modelling the IDW method is popular and widely used among scholars (Hoek et al., 2002; Salam et al., 2005; Neupane et al., 2010; Chen et al., 2014). It is applied operationally by the Environmental Protection Agency (EPA) for generating real-time O3, PM_{10}, and Air Quality Index spatial predictions in nationwide scales (Deligiorgi and Philippopoulos, 2011). The value Z_0 at the unknown point is calculated as:

$$Z_0 = \frac{\sum_{i=1}^{N} Z_i\, d_i^{-n}}{\sum_{i=1}^{N} d_i^{-n}}$$

Where Z_0 is the estimation value of variable Z at point i, Z_i is the sample value in point i, d_i is the distance of the sample point to the estimated point, N is the coefficient that determines weight based on a distance, and n is the total number of predictions for each validation case.

The basic principle of the interpolation methods is based on the assumption that points closer to each other are highly correlated and more similar than those farther. This method will be used by a region in which there are enough sample points (at least 14 points) that are spatially dispersed all over the region (Burrough and McDonnell, 1998).

RESULTS AND DISCUSSION

Temporal trends of air pollution before and during the lockdown

There has been a significant change in the levels of $PM_{2.5}$ before and during the days of COVID-19 lockdown in Delhi (Table 1 and Fig. 2). All the stations in the city have recorded considerable lowering of $PM_{2.5}$ concentrations during the studied period. The average $PM_{2.5}$ concentrations in the city has reduced from 122.48 µg/m^3 on 25 February 2020 to 17.71 µg/m^3 on 21 April 2020. Moreover, at the beginning, all stations within the city have reordered $PM_{2.5}$ concentrations much higher than the standard (25 µg/m^3) set by the WHO. A noteworthy point here is that, on the last day of studied time, 29 stations out of the 35 have recorded $PM_{2.5}$ concentrations below the WHO standard.

The levels of PM_{10} concentration have strikingly reduced all over Delhi after the imposition of COVID-19 lockdown in the city (Fig. 2). Table 2 shows the declining levels of PM_{10} concentration before lockdown (25 February) and during lockdown (21 April). It should be noted that the average PM_{10} concentration in the city has remarkably reduced to 47.46 µg/m^3 on 21 April (during lockdown) from the critically higher level of 216.49 µg/m^3 on 25 February (before lockdown). Furthermore, the concentration of PM_{10} was recorded extremely higher than the WHO standards (50 µg/m^3) in all stations. These critical levels of PM_{10} in the city have reduced after the lockdown and 17 out of 31 stations have recorded the concentration below WHO standards.

Table 1 Details of the ground monitoring stations selected for the study and levels of $PM_{2.5}$, PM_{10} and NO_2 concentration before and during COVID-19 lockdown

ID	Station name, authority			Before COVID-19 lockdown (25 February 2020)			During COVID-19 lockdown (21 April 2020)		
		Lat	Lon	$PM_{2.5}$	PM_{10}	NO_2	$PM_{2.5}$	PM_{10}	NO_2
1	Alipur, Delhi - DPCC	28.7972	77.1331	110.12	206.45	52.61	52.61	52.61	13.4
2	Anand Vihar, Delhi - DPCC	28.6502	77.3027	88.52	209.39	57.14	20.88	81.18	33.55
3	Ashok Vihar, Delhi - DPCC	28.6909	77.1765	136.33	218.4	62.79	8	36.5	6.2
4	Aya Nagar, Delhi - IMD	28.4720	77.1329	72.75	154.72	24.52	36.88	34.54	12.2
5	Bawana, Delhi - DPCC	28.7932	77.0483	140.54	236.46	36.48	13.64	61.27	12.95
6	Burari Crossing, Delhi - IMD	28.7551	77.1607	NA	NA	NA	NA	NA	NA
7	Dr. K S Shooting Range, Delhi - DPCC	28.4997	77.2670	124.28	206.47	75.09	4.6	24.75	1.32
8	DTU, Delhi - CPCB	28.7499	77.1183	167.98	300.16	33.55	6.95	46.41	16.44
9	Dwarka-Sector 8, Delhi - DPCC	28.5720	28.5720	151.08	293.88	55.41	8.68	39.23	9.59
10	East Arjun Nagar, Delhi - CPCB	28.6561	77.2947	NA	NA	65.67	NA	NA	20.85
11	IGI Airport (T3), Delhi - IMD	28.5550	77.0844	92.32	191.91	27.62	7.68	28.81	NA
12	IHBAS, Dilshad Garden, Delhi - CPCB	28.6811	77.3047	103.69	NA	52.32	11.35	NA	10.06
13	ITO, Delhi - CPCB	28.6275	77.2437	177.24	238.21	28.17	133.46	128.89	18.67
14	Jahangirpuri, Delhi - DPCC	28.7296	77.1666	132	275.5	99.03	10.95	39.41	62.99
15	Jawaharlal Nehru Stadium, Delhi - DPCC	28.5828	77.2343	90.64	176.33	41.04	3	27.77	8.8
16	Lodhi Road, Delhi - IMD	28.5910	77.2280	84.02	175.81	31.17	59.93	73.8	22.58
17	MDCNS, Delhi - DPCC	28.6125	77.2373	117.83	204.93	59.93	7.35	22.85	8.84
18	Mandir Marg, Delhi - DPCC	28.6341	77.2004	90.78	204.65	54.45	14.05	38.3	26.14
19	Mathura Road, Delhi - IMD	28.6112	77.2401	100.97	234.49	45.94	6.94	39.63	15.52
20	Mundka, Delhi - DPCC	28.6823	77.0349	207.6	315.64	25.94	9	62	26
21	Najafgarh, Delhi - DPCC	28.6090	76.9854	119.46	164.06	27.54	46.24	154.73	NA
22	Narela, Delhi - DPCC	28.8548	77.0892	136.15	245.52	44.75	6.3	52.4	30.49
23	Nehru Nagar, Delhi - DPCC	28.5638	77.2608	147.88	241.8	34.14	7.72	29.5	11.88
24	North Campus, DU, Delhi - IMD	28.6889	77.2141	84.09	172	31.67	24.4	NA	12.88
25	NSIT Dwarka, Delhi - CPCB	28.6102	77.0378	134.63	NA	30.89	28.05	NA	11
26	Okhla Phase-2, Delhi - DPCC	28.5492	77.2678	133.5	238.27	48.61	8.5	33.1	10.58
27	Patparganj, Delhi - DPCC	28.6347	77.3045	106.91	144.35	29.41	4.18	27.09	8.72
28	Punjabi Bagh, Delhi - DPCC	28.6619	77.1241	146.86	212.91	41.87	7.67	37.36	13.67
29	Pusa, Delhi - DPCC	28.6376	77.1571	131.78	215.6	71.16	1.08	22.45	18
30	Pusa, Delhi - IMD	28.6340	77.1678	73.27	152.18	14.15	NA	NA	NA
31	R K Puram, Delhi - DPCC	28.5503	77.1851	98.73	219.36	54.32	5.75	21.2	7.55
32	Rohini, Delhi - DPCC	28.7382	77.0822	164.95	233.29	26.12	11.91	56.09	8.06
33	Shadipur, Delhi - CPCB	28.6510	77.1562	107.44	NA	86.72	13.21	NA	11.15
34	Sirifort, Delhi - CPCB	28.5505	77.2147	144.53	254.05	47.74	7.8	38.85	9.08
35	Sonia Vihar, Delhi - DPCC	28.7332	77.2495	104.68	183.97	47.29	6.2	35.3	17.27
36	Sri Aurobindo Marg, Delhi - DPCC	28.5563	77.2063	113.35	174.23	32.3	5	19	2.66
37	Vivek Vihar, Delhi - DPCC	28.6712	77.3176	124.02	199.71	43.5	9.5	64	16.41
38	Wazirpur, Delhi - DPCC	28.6975	77.1604	148.51	249.38	75.81	10.3	42.2	22.29
	Average			122.48	216.49	46.40	17.71	47.46	15.82

DPCC: Delhi Pollution Contro Committee, IMD: Indian Meteorological Department, CPCB: Central Pollution Control Board
N.A.= data not available for particular day
Source: Central Control Room for Air Quality Management, Delhi NCR

Table 1 illustrates the NO_2 concentrations in Delhi at various stations for two time periods i.e. before COVID-19 lockdown (25 February 2020) and during COVID-19 lockdown (21 April 2020). All the stations have recorded a pronounced reduction in NO_2 concentrations during the considered period. Though the majority of the stations have recorded NO_2 concentrations below the WHO standard (80 μg/m^3), the average 24-hour levels have further dropped from 46.40 μg/m^3 on 25 February to 15.82 μg/m^3 on 21 April. The trend of day to day NO_2 concentration level decrease before and during the lockdown in all the stations of Delhi has been presented by the line diagram (Fig. 2). There has been a remarkable lowering of NO_2 levels after 24 March when the COVID-19 lockdown started in India. It is also noticeable that the levels of NO_2 are considerably under control in the city compared to the critical levels of particulate matter.

It is indicative that the levels of air pollution declined gradually over the studied period with a steep fall from 25 March and reached historical low levels. Moreover, there is a notable difference between declining patterns of PM and NO_2 (Fig. 2). This difference can be justified with various reasons. The lockdown due to COVID-19 has strictly restricted all construction activities and movement of vehicles, which were responsible for previously higher levels of PM in Delhi (Kathuria, 2004; Taneja et al., 2016). Thus there is a sharp change in PM levels before and during the lockdown. However, as noted by Sikarwar and Chattopadhyay (2020) the levels of NO_2 concentrations in the city were already recorded below the standards and thus, showed a gradual decline during the lockdown.

Spatial changes in the level of air pollution before and during the lockdown

Before lockdown (25 February) the stations have recorded high levels of $PM_{2.5}$ and the most polluted areas of the city have $PM_{2.5}$ concentrations above 106 μg/m^3 (Fig. 3). Furthermore, our analysis found that the concentration was significantly high in the western part of the city but these concentration levels have trickled down remarkably during the lockdown (25 February)

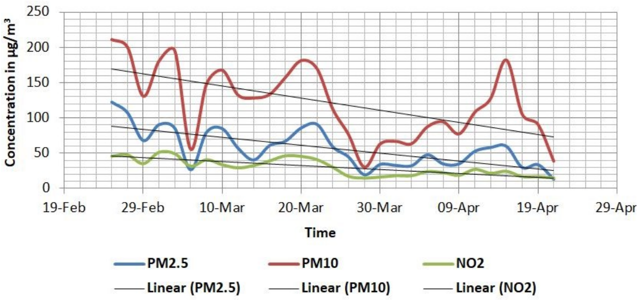

Fig. 2 Trend of $PM_{2.5}$, PM_{10}, and NO_2 concentrations [μg/m^3] before and during the lockdown in Delhi

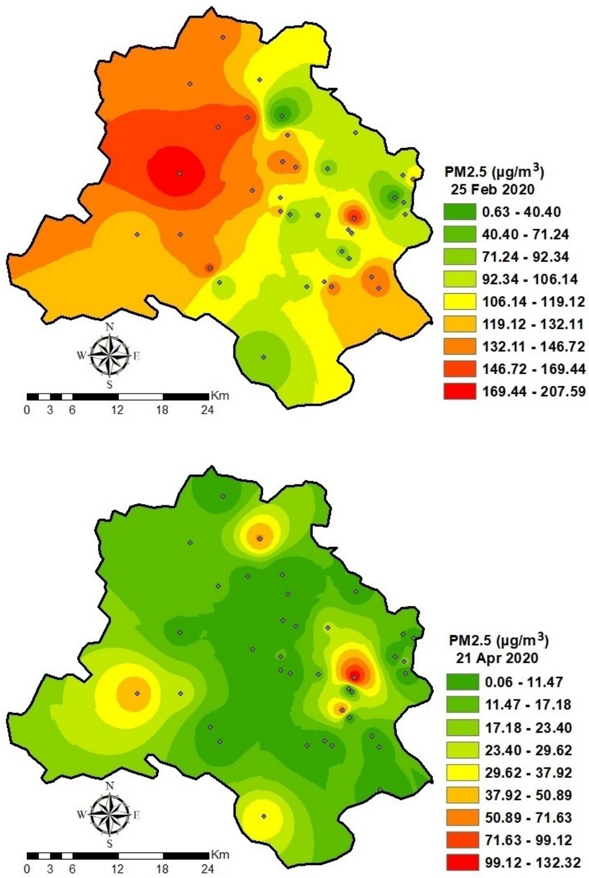

Fig. 3. Spatial concentrations of $PM_{2.5}$ in Delhi before (25 February 2020) (top) and during (21 April 2020) (bottom) COVID-19 lockdown.

when $PM_{2.5}$ concentrations were below 30 μg/m^3 in the maximum areas of the city.

The concentration of PM_{10} in the city before and during lockdown is presented with spatially interpolated surface maps too (Fig. 4). Before lockdown (25 February), the concentration of PM_{10} was critically high, when PM_{10} concentration was observed above 140 μg/m_3 in the most polluted areas of Delhi. The north-western and south-eastern parts exhibit the presence of an extreme level of PM_{10} in the air. However, these concentration levels have reduced significantly to lower levels during the lockdown (25 February) as the maximum area of the city has PM_{10} concentration below 56 μg/m^3.

The interpolated maps of NO_2 concentrations before and during the lockdown in Delhi clearly show that the NO_2 concentration in Delhi has reduced to notable levels after the implementation of lockdown in the city (Fig. 5). The analysis shows, that before the lockdown, mainly the eastern part of the city had higher concentrations of NO_2, which further declined during the lockdown. It was also found that the southern part of the city has experienced better air quality in terms of NO_2, during the lockdown. However, the levels of NO_2 concentration remained higher in the northern parts of the city.

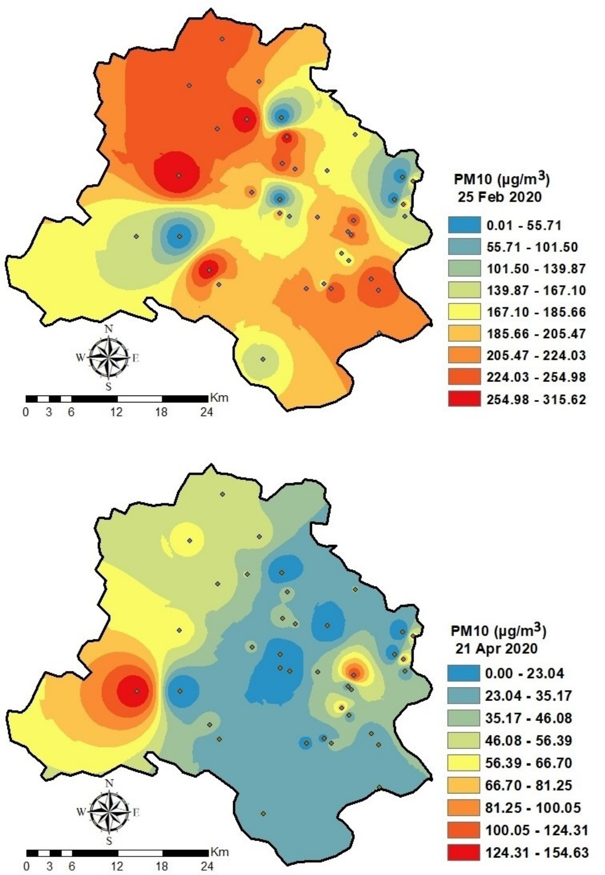

Fig. 4. Spatial concentrations of PM_{10} in Delhi before (25 February 2020) (top) and during (21 April 2020) (bottom) COVID-19 lockdown

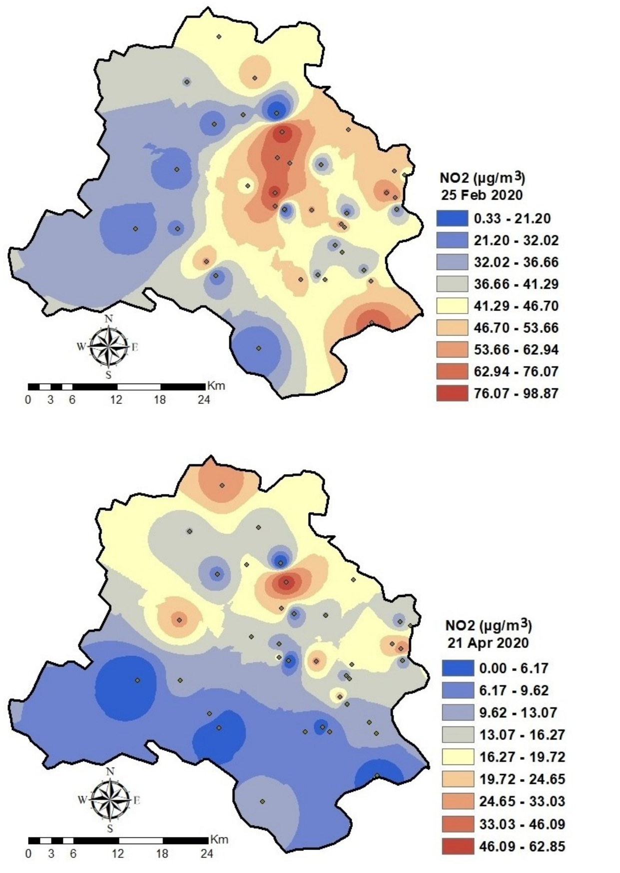

Fig. 5. Spatial concentrations of NO_2 in Delhi before (25 February 2020) (top) and during (21 April 2020) (bottom) COVID-19 lockdown

CONCLUSIONS

Since many Indian metro cities have been in the list of the world's most polluted cities, a sudden significant improvement in the air quality of Delhi has international relevance for environmental policies. Lockdown due to COVID-19 in various parts of the world has provided an opportunity to measure human impact on the natural environment particularly in big cities. When urban mega hubs have been running continuously for economic development without considering the limits of natural resources, measures like temporary lockdown may emerge as an effective solution to control environmental imbalance.

With the use of the IDW method of spatial interpolation, the study estimated concentrations of $PM_{2.5}$, PM_{10}, and NO2 before and during COVID-19 lockdown in Delhi. It is found that the lockdown in the city has positively impacted the air quality. The results reveal that just after one month of the lockdown the reductions in $PM_{2.5}$, PM_{10}, and NO_2 concentrations were by 93%, 83%, and 70% respectively. Consequently, the levels of air pollution are historically low during the lockdown when compared to the levels estimated in previous studies on Delhi (Kumar and Foster, 2009; Dholakia et al., 2013; Rizwan et al., 2013). Considering the critically degraded air quality for decades and higher morbidity and mortality rates due to unhealthy air, the improvement in air quality due to lockdown may result as a boon for the better health of the city's population. This temporary improvement in the air of the capital city gives a positive indication of another chance to mitigate the damage we have done to the environment. Therefore, the study should be considered as a useful supplement to the regulatory authorities that may lead to reconsider the current plan and policies to combat degraded air quality in the city.

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