Assessing the immediate effect of COVID-19 lockdown on air quality: A case study of Delhi, India

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Keywords: COVID-19, lockdown, air pollution, Delhi, India

Posted Date: May 29th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-31822/v1

Version of Record: A version of this preprint was published at Journal of Environmental Geography on November 1st, 2020. See the published version at https://doi.org/10.2478/jengeo-2020-0009.

Abstract

In India, the 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 ($PM_{2.5}$, PM_{10}, and 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 the lowering 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 before one month of the lockdown the levels of air pollution in Delhi were critically high and far beyond the guideline values set by the World Health Organization. The levels of air pollution are 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.

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 have made it a global pandemic that has led to pernicious consequences in various parts of the world. First identified in December month of 2019, in the province of Wuhan, China (Kucharski et al. 2020; Zhu et al. 2020), COVID-19, around four months later have adversely affected life and economy in more than 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 interaction among individuals such as banning large-scale public and private gatherings, imposing a curfew, restraining transportation, promoting social distancing, strict quarantine instructions, and locking down the country, states and cities, depending on the country-specific situation.

On the one hand, the cost of enacting, the preventive measures against COVID-19 are immense, but on the brighter side, it could have some significant benefits on society. Among them, 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 was home to 14 of the 20 most polluted cities in the world last year, 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; Sharma et al. 2020; Wang et al. 2020; Li et al. 2020; Muhammad et al. 2020).

Since the 1990s, Delhi has been ranked as one of the most polluted cities among the world's developing countries (Gurjar et al. 2004; WHO 2016). Particularly, in the northern part of India, air pollution caused due to the onsite burning of agricultural crop residue is one of the many causes of critical levels of air pollution (Satyendra et al. 2013). These higher levels of air pollution in the overcrowded Delhi cause significant public health problems (Dholakia et al. 2013; Rizwan et al. 2013). Due to very high levels of air pollution, in 2017, a community health emergency was declared in Delhi by the Indian Council of Medical Research (Chowdhury et al. 2019). Recent research point out that vehicular emission has shown a decreasing trend in the last decade. But, the overall particulate matter concentration has seen a consistent rise (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 of paramount public health, environmental, and development point of concern (Kampa and Castanas 2008).

India first announced a public curfew on 22 March 2020 and later imposed nationwide lockdown from 25 March 2020 till 15 April and extended it further till 3 May 2020 to contain 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. However, the extent of lockdown varies across different countries and cities around the globe depending on the level of cases. Undoubtedly, the lockdown has put a temporary rest to a significant number of social and economic activities in the country and its people (Alvarez et al. 2020; Inoue and Todo 2020; Karin et al. 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, understanding the temporary improvement in air quality of Delhi, one of the most polluted cities in the world; due to COVID-19 lockdown is important because this could be considered as an effective alternative measure to combat air pollution issues. 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; Sharma et al. 2020; Wang et al. 2020; Li et al. 2020; Muhammad et al. 2020), this study attempts to analyze data from 38 ground monitoring stations to study the lockdown effect in Delhi.

Study Area

Delhi, officially the National Capital Territory of Delhi (NCT), is a city and a union territory of India located at 28.61° N 77.23° E (Fig. 1). This city is the administrative and second financial capital of India. With the geographical area of 1485 km^2, 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 1.5 crore population with population density of 11297 people per km^2 (Chandramouli and General 2011). Two prominent features about the geography of Delhi are the Yamuna flood plains and the Delhi ridge. The Yamuna River was the historical boundary between Punjab and UP, and its flood plains provide fertile alluvial soil suitable for agriculture but are prone to recurrent floods. Delhi has been continuously inhabited since the sixth 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).

Data And Methods

In order to assess the air quality status of Delhi before and during the lockdown period, data from thirty-eight 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.

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 modeling 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 O_3, 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: (see Equation 1 in the Supplementary Files)

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 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).

Table 1 Details of the ground monitoring stations selected for the study

Sr no.	Station name (authority)	Latitude	Longitude
1	Alipur, Delhi - DPCC	28.797226°	77.133136°
2	Anand Vihar, Delhi - DPCC	28.650218°	77.302706°
3	Ashok Vihar, Delhi - DPCC	28.690979°	77.176524°
4	Aya Nagar, Delhi - IMD	28.472044°	77.132942°
5	Bawana, Delhi - DPCC	28.793229°	77.048335°
6	Burari Crossing, Delhi - IMD	28.755130°	77.160724°
7	Dr. Karni Singh Shooting Range, Delhi- DPCC	28.499727°	77.267095°
8	DTU, Delhi - CPCB	28.749987°	77.118314°
9	Dwarka-Sector 8, Delhi - DPCC	28.572038°	28.572038°
10	East Arjun Nagar, Delhi - CPCB	28.656173°	77.294747°
11	IGI Airport (T3), Delhi - IMD	28.555084°	77.084401°
12	IHBAS, Dilshad Garden, Delhi - CPCB	28.681169°	77.304712°
13	ITO, Delhi - CPCB	28.627541°	77.243793°
14	Jahangirpuri, Delhi - DPCC	28.729617°	77.166631°
15	Jawaharlal Nehru Stadium, Delhi - DPCC	28.582846°	77.234366°
16	Lodhi Road, Delhi - IMD	28.591063°	77.228079°
17	MDCNS, Delhi - DPCC	28.612547°	77.237335°
18	Mandir Marg, Delhi - DPCC	28.634175°	77.200475°
19	Mathura Road, Delhi - IMD	28.611254°	77.240116°
20	Mundka, Delhi - DPCC	28.682314°	77.034937°
21	Najafgarh, Delhi - DPCC	28.609013°	76.985453°
22	Narela, Delhi - DPCC	28.854882°	77.089215°
23	Nehru Nagar, Delhi - DPCC	28.563867°	77.260810°
24	North Campus, DU, Delhi - IMD	28.688944°	77.214125°
25	NSIT Dwarka, Delhi - CPCB	28.610273°	77.037882°
26	Okhla Phase-2, Delhi - DPCC	28.549291°	77.267814°
27	Patparganj, Delhi - DPCC	28.634731°	77.304571°
28	Punjabi Bagh, Delhi - DPCC	28.661975°	77.124156°

29	Pusa, Delhi - DPCC	28.637672°	77.157144°
30	Pusa, Delhi - IMD	28.634055°	77.167847°
31	R K Puram, Delhi - DPCC	28.550350°	77.185149°
32	Rohini, Delhi - DPCC	28.738268°	77.082215°
33	Shadipur, Delhi - CPCB	28.651027°	77.156220°
34	Sirifort, Delhi - CPCB	28.550583°	77.214799°
35	Sonia Vihar, Delhi - DPCC	28.733247°	77.249589°
36	Sri Aurobindo Marg, Delhi - DPCC	28.556310°	77.206338°
37	Vivek Vihar, Delhi - DPCC	28.671246°	77.317654°
38	Wazirpur, Delhi - DPCC	28.697544°	77.160440°

DPCC: Delhi Pollution Contro Committee, IMD: Indian Meteorological Department, CPCB: Central Pollution Control Board

Source: Central Control Room for Air Quality Management, Delhi NCR

Results And Discussion

Temporal trends of air pollution before and during lockdown

It is evident from Table 2 and Fig. 2 that there has been a significant change in the levels of $PM_{2.5}$ before and during the days of COVID-19 lockdown in Delhi. All the stations in the city have recorded considerable lowering of $PM_{2.5}$ concentration during the studied period. The average $PM_{2.5}$ concentration 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, in the beginning, all the stations within the city have reordered $PM_{2.5}$ concentration far beyond the standard (25 μg/m^3) set by the WHO. Noteworthy point here is that, on the last day of studied time, 29 stations out of the 35 have recorded $PM_{2.5}$ concentration 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/m3 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/m3) in all the 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 2 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 time span. 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 levels 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 time period with a steep fall from 25 March and reached to historically lower levels.

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

Fig. 3 and Fig. 4 show the interpolated surface of $PM_{2.5}$ in Delhi at two times considered in the study. Before lockdown (25 February), the stations have recorded higher levels of $PM_{2.5}$ and the maximum areas of the city have $PM_{2.5}$ concentration above 106 μg/m^3. Furthermore, our analysis found that the concentration was significantly high in the western part of the city but these concentration levels have gone/trickled down remarkably during the lockdown (25 February) when $PM_{2.5}$ concentration was 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 (Fig. 5 and Fig. 6). Before lockdown (25 February), the concentration of PM_{10} was critically high, when PM_{10} concentration was observed above 140 μg/m^3 in maximum areas of Delhi. The areas in the north-west and south-east directions exhibit the presence of 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/m3.

Fig. 7 and Fig. 8 present the spatially interpolated surface of NO_2 concentrations before and during the lockdown in Delhi. From the surface maps, it becomes clear that the NO_2 concentration in Delhi has reduced to notable levels after the implementation of lockdown in the city. 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 for the Jahangirpuri station situated on the northern side of the city.

Table 2 Levels of $PM_{2.5}$, PM_{10} and NO_2 concentration at various stations of Delhi before and during COVID-19 lockdown

Sr no.	Station name	Before COVID-19 lockdown (25 February 2020)			During COVID-19 lockdown (21 April 2020)		
		$PM_{2.5}$	PM_{10}	NO_2	$PM_{2.5}$	PM_{10}	NO_2
1	Alipur, Delhi - DPCC	110.12	206.45	52.61	52.61	52.61	13.4
2	Anand Vihar, Delhi - DPCC	88.52	209.39	57.14	20.88	81.18	33.55
3	Ashok Vihar, Delhi - DPCC	136.33	218.4	62.79	8	36.5	6.2
4	Aya Nagar, Delhi - IMD	72.75	154.72	24.52	36.88	34.54	12.2
5	Bawana, Delhi - DPCC	140.54	236.46	36.48	13.64	61.27	12.95
6	Burari Crossing, Delhi - IMD	NA	NA	NA	NA	NA	NA
7	Dr. K S Shooting Range, Delhi - DPCC	124.28	206.47	75.09	4.6	24.75	1.32
8	DTU, Delhi - CPCB	167.98	300.16	33.55	6.95	46.41	16.44
9	Dwarka-Sector 8, Delhi - DPCC	151.08	293.88	55.41	8.68	39.23	9.59
10	East Arjun Nagar, Delhi - CPCB	NA	NA	65.67	NA	NA	20.85
11	IGI Airport (T3), Delhi - IMD	92.32	191.91	27.62	7.68	28.81	NA
12	IHBAS, Dilshad Garden, Delhi - CPCB	103.69	NA	52.32	11.35	NA	10.06
13	ITO, Delhi - CPCB	177.24	238.21	28.17	133.46	128.89	18.67
14	Jahangirpuri, Delhi - DPCC	132	275.5	99.03	10.95	39.41	62.99
15	Jawaharlal Nehru Stadium, Delhi - DPCC	90.64	176.33	41.04	3	27.77	8.8
16	Lodhi Road, Delhi - IMD	84.02	175.81	31.17	59.93	73.8	22.58
17	MDCNS, Delhi - DPCC	117.83	204.93	59.93	7.35	22.85	8.84
18	Mandir Marg, Delhi - DPCC	90.78	204.65	54.45	14.05	38.3	26.14
19	Mathura Road, Delhi - IMD	100.97	234.49	45.94	6.94	39.63	15.52
20	Mundka, Delhi - DPCC	207.6	315.64	25.94	9	62	26
21	Najafgarh, Delhi - DPCC	119.46	164.06	27.54	46.24	154.73	NA
22	Narela, Delhi - DPCC	136.15	245.52	44.75	6.3	52.4	30.49
23	Nehru Nagar, Delhi - DPCC	147.88	241.8	34.14	7.72	29.5	11.88
24	North Campus, DU, Delhi - IMD	84.09	172	31.67	24.4	NA	12.88
25	NSIT Dwarka, Delhi - CPCB	134.63	NA	30.89	28.05	NA	11
26	Okhla Phase-2, Delhi - DPCC	133.5	238.27	48.61	8.5	33.1	10.58
27	Patparganj, Delhi - DPCC	106.91	144.35	29.41	4.18	27.09	8.72
28	Punjabi Bagh, Delhi - DPCC	146.86	212.91	41.87	7.67	37.36	13.67
29	Pusa, Delhi - DPCC	131.78	215.6	71.16	1.08	22.45	18
30	Pusa, Delhi - IMD	73.27	152.18	14.15	NA	NA	NA
31	R K Puram, Delhi - DPCC	98.73	219.36	54.32	5.75	21.2	7.55
32	Rohini, Delhi - DPCC	164.95	233.29	26.12	11.91	56.09	8.06
33	Shadipur, Delhi - CPCB	107.44	NA	86.72	13.21	NA	11.15
34	Sirifort, Delhi - CPCB	144.53	254.05	47.74	7.8	38.85	9.08
35	Sonia Vihar, Delhi - DPCC	104.68	183.97	47.29	6.2	35.3	17.27
36	Sri Aurobindo Marg, Delhi - DPCC	113.35	174.23	32.3	5	19	2.66
37	Vivek Vihar, Delhi - DPCC	124.02	199.71	43.5	9.5	64	16.41
38	Wazirpur, Delhi - DPCC	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

N.A.= data not available for particular day

Source: Central Control Room for Air Quality Management, Delhi NCR

Conclusion

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 NO_2 before and during COVID-19 lockdown in Delhi. It is found that the lockdown in the city has impacted the air quality in a positive manner. The results reveal the reduction in $PM_{2.5}$, PM_{10}, and NO_2 concentrations in the city by 93%, 83%, and 70% just after one month of lockdown respectively. Consequently, the levels of air pollution are 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. This temporary improvement in the air of capital city gives a positive indication towards 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.

Declarations

Competing interests: The authors declare no competing interests.

References

Alvarez FE, Argente D, Lippi F (2020) A simple planning problem for covid-19 lockdown. National Bureau of Economic Research. https://doi.org/10.3386/w26981

Asher CB (2000) Delhi Walled: Changing Boundaries: The Urban Enceinte in Global Perspective. In City Walls: The Urban Enceinte in Global Perspective. Cambridge

Burrough PA, McDonnell RA (1998) Creating continuous surfaces from point data. Principles of Geographic Information Systems. Oxford University Press, Oxford, UK

Chandramouli C, General R (2011) census of India 2011. Provisional population totals. New Delhi: Government of India

Chen G, Li J, Ying Q, Sherman S, Perkins N, Sundaram R, Mendola P (2014) Evaluation of observation-fused regional air quality model results for population air pollution exposure estimation. Science of the total environment. https://doi.org/10.1016/j.scitotenv.2014.03.107

Chowdhury S, Dey S, Guttikunda S, Pillarisetti A, Smith KR, Di Girolamo L (2019) Indian annual ambient air quality standard is achievable by completely mitigating emissions from household sources. Proceedings of the National Academy of Sciences. https://doi.org/10.1073/pnas.1900888116

Deligiorgi D, Philippopoulos K (2011) Spatial interpolation methodologies in urban air pollution modeling: application for the greater area of metropolitan Athens, Greece. In: Advanced Air Pollution. https://doi.org/10.5772/17734

Dholakia HH, Purohit P, Rao S, Garg A (2013) Impact of current policies on future air quality and health outcomes in Delhi, India. Atmospheric environment. https://doi.org/10.1016/j.atmosenv.2013.04.052

Dutheil F, Baker JS, Navel V (2020) COVID-19 as a factor influencing air pollution?. Environmental Pollution. https://doi.org/10.1016/j.envpol.2020.114466

Gurjar BR, Ravindra K, Nagpure AS (2016) Air pollution trends over Indian megacities and their local-to-global implications. Atmospheric Environment. https://doi.org/10.1016/j.atmosenv.2016.06.030

Gurjar BR, Van Aardenne JA, Lelieveld J, Mohan M (2004) Emission estimates and trends (1990–2000) for megacity Delhi and implications. Atmospheric Environment. https://doi.org/10.1016/j.atmosenv.2004.05.057

Hoek G, Brunekreef B, Goldbohm S, Fischer P, van den Brandt PA (2002) Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. The lancet. https://doi.org/10.1016/s0140-6736(02)11280-3

Inoue H, Todo Y (2020) The propagation of the economic impact through supply chains: The case of a mega-city lockdown to contain the spread of COVID-19. Covid Economics. https://doi.org/10.2139/ssrn.3564898

Kampa M, Castanas E (2008) Human health effects of air pollution. Environmental pollution. https://doi.org/10.1016/j.envpol.2007.06.012

Karin O, Bar-On YM, Milo T, Katzir I, Mayo A, Korem Y, Dudovich B, Yashiv E, Zehavi AJ, Davidovich N, Milo R (2020) Adaptive cyclic exit strategies from lockdown to suppress COVID-19 and allow economic activity. medRxiv. https://doi.org/10.1101/2020.04.04.20053579

Kucharski AJ, Timothy WR, Charlie D et al (2020) Early dynamics of transmission and control of COVID-19: a mathematical modelling study. The lancet infectious diseases. https://doi.org/10.1016/s1473-3099(20)30144-4

Li L, Li Q, Huang L, Wang Q, Zhu A, Xu J, Liu Z, Li H, Shi L, Li R, Azari M (2020) Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2020.139282

Mahato S, Pal S, Ghosh KG (2020) Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2020.139086

Muhammad S, Long X, Salman M (2020) COVID-19 pandemic and environmental pollution: A blessing in disguise?. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2020.138820

Nagpure AS, Gurjar BR, Kumar V, Kumar P (2016) Estimation of exhaust and non-exhaust gaseous, particulate matter and air toxics emissions from on-road vehicles in Delhi. Atmospheric environment. https://doi.org/10.1016/j.atmosenv.2015.12.026

Neupane B, Jerrett M, Burnett RT, Marrie T, Arain A, Loeb M (2010) Long-term exposure to ambient air pollution and risk of hospitalization with community-acquired pneumonia in older adults. American journal of respiratory and critical care medicine. https://doi.org/10.1164/rccm.200901-0160oc

Rizwan SA, Nongkynrih B, Gupta SK (2013) Air pollution in Delhi: its magnitude and effects on health. Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine. https://doi.org/10.4103/0970-0218.106617

Salam MT, Millstein J, Li YF, Lurmann FW, Margolis HG, Gilliland FD (2005) Birth outcomes and prenatal exposure to ozone, carbon monoxide, and particulate matter: results from the Children's Health Study. Environmental health perspectives. https://doi.org/10.1289/ehp.8111

Satyendra T, Singh RN, Shaishav S (2013) Emissions from crop/biomass residue burning risk to atmospheric quality. Int Res J Earth Sci 1(1):1-5

Sharma S, Zhang M, Gao J, Zhang H, Kota SH (2020) Effect of restricted emissions during COVID-19 on air quality in India. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2020.138878

Sikarwar A, Chattopadhyay A (2020) Analyzing Population and Land Use Change: Selected Case Studies of Indian Metropolitan Cities. Springer, Singapore. https://doi.org/10.1007/978-981-15-5036-2

Singh RK, Chakraborty D (2020) World's Dirtiest Air Gets Cleaner After India's Lockdown. Bloomberg-Quint. https://www.bloombergquint.com/. Accessed on 1 May 2020

United Nations Department of Economic and Social Affairs (2018) Revision of world urbanization prospects

Wang P, Chen K, Zhu S, Wang P, Zhang H (2020) Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. Resources, Conservation and Recycling.

https://doi.org/10.1016/j.resconrec.2020.104814

World Health Organization (2016) WHO global urban ambient air pollution database (update 2016). Geneva, Switzerland: WHO

World Health Organization (2020) Coronavirus disease (COVID-2019) situation reports. https://www.WHO. Int/docs/default-source/coronaviruse/situationreports/20200221-sitrep-32-covid. Accessed on 28 April 2020

Xie X, Semanjski I, Gautama S, Tsiligianni E, Deligiannis N, Rajan RT, Pasveer F, Philips W (2017) A review of urban air pollution monitoring and exposure assessment methods. ISPRS International Journal of Geo-Information. https://doi.org/10.3390/ijgi6120389

Zhu N, Zhang D, Wang W et al (2020) A novel coronavirus from patients with pneumonia in China, 2019. New England Journal of Medicine. https://doi.org/10.1056/nejmoa2001017

Figures

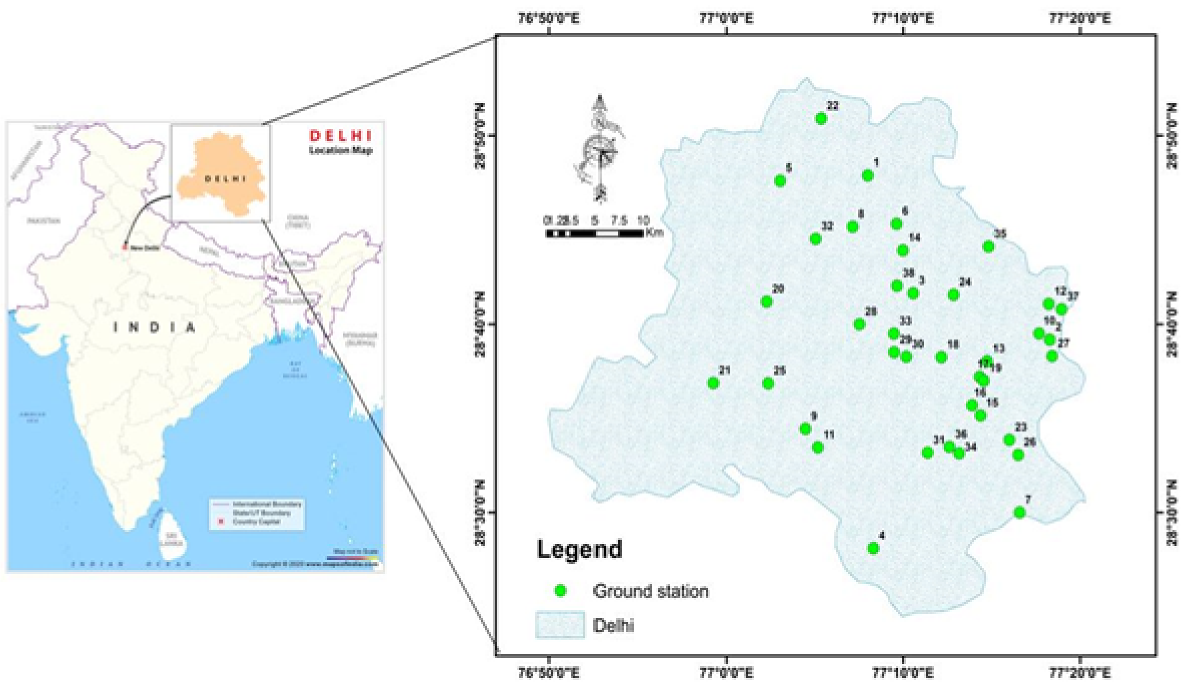

Figure 1

Location map of Delhi showing the administrative extent and ground monitoring stations considered in the present study

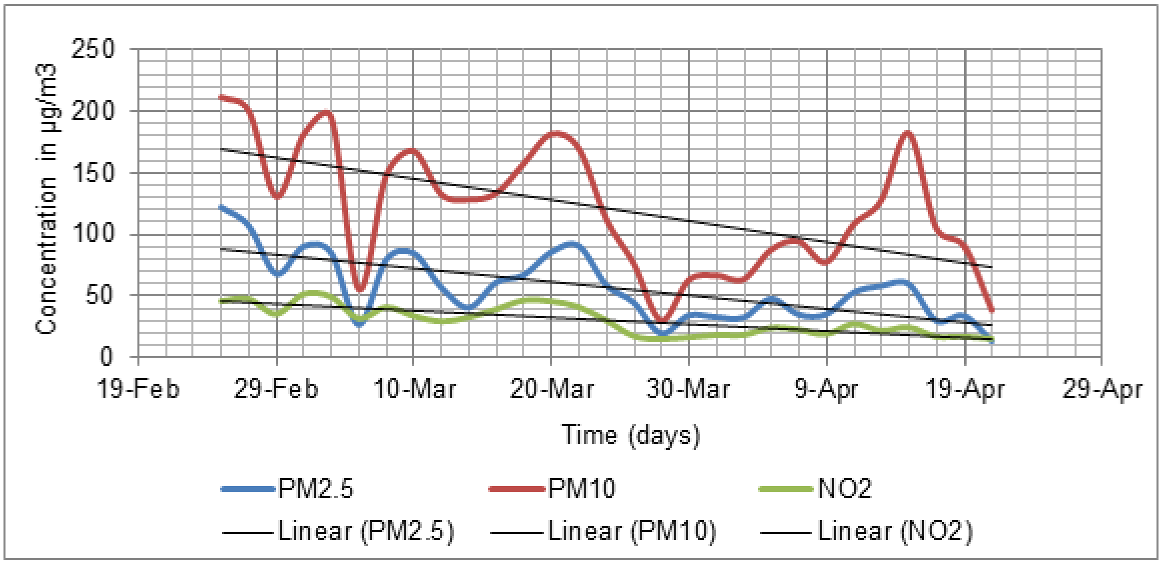

Figure 2

Trend of PM2.5, PM10, and NO2 concentrations before and during the lockdown in Delhi

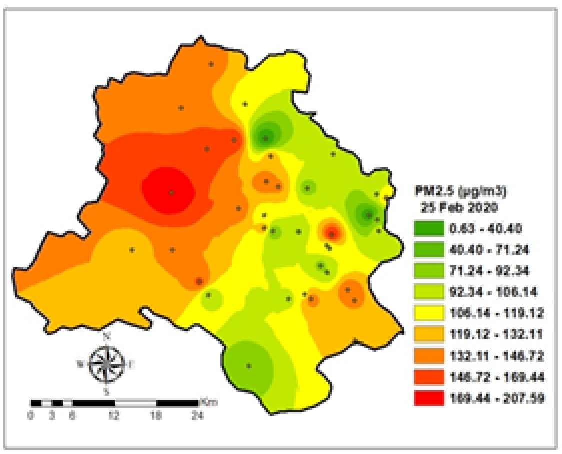

Figure 3

Spatial concentrations of PM2.5 in Delhi before COVID-19 lockdown (25 February 2020)

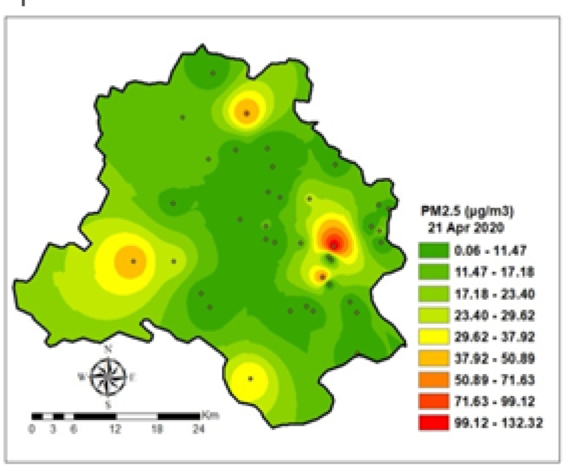

Figure 4

Spatial concentrations of PM2.5 in Delhi during COVID-19 lockdown (21 April 2020)

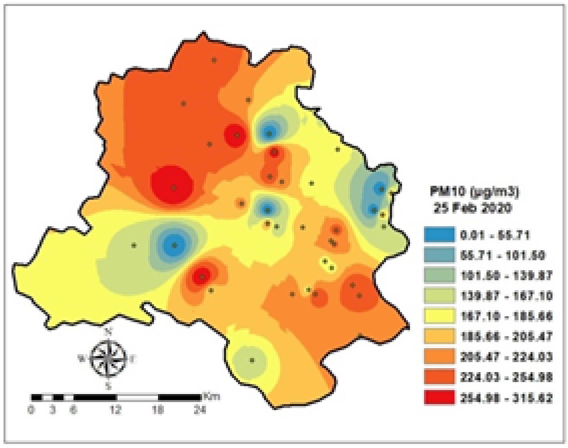

Figure 5

Spatial concentrations of PM10 in Delhi before COVID-19 lockdown (25 February 2020)

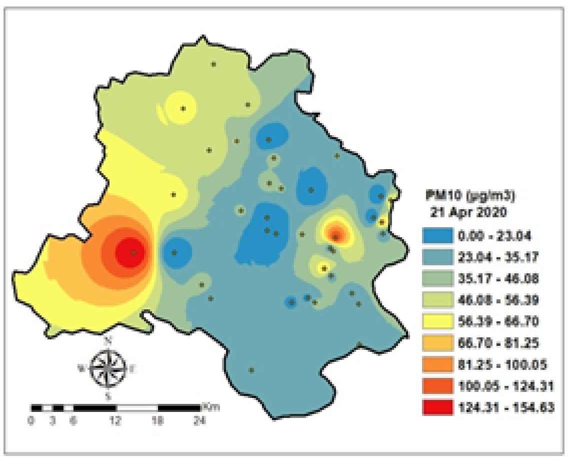

Figure 6

Spatial concentrations of PM10 in Delhi during COVID-19 lockdown (21 April 2020)

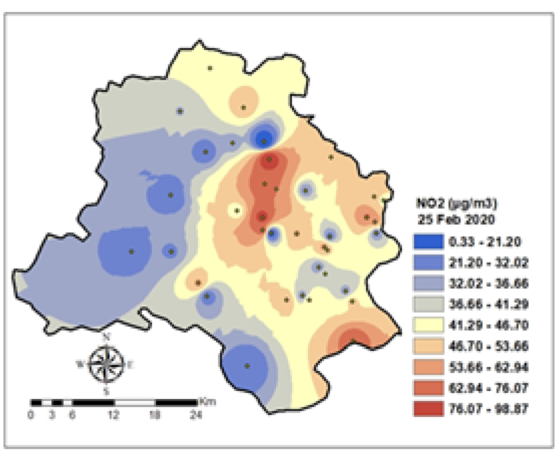

Figure 7

Spatial concentrations of NO2 in Delhi before COVID-19 lockdown (25 February 2020)

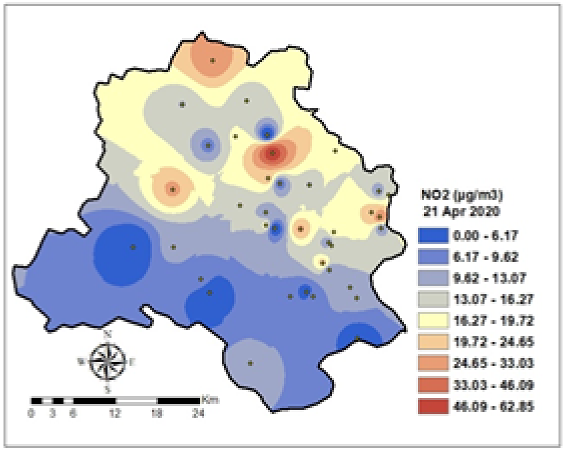

Figure 8

Spatial concentrations of NO2 in Delhi during COVID-19 lockdown (21 April 2020)

Supplementary Files

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