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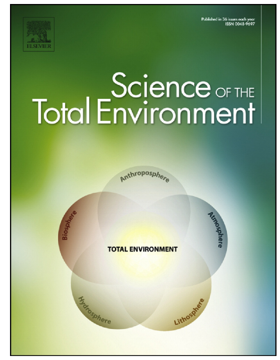

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Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India

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Abstract:

Amid the COVID-19 pandemic, a nationwide lockdown is imposed in India initially for three weeks from 24th March to 14th April, 2020 and extended up to 3rd May, 2020. Due to the forced restrictions, pollution level in cities across the country drastically slowed down just within few days which magnetize discussions regarding lockdown to be the effectual alternative measures to be implemented for controlling air pollution. The present article eventually worked on this direction to look upon the air quality scenario amidst the lockdown period scientifically with special reference to the megacity Delhi. With the aid of air quality data of seven pollutant parameters (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3 and NH_3) for 34 monitoring stations spread over the megacity we have employed National Air Quality Index (NAQI) to show the spatial pattern of air quality in pre and during-lockdown phases. The results demonstrated that during lockdown air quality is significantly improved. Among the selected pollutants, concentrations of PM_{10} and $PM_{2.5}$ have witnessed maximum reduction (>50%) in compare to the pre-lockdown phase. In compare to the last year (i.e. 2019) during the said time period the reduction of PM_{10} and $PM_{2.5}$ is as high as about 60% and 39% respectively. Among other pollutants, NO_2 (-52.68%) and CO (-

30.35%) level have also reduced during-lockdown phase. About 40% to 50% improvement in air quality is identified just after four days of commencing lockdown. About 54%, 49%, 43%, 37% and 31% reduction in NAQI have been observed in Central, Eastern, Southern, Western and Northern parts of the megacity. Overall, the study is thought to be a useful supplement to the regulatory bodies since it showed the pollution source control can attenuate the air quality. Temporary such source control in a suitable time interval may heal the environment.

Keywords*:* Covid-19; Lockdown; Megacity Delhi; National Air quality Index; Change of air quality

1.0 Introduction

The World Urbanization Prospect 2018 Revision predicted that the megacities of the Asia and Africa is likely to be experienced about 90% growth of its population (World Urbanization Prospect 2018 Revision) by 2050. Delhi, the second largest megacity in the world (TickellandRanasinha 2018) is the single largest contributors to the urban population (about 7.6%) in India with about 16.8 million inhabitants distributed over 1485 km^2 area (Census 2011). Over the last two decades, the population density has increased from nearly 9340 people/km^2 in 2001 to 11297 persons/km^2 in 2011, growing at an average annual rate of 37.60%. Along with this population boost, economic development initiatives in the city have enhanced pollution level emitted from different sectors. For example, since 2008 the sales of domestic manufactured vehicles have increased by at least 15%/annum (SIAM 2013), the transport demand is expected to rise as much as 200% between 2015-2030 (Amann et al. 2017), the traffic quantities are likely to increase by 10.5%/year (MoSPI 2015), whereas power generation is expected to increase by 11.1%/year (CEA 2015; 2016). The impacts of the unprecedented population boost on environment together with uncontrolled urban growth, consequent industrialization and automation have made environmental pollution seriously thought provoking. The most obvious consequence of it is deterioration of air quality (Goyal 2003; Amann et al. 2017; Gulia et al. 2018; Kanawade et al. 2020).

Delhi is considered amongst the most polluted megacities of the globe based on environment performance index (WHO 2016). According to the environmental monitoring database for the world leading megacities encompassing 100 countries published in April 2018 by WHO for the period of 2011 and 2016 Delhi ranks high in the list of PM10 pollution (WHO 2018). In NCT Delhi, for the last several years, PM 2.5 concentration is recorded very high and it is far beyond the tolerable limits as per National Ambient Air Quality Standards (NAAQS) (Mohan and Kandya 2007; Kumar et al. 2017; CPCB 2015). This high air pollution intensity causes significant public health problems (Heal et al. 2012; Dholakia et al. 2013) particularly shortness of breath, chronic respiratory disorders, pneumonia, acute asthma etc. (Rizwan et al. 2013). Due to the public health threats, in 2017, the Indian Council of Medical Research (ICMR) has declared community health emergency for the National Capital Region (NCR) of Delhi (Chowdhury et al. 2019). WHO (2014) reported that it is one of the chief reasons behind premature deaths in India. According to the study executed by India State-Level Disease Burden Initiative Collaborators (Dandona et al. 2017) and ICMR, PHFI & IHME (2017), in India, one out of every eight deaths in 2017 is associated with air pollution and is the second major threat causative to infection load after undernourishment in 2016. Therefore proficient air quality mapping and analysis at city scale could be an important means for understanding air quality state and formulating efficient policy for combating the situation.

Mass scale health problems due to air pollution also imposes considerable burden to the national economy, particularly for the developing countries where government is the foremost contributor of the health care facilities (WHO 2006). As per the estimation of the World Bank (World Bank 2016; Lim et al. 2012) welfare expenditure is equivalent to about 8% of national GDP in the developing countries. In order to minimize the health burden due to air pollution the Central government and the government of NCT Delhi, have imposed several regulation measures since long as per international guidelines. For instance, CPCB ENVIS (2012) identified 17 categories of highly polluting industries with restricted operation within the jurisdiction of the NCT Delhi; implementation of strict emission standard for vehicles, renovating complete municipal transportation to CNG fuel, converting coal-based power plants to natural gas (CPCB 2011), ban on entrance of weighty vehicles during peak hours, odd-even car trial system (Kumar et al. 2017) and many more. In spite of these efforts, air pollution level is not reduced considerably in Delhi. However, efficacy of these policy interventions has generated lots of questions for achieving success. Therefore, unless effective counter measures are taken and implemented, ambient air quality will not be restored.

COVID-19 is a highly contagious disease firstly identified in Wuhan, Central China in December 2019. Up to March 23 globally, over 14,000 people have died, and more than 334,000 have been infected by COVID-19 (WHO 2020). The death toll is reached to 200000 as on 26.04.2020 over the world. Due to the contagion of COVID-19, a nationwide lockdown is imposed in India from March 24th for three weeks up to 14th of April and later extended up to 3rd May. By this nationwide lockdown almost all industrial activities and mass transportation have been prohibited. As a result, the pollution level in 88 cities across the country drastically reduced down (Sharma et al 2020) only after four days of commencing lockdown event according to the official data from the CPCB. Therefore lockdown presumes to be the effective alternative measure to be implemented for controlling air pollution and the present work intended to explore the degree of air quality change during lockdown at spatial scale in the megacity Delhi.

In order to express the magnitude of air pollution of a region, Air Quality Index (AQI) often in addition is termed as Air Pollution Index (API) (Shenfeld 1970; Thom and Ott 1976; Ott and Thom 1976; Murena 2004) or in few cases Pollutant Standards Index (PSI) (Ott and Hunt 1976; USEPA 1994) are commonly in use. Green Index (GI) (Green 1966), Fenstock Air Quality Index (FAQI) (Fenstock 1969), Ontario Air Pollution Index (OAPI) (Shenfeld 1970), Most Undesirable Respirable Contaminants Index (MURC) (taken from Ott 1978) and Oak Ridge Air Quality Index (ORAQI) (Babcock and Nagda 1972) are some of the earlier methods to appraise the air quality in built-up areas. In 1976, the USEPA has launched Pollutant Standards Index (PSI) in order evaluate air quality incorporating five major pollutants (PM_{10}, O_3, SO_2, NO_2 and CO). However, PSI has excluded several other pollutants, a few of which possibly harmful for persons having respiratory trouble (Radojevic and Hassan 1999; Qian et al. 2004). In this course, Integral Air Pollution Index (IAPI) has been developed particularly for the metropolis of Russia (Bezuglaya et al. 1993). Later on in 1999 PSI was renamed as Air Quality Index (AQI) by the US EPA (1999) incorporating few other pollutants parameters. Subsequently, several other indices have come into force like Aggregate Air Quality Index, (AQI) (Kyrkilis et al. 2007), Common Air Quality Index, (CAQI) (van den Elshout et al. 2008), New Air Quality Index, NAQI (Bishoi et al. in 2009), Pollution index, PI (Cannistraro et al. 2009), Aggregate Risk Index, ARI (Sciard et al. 2011) etc. AQI prediction based on Fuzzy aggregation (Mandal et al. 2012), coupled Artificial Neural Network (ANN) and Principal Component Analysis (PCA) (Kumar and Goyal 2013) are some of the recent development. However, among the commonly used air quality indices there is no unanimously accepted methodology does exist fit for all circumstances (Stieb et al. 2005; Maynard and Coster 1999). Of late technological advancement along with information technology collection and compilation real-time of site-specific air pollution data is in practice throughout the world. In India the attempt to quantify integrated air quality started much later only after 1984 in name of National Air Quality Monitoring Programme. Up to date only few handful studies (Agharkar 1982; Swami and Tyagi 1999; Gurjar et al. 2008; Beig et al. 2010a and 2010b etc.) have successfully attempted to quantify and report air quality for megacities of the country. However, eclipsing and ambiguity are frequent to many of the indices used in those studies and there is found considerable discrepancy among air quality professed by the indices and real air quality. In this direction, in place of additive and multiplicative indices developed earlier the CPCB (2014) have come up with a new revised National Air Quality Index (NAQI) derived from Maximum operator approach in an attempt to remove uncertainty and eclipsing. In this regard, the CPCB has also notified a fresh set of Indian National Air Quality Standards (INAQS) (http://www.cpcb.nic.in). In the present work NAQI is used for interim estimation of air quality of the megacity Delhi amidst the lockdown period.

Overall the significance and impacts of lockdown are still not well understood and likely to have significant role on restoration of air quality. Nationwide lockdown amid the COVID-19 pandemic provides a unique opportunity to work in this direction. Consequently, quantitative appraisal of air pollution desires to be carried out so as to understand the upshot of lockdown measures on air quality particularly when there is a need to implement such alternative control actions. The present study is an effort in this direction to assess the usefulness of the lockdown as an alternative strategy for diminution of air pollution level in NCT Delhi. The objectives of the present study is (i) to compare the atmospheric pollutant concentrations in Delhi during the pre and during lockdown periods, (ii) to quantify the integrated air quality due to the implementation of lockdown regulation during Lockdown period and (iii) to unveil the level of major pollutant concentration in the past few years during the same window period. Focusing on the NCT of Delhi, the study is thought to be a conceivable addition to the scientific community and policy makers not only to assess the impacts of lockdown on air quality, but also its efficiency as an easy alternative action plans for upgrading in air quality of NCT Delhi with public involvement in upcoming years.

2.0 The study area

The present study has focused on Delhi as the administrative and second financial capital of India. The National Capital Territory (NCT) Delhi is the second leading megacity in the world (The World’s Cities in 2018, Data Booklet, United Nations, 2018) and the largest urban agglomeration in India with 1.68 crore residents exhibiting a decadal growth rate of 21% and density of 11297person/km^2 (Census 2011; http://census2011.co.in). NCT Delhi occupies an area about 1485 km^2 which lies between geo-coordinate 28°24’17’’N to 28053’00”N and 76°50’24”E to 77°20’37”E (Figure 1). Geographically the megacity is located within the Indo-Gangetic alluvial plain region with an altitude range of 198 m to 220m above msl and surrounded by lesser Himalaya in the north, peninsular region in the south, hilly region in the east and Great Indian Desert in the west (Sahay 2018; Yadav et al. 2017). NCT Delhi has dual status as a city and a state incorporating Kanjhawla Block, MehrauliBlock,Najafgarh Block and Shahadra Block. The land-locked mega city is bordered with adjacent cities like Sonipat (North-West), Bahadurgarh, Jhajjar and Rohtak (West), Gurgaon and Manesar (South), Faridabad (South–East), and Noida and Ghaziabad (East) and are incorporated into the National Capital Region (NCR).

The city experiences semi-arid climate having five major seasons: Summer (Mar-May), Monsoon (Jun-Sept), short Post-monsoon (Oct-Nov), Winter (Dec-Feb) and Pre-monsoon (March-May). Temperature ranges between 4°C to 10°C in winter and 42° C to 48°C in summer (Kumar et al. 2017). More than 80% of the total annual precipitation occurs during the monsoon months (Perrino et al. 2011). A momentous proportion (about 90%) of the population working in NCT Delhi residing in urban areas, which is much higher than the nationwide average of 31.16% (SAD 2014). About 6.93 million registered vehicles was on roads during 2011 in Delhi which is the highest in the country and it is further expected to increase as much as 25.6 million by 2030 (Kumar et al. 2017). NCT Delhi's existing road length is 33198 km with about 864 km signalized road and 418 blinkers traffic intersections (NCR 2013; GoD 2016).

Table 1. Expected growth of key indicators in NCT Delhi during 2015 and 2030

Aspect	**Annual Growth**	**Expected change between 2015-2030**		**Aspect**	**Annual Growth**	**Expected change between 2015-2030**
Population	+2.8%/yr	+50%		Energy intensity	-3.6%/yr	-40%
GDP per capita	+5%/yr	+110%		Natural gas	+7.3%/yr	+190%
GDP	+8%/yr	+200%		Liquid fuels	+2.9%/yr	+80%
Transport demand	+8%/yr	+200%		Coal, Biomass	0%	0%

Source: *Amann et al.(2017)*

Currently a total of 34 air monitoring stations are in operation in NCT Delhi with a capacity to monitor and record pollutants. The locations of the air quality monitoring stations are indicated in Figure 1.

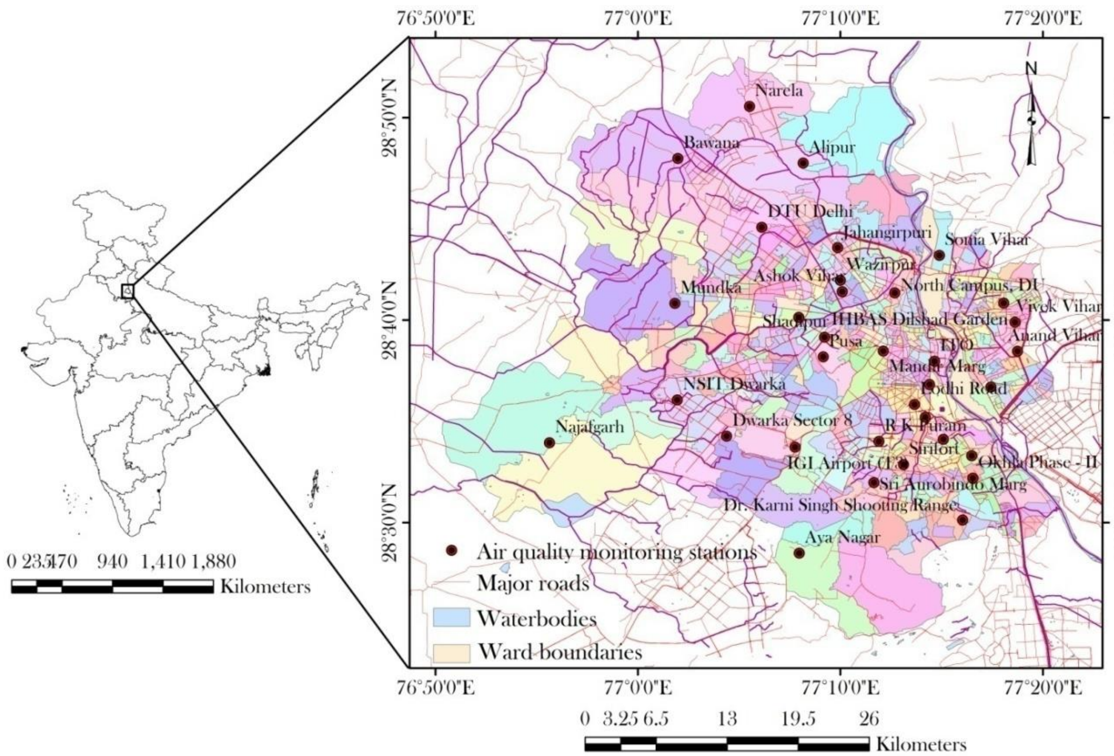


Figure 1. Reference map of the NCT-Delhi showing administrative units and the air pollution monitoring stations used for the present analysis

3.0 Air pollution reduction policies across the country and in NCT Delhi

To cope up with the ever rising pollution beyond permissible limit in the NCT of Delhi, different policy interventions have come up time to time. In this direction the MoEFCC (http://moef.nic.in/) of the Central Government works as the nodal agency in co-ordination with the UNEP for the preclusion & manage of pollution and protection of environment. Along with MoEFCC, the CPCB, (https://www.cpcb.nic.in/) works as a statutory organization which functions under the Air Prevention and Control of Pollution Act 1981 (amended 1987). CPCB also extends technical support to the MoEFCC under the proviso of the Environment Protection Act, 1986. The Delhi Pollution Control Board (DPCB) is another organization functions at the state. 4 landmark strategy to protect environment in India are- The Air (Prevention & Control of

Pollution) Act(1981); Environment (Protection) Act(1986); The Motor Vehicles Act(1988); The Public Liability Insurance Act (1991); The National Environmental Tribunal Act(1995); National Environment Policy(2006). Further, in NCT Delhi there are a range of vehicle emission control strategies executed by the government over the decades. These include beginning of unleaded petrol (1998), catalytic converter for fare cars (1995), lessening of sulfur in diesel (2000) and cutback of benzene content in fuels (2000); CNG for commercial transport vehicles (2001) (Rizwan et al. 2017; Gulia et al. 2018). Apart from these in NCT Delhi first Industrial Policy has initiated in 1982 and afterward, a second Industrial policy (2010–2021) has introduced by the Department of Industries, Government of Delhi (Rizwan et al. 2017). In January 2016, the GoI has implemented Euro IV emission standard for petrol and Euro VI norm for diesel. The BS-VI standard will be put into practice for new and existing vehicles by April 2020 and 2021 respectively (Ministry of Road Transport & Highways, GoI, 2016: A draft notification https://morth.nic.in/). The GoI also targeted to develop 6 to 7 million Plug-in electric and hybrid vehicles (PEVs) on roads by 2020 (Sheppard et al. 2016). The National Bio-fuels Policy have aimed to convert at least 20% of the diesel and petrol (gasoline) based engines into bio-diesel and bio-ethanol by 2017 (Purohit and Dhar 2015). The National Clean Air Programme (NCAP), 2019 aimed at reducing PMby 30% nationwide (MoEFC, 2019). Besides the government efforts, there are several other institutions that work parallely to reduce air pollution in the megacity like-Centre for Science and Environment, CEC (https://www.cseindia.org/); The Energy and Resources Institute, TERI (https://www.teriin.org/); the Indian Association for Air Pollution Control (Delhi Chapter) (http://www.iaapc.in/) etc.

4.0 Materials and Methods

4.1 Materials used

In order to assess air quality status of NCT Delhi during the lockdown period, data form thirty four air quality monitoring stations covering different regions of the megacity has been taken into consideration (Figure 1).The monitoring organization for these air quality monitoring stations includes CPCB (manual ambient air quality monitoring, MAAQM); CPCB (continuous ambient air quality monitoring, CAAQM); DPCC (Delhi Pollution Control Committee) and SAFAR (System of Air Quality and Weather Forecasting and Research), IITM (Indian Institute of Tropical Meteorology), Pune. The daily or hourly concentration of seven air pollutants including Particulate Matters ($PM_{2.5}$ and PM_{10}), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Ozone (O_3) and Ammonia (NH_3) have been obtained from the CPCB online portal for air quality data dissemination (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing). CPCB provides data quality assurance or quality control (QA/QC) programs by defining rigorous protocols for the sampling, analysis and calibration.

4.2 Methodology

The AQI is usually based on pollutants criteria where the deliberation of an individual pollutant is transformed into a sole index using appropriate aggregation method (Ott 1978). Conventionally, calculation of the AQI was supposed as a maximum sub-index approach using five criteria pollutants (i.e. PM_{10} and $PM_{2.5}$, SO_2, NO_2 and CO) (Sharma 2001). In recent times, IITM, Pune has come up with a new AQI (IITM-AQI) that provides sub-index additionally for O_3 (Beig et al. 2010). IITM-AQI has portrayed air quality in five point scale namely- very unhealthy, very poor, poor, moderate and good. The revised Indian National Air Quality Standards (INAQS) (CPCB 2015) has taken twelve parameters [namely, Particulate Matter (PM) of >10 microns size (PM10), Particulate Matter (PM) of >2.5 microns size ($PM_{2.5}$), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Ozone (O_3), Lead (Pb), Ammonia (NH_3), Benzo(a)Pyrene (BaP), Benzene (C_6H_6), Arsenic (As) and Nickel (Ni)] for developing the same. Out of the 12 parameters, only four parameters have annual standard and rest of the first eight parameters (Table 3) have short-term (i.e. 1/8/24 hrs) and annual standards (except for O_3 and CO). In the present work, in order to investigate the possible impacts of unconventional policy intervention in form of lockdown on air pollution seven pollutant parameters (PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, CO and NH_3) have been analyzed individually and as an integrated index during-lockdown period and compared with the result of the same for pre-lockdown period.

Table 2 Revised Indian National Air Quality Standards (INAQS)

Pollutants	**Time weighted average**	**Industrial, residential and other area**	**Economically sensitive area (Notified by GoI)**
		Concentration of ambient air	
PM_{10} (μg/m^3)	24 hrs	100	100
$PM_{2.5}$ (μg/m^3)	24 hrs	60	60
SO_2 (μg/m^3)	24 hrs	80	80
NO_2 (μg/m^3)	24 hrs	80	80
O_3 (μg/m^3)	1 hrs	180	180
CO (mg/m^3)	8 hrs 1 hrs	02 04	02 04
NH_3 (μg/m^3)	24 hrs	400	400

Source:*CPCB 2015*

The selection of the 7 parameters is primarily based on the objectives outlined earlier, period, monitoring regularity and data accessibility. Furthermore, in the present scheme, six National Air Quality Index (NAQI) categories (CPCB 2015) (Table 3) is used to assess the expected health exposure (also called- Health Breakpoints) in different quality classes as approved by the NAQS.

Table 3. National AQI classes, range, health impacts and health breakpoints for the seven pollutants (Scale: 0-500)

AQI Class (Range)	Health Impact	PM_{10} 24 hrs (µg/m³)	$PM_{2.5}$ 24 hrs (µg/m³)	SO_2 24 hrs (µg/m³)	NO_2 24hrs (µg/m³)	O_3 8hrs (µg/m³)	CO 8 hrs (mg/m³)	NH3 24 hrs (µg/m³)
		Concentration Range						
Good (0–50)	Minimal Impact	0–50	0–30	0–40	0–40	0–50	0–1	0–200
Satisfactory (51–100)	Minor breathing discomfort to sensitive people	51–100	31–60	41–80	41–80	51–100	1.1 - 2	201–400
Moderately polluted (101–200)	Breathing discomfort to the people with lung,	101–250	61–90	81–380	81–180	101–168	2.1–10	401–800
Poor (201–300)	Breathing discomfort to people on prolonged exposure	251–350	91–120	381–800	181–280	169–208	10–17	801–1200
Very poor (301–400)	Respiratory illness to the people on prolonged exposure	351–430	121–250	801–1600	281–400	209–748*	17–34	1200–1800
Severe (401–500)	Respiratory illness to the people on prolonged exposure	>430	>250	>1600	>400	>748	>34	>1800

The sub-indices for entity pollutants at a monitoring station has been calculated based on 24-hrs mean (8hrs for CO and O_3) data and health breakpoint range (CPCB 2015). However, all the seven pollutants may possibly not monitor at all the stations simultaneously. Largely NAQI is measured if data does exist for at least three pollutants and must include $PM_{2.5}$ or PM_{10} within the three. Otherwise, data are regarded as inadequate for NAQI calculation. Likewise, at least 16 hours' data is required for sub-index calculation and air quality of a pollutant is the sub-index value of that pollutant. Currently CPCB also provide real time NAQI rooted in a web-based system. The web-based system is programmed for the continuously monitoring stations whereas for manual monitoring stations an NAQI calculator has developed to obtain the NAQI value. Calculation procedure of NAQI is briefly outlined following CPCB (2015).

Principally two steps are implicated to formulate an NAQI-

First: Formulation of sub-indices (for each individual pollutant) and

Second: Combination of sub-indices to obtain the NAQI.

Formulation of sub-indices (I_1, I_2, I_3...., In) for n pollutants (X_1, X_2, X_3...., X_n) are measured using sub-index functions. Every sub-index corresponds to an association between pollutant concentration and health impact.

Scientifically-

$$I_i = f\left(X_i\right),\ i = 1,\ 2, ..., n \qquad \text{[eq. 1]}$$

Combination of sub-indices to obtain the NAQI is processed with some numerical function (ascribed underneath) to get the overall index (I) called NAQI.

$$I = F\left(I_1, I_2, ..., I_n\right) \qquad \text{[eq. 2]}$$

Combination of sub-indices is simply mathematical summation or multiplication or a maximum operator.

Sub-indices (Step I):

Sub-index function symbolizes the relationship among pollutant concentration X_i and subsequent sub-index I_i. This portrays ecological upshot as the concentration of a pollutant alter. It may typically take different form like linear, non-linear or segmented linear.

Usually, the I-X relationship is presented as below:

$$I = \alpha X + \beta \qquad \text{[eq. 3]}$$

Where, α is slope of the line, β implies intercept at X=0.

Equation for the sub-index (Ii) for a known pollutant concentration (Cp) rooted in linear segmented principle is measured as:

$$I_i = \left[\left\{ \left(I_{HI} - I_{LO} \right) / \left(B_{HI} - B_{LO} \right) \right\} * \left(C_p - B_{LO} \right) \right] + I_{LO} \qquad \text{[eq. 4]}$$

Where, BHI refers to Breakpoint concentration ≥ known concentration; BLO stands for Breakpoint concentration ≤ known concentration; IHI means AQI value equivalent to BHI; ILO means AQI value equivalent to BLO and Cp indicates Pollutant concentration.

Combination of sub-indices (Step II):

After calculating sub-indices, they are combined often in a weighted additive form, non-linear aggregation form, root-mean-square form or min or max operator form

Weighted Additive form:

$$I = Aggregated\ Index = \Sigma w_i I_i \ \left(For\ i = 1,\ \ldots..,n \right) \qquad \text{[eq. 5]}$$

Where, Σw_iequals 1; I_i refers to sub-index for pollutant I; n is number of pollutant variables and w_i means weight of the pollutant.

Non-Linear Aggregation Form: Root-Sum-Power Form

$$I = Aggregated\ index = \left[\Sigma I_i{}^{p} \right]^{(1/p)} \qquad \text{[eq. 6]}$$

Where, p is the positive real number >1.

Root-Mean-Square Form:

$$I = Aggregated\ Index = [1/k \ \left(I_1{}^2 + I_2{}^2 + \ \ldots\ldots \ + I_k{}^2 \right]^{0.5} \qquad \text{[eq. 7]}$$

Min or Max Operator form (Ott 1978):

$$I = Min\ or\ Max\ \left(I_1,\ I_2,\ I_3,\ ...,\ I_n\right) \qquad \text{[eq. 8]}$$

5.0 Results

5.1 Changes in concentrations of major pollutants for the pre-lockdown and during-lockdown period

After declaration of three weeks of lockdown starting from 24th of March, 2020, pollution of the megacity Delhi has witnessed substantial diminution of the pollutants (Figure 2 and Table 4). Especially, during the study period PM_{10}, $PM_{2.5}$, NO_2 and CO concentration have shown significant declining trends (Figure 2a, 2b, 2d, 2e). Averaged concentrations of PM_{10} and $PM_{2.5}$ have reduced by about -51.84% and -53.11% respectively. For the traffic and industrial background stations the magnitude of decline of $PM_{2.5}$ is as high as about -62.61% and -59.74% respectively. Other pollutants that have shown considerable variation between pre and during lockdown are NO_2 (-52.68%) and CO (-30.35%). However, for SO_2 (-17.97%), and NH_3 (-12.33%) the reduction have counted very low in comparison to the others and the trend also not evidencing prominent definite trend (Figure 2c, 2g). 8 hrs average daily maximum concentration of O_3 (+0.78% overall variation) in the study period shows negligible increase with insignificant rising trend (Figure 2f). In this case, considering that April to August in Indian subcontinent is the usual high O_3 period (Gorai*et al.* 2017) due to the increase in insolation is quite feasible. Important to note that, the concentration of O_3 increases especially in the industrial and transport dominated locations (>10% increase) (Table 4). The cause for this increase in O_3 concentration, especially in the industrial and transport dominated areas is the decrease of nitrogen oxide (NO) which leads to lowering of the O_3 consumption (titration, $NO+O_3=NO_2+O_2$) and causes an increase in O_3 concentrations. The overall air quality reduction as evident from NAQI value for past-lockdown and during-lockdown (Figure 4h) counted about -60.95% with the net reduction counting -113.36 (Table 2). For the transportation and industrial location the air quality have improved up to -59.45% (net reduction in NAQI: -128.0) and -52.92 (Net reduction in NAQI: -103.93) respectively. This is a clear indication that a substantial improvement of the air quality could be expected if strict implementation of air quality control measures like lockdown is put into practice.

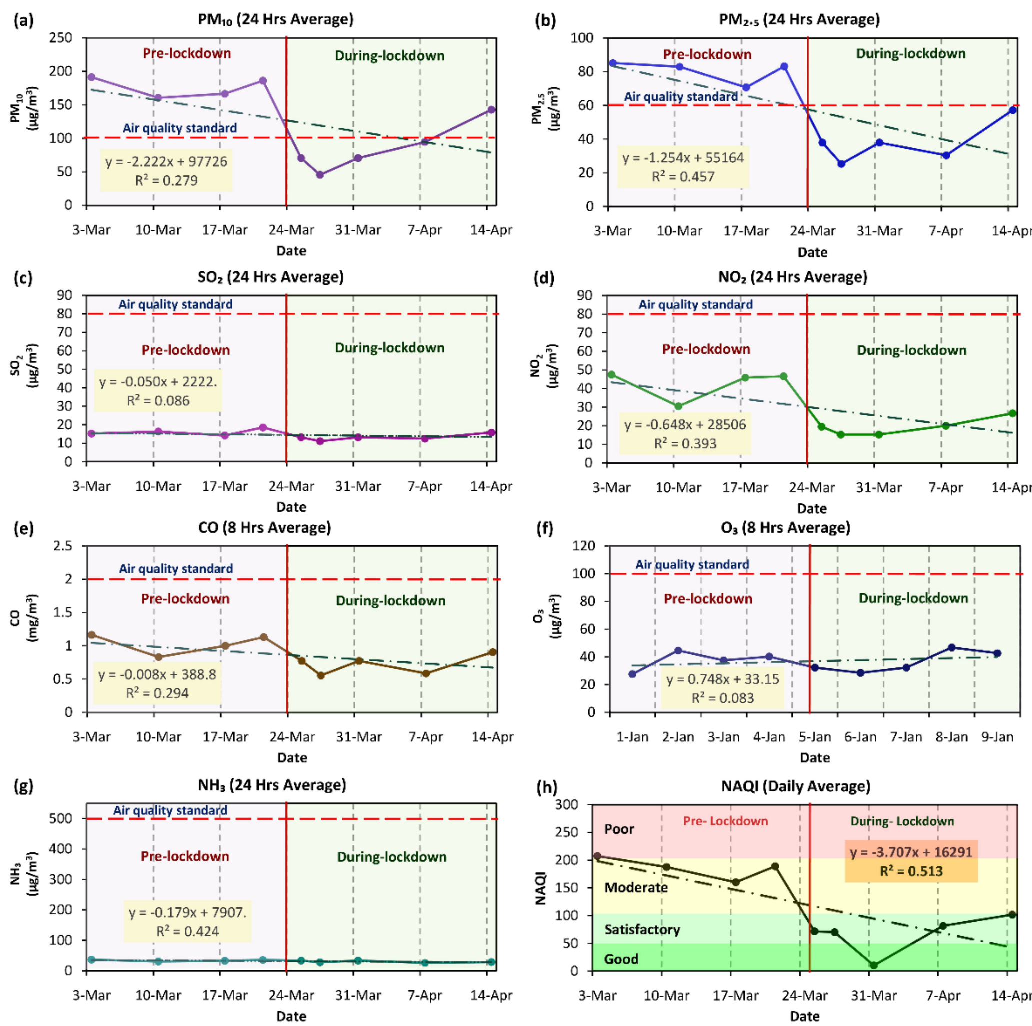


Figure 2. Trend of 24 hrs average concentrations of (a) PM_{10}, (b) $PM_{2.5}$, (c) SO_2, (d) NO_2, (g) NH_3& (h) NAQI and 8 hrs average daily maxima of (e) CO & (f) O_3 between 3rd March and 14th April (lockdown started on 24th March) in NCT Delhi, India

Table 4: Mean concentrations and variation of criterion pollutants during 2nd March to 21st March (before the lockdown) and 25th March to 14th April (during the lockdown) in NCT Delhi, India

Type of station/ Pollutants	**Before lockdown**				**During lockdown**				**Overall variation**	
	NCT Delhi avg.	**Industrial locations avg.**	**Transport location avg.**	**Residential and other location avg.**	**NCT Delhi avg.**	**Industrial locations avg.**	**Transport location avg.**	**Residential and other location avg.**	**Net**	**%**
PM_{10}	176.07	190.74	195.77	160.48	84.79	91.25	90.11	76.48	-91.28	-51.85
$PM_{2.5}$	80.51	88.05	94.83	72.67	37.75	39.67	44.23	31.09	-42.76	-53.11
SO_2	16.08	15.48	14.56	14.17	13.19	14.07	12.53	11.20	-2.89	-17.97
NO_2	42.59	34.81	47.35	48.75	20.16	18.80	23.38	18.79	-22.44	-52.68
CO	1.03	1.33	1.13	1.01	0.72	1.04	0.71	0.64	-0.31	-30.35
O_3	34.05	26.37	35.07	37.36	34.32	31.00	38.87	37.97	0.27	0.78
NH_3	33.93	38.43	38.02	30.66	29.75	35.84	33.06	25.97	-4.18	-12.33
NAQI	185.99	196.38	215.29	174.78	72.64	92.45	87.29	79.8	-113.36	-60.95

5.2 Spatial pattern of National Air Quality Index (NAQI) for the pre-lockdown and during-lockdown period

Figure 3 depicts the pattern of variation in air quality during pre-lockdown and post-lockdown days between 3rd March and 14th April. As stated earlier the lockdown started on 24th of March and just after 1 day of the commencement of lockdown (i.e. 25th of March) there is significant improvement in the air quality (Figure 3e) in comparison to that of the pre-lockdown phase. As much as about 51% reduction of NAQI has been observed on the 4th day (i.e. 27th of March) of lock down (Figure 3f) in compare to the 3rd preceding day (i.e. 21st March) of the lockdown (Figure 3d). On an average there is about 43% decrease in NAQI during the 3 week lockdown period (from 24th of March to 14th of April) in comparison to the average NAQI during the first three week of March (from 3rd March to 21st March). About 54%, 49%, 43%, 37% and 31% reductions in NAQI are observed in Central, Eastern, Southern, Western and Northern regions of the NCT Delhi respectively. This diminution in NAQI is primarily associated with the alteration of prevailing pollutants, primarily PM_{10}, $PM_{2.5}$, NO_2 and CO discussed afterward. However, after two weeks of lockdown due to partial relaxation on necessary transportation and controlled industrial activity outside the COVID-19 infected areas results slight increase in NAQI on the 7th April and 14th April (Figure 3h and 3i). Moreover there is a partial restriction on power plants operating within the NCT Delhi region in particular and northern India in general (Sharma et al. 2020) in order to procure coal powered energy, an essential commodity during the lockdown period.

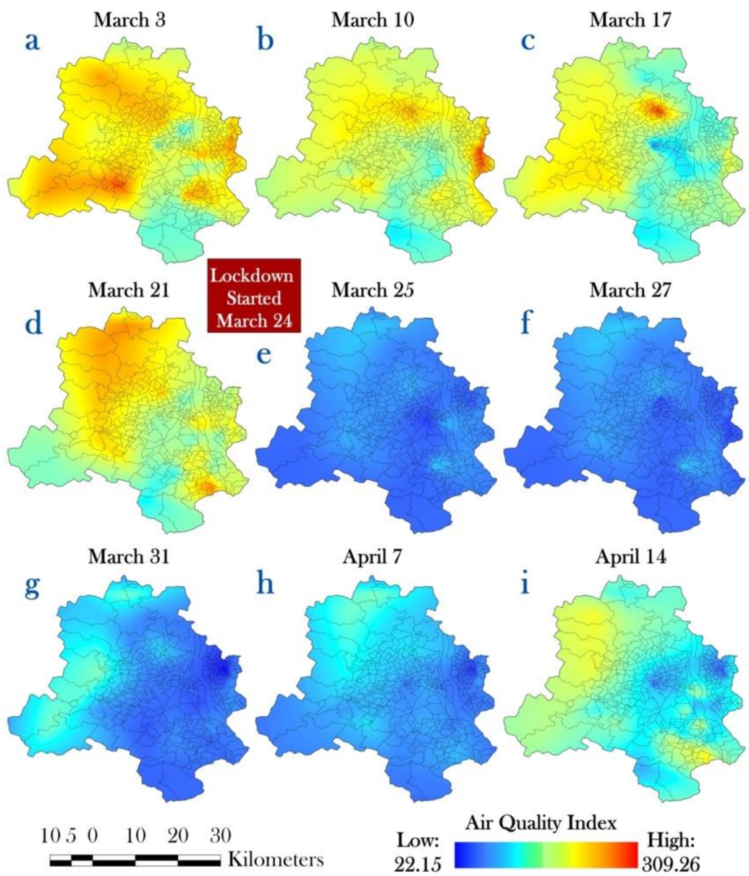


Figure 3. Change in NAQI in the NCT Delhi during 3rd March to 14th April 2020.

5.3 Spatial concentration pattern of major pollutants during lockdown and pre-lockdown phase

In order to minimize the movement and social contact of the people as it could be expected strict measures have been implemented to execute the lockdown. This has substantially reduced the movement of vehicles and the closing of industries, restaurants, shops, administrative centers and many others. This has caused drastic improvement of air quality particularly the primary dominated ones like PM_{10}, $PM_{2.5}$, NO_2 and CO (Figure 4 to Figure 7).

The most momentous dissimilarity is evident for PM_{10} (Figure 4) and $PM_{2.5}$ (Figure 5). This can be visible clearly from the spatial pattern of concentration of these two pollutants in different days of the pre-lockdown and during lockdown period. The main source of PM_{10} and $PM_{2.5}$ in the megacity Delhi is road traffic (about 30% of the annual mean). Industrial activity, construction works and dust re-suspension are the other sources. Notably, only within 4 days of the lockdown (from March 24th to March 27th) concentrations of the two pollutants have reduced below the permissible limit. As a pertinent amount of PM_{10} and $PM_{2.5}$ have a regional background-origin, mostly from traffic and industrial sources, slight relaxation of lockdown measures for necessary vehicles and localized industries beyond the red zone (i.e. COVID-19 infected area) after two weeks from 7th April might have influenced PM_{10} and $PM_{2.5}$ to increase slightly on 7th of April and 14th of April (Figure 4h, 4i and Figure 5h, 5i).

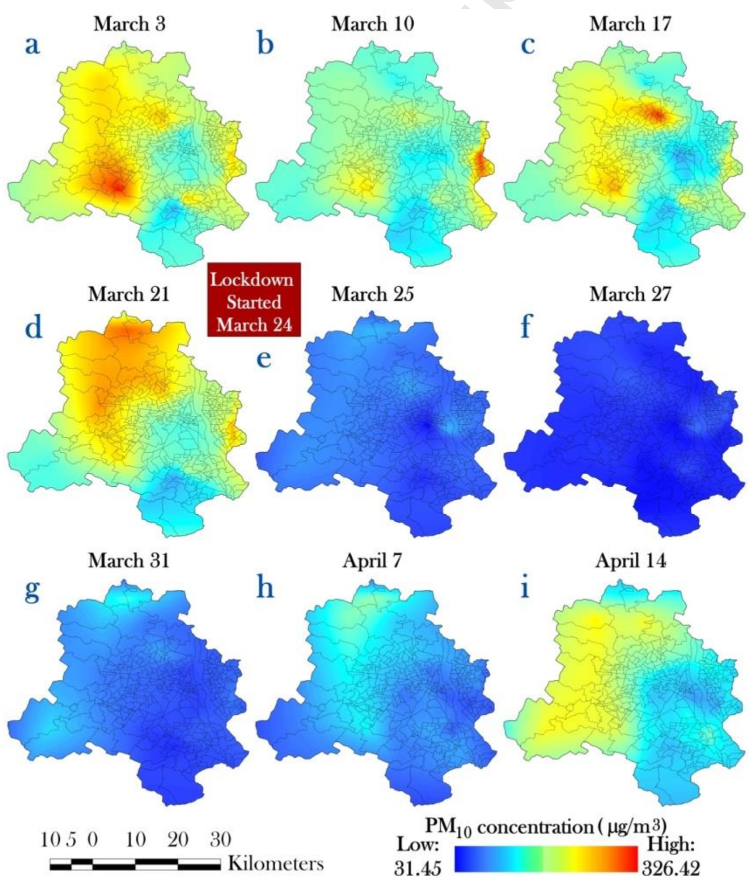


Figure 4. Status of PM_{10} concentration in pre-lockdown and during lockdown period over NCT Delhi

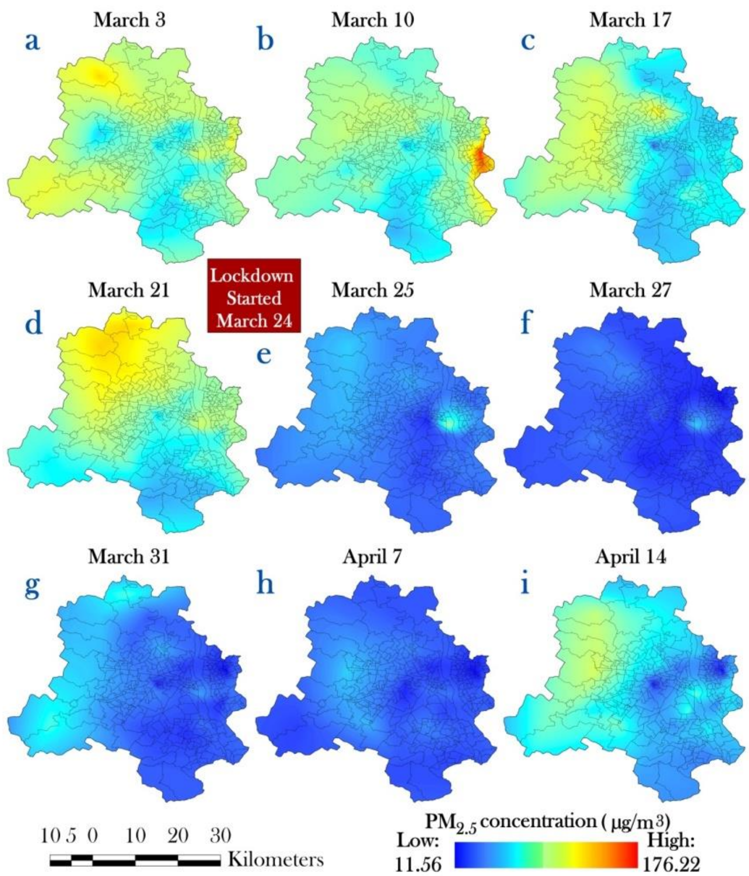


Figure 5. Status of $PM_{2.5}$ concentration in pre-lockdown and during lockdown period over NCT Delhi

Other important pollutants other than PM_{10} and $PM_{2.5}$ that have also shown significant reduction during the lockdown period are NO_2 and CO (Figure 6 and Figure 7). In urban areas NO_2 and CO is mainly emitted from combustion practice by and large from road traffic, particularly diesel and to a smaller degree gasoline, vehicles, manufacturing industry and power plants. During this lockdown period all of these sectors closed their functioning and thereby resulted in the decrease of pollutants like NO_2 and CO. In industrial locations average concentrations of NO_2 and CO have decreased as much as -45.99% and -21.43% respectively. Whereas, in traffic dominated locations the concentration of the two pollutants namelyNO_2 and CO have decreased as much as -50.61 and -36.84% respectively.

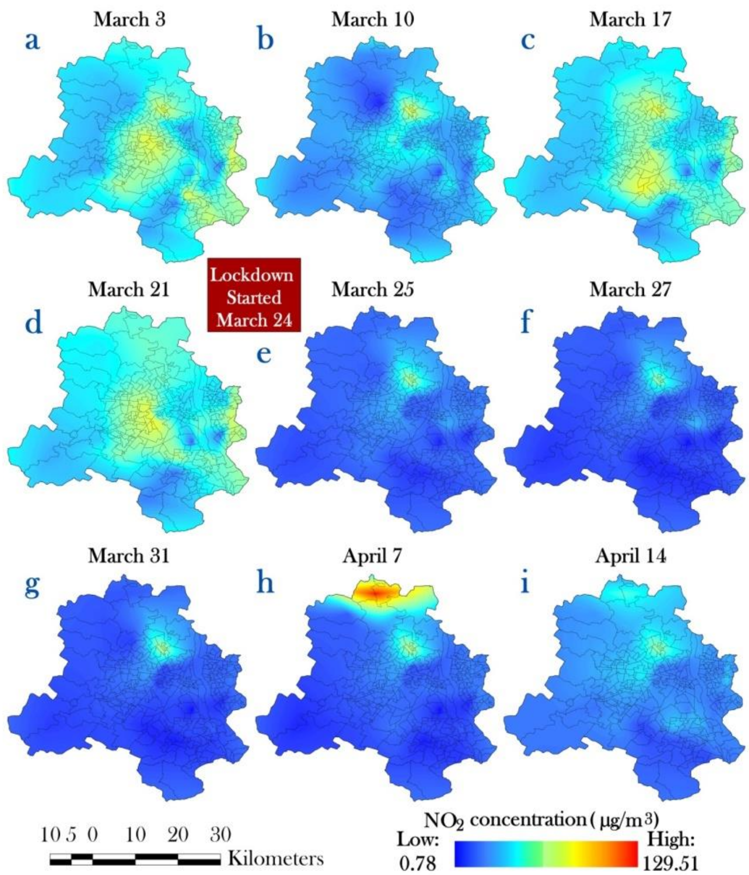


Figure 6: Status of NO_2 concentration in pre-lockdown and during lockdown period over NCT Delhi

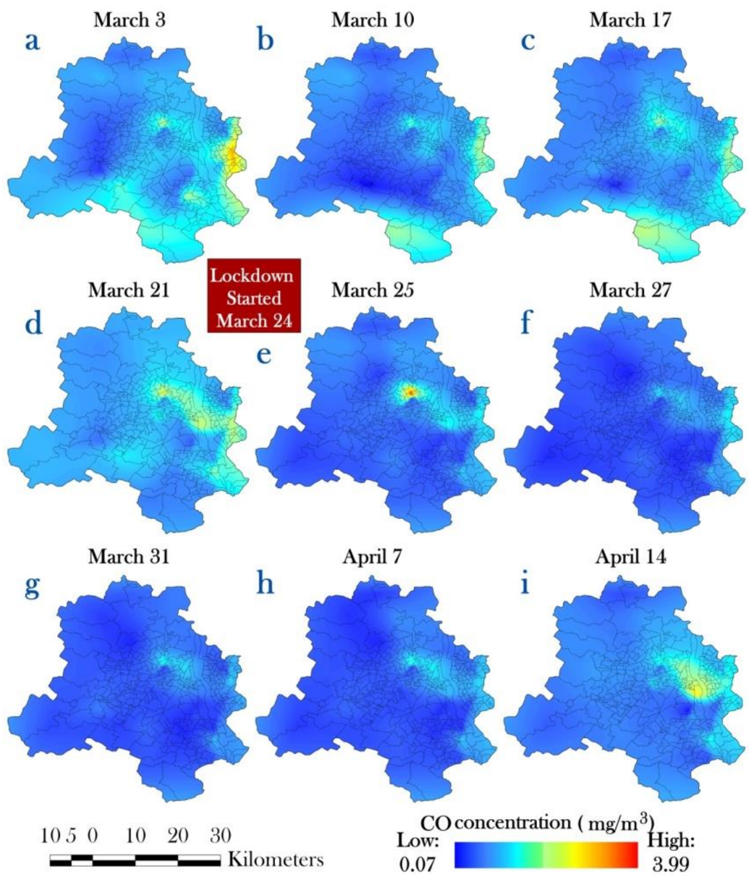


Figure 7: Status of CO concentration in pre-lockdown and during lockdown period over NCT Delhi

Finally, the concentration levels of O_3 noticeably increase during the lockdown period in the mega city Delhi (Figure 8) as a result of three potential collective reasons. First, the lessening of NOx (Appendix 1) as a result of lockdown may result urban O_3 to bump up, contrasting to the behavior at the rural area where largely NOx concentration is limited (Monks et al. 2015). Second: The dwindle of Nitrogen Oxide (NO) diminish the O3 utilization (titration, $NO+O_3 = NO_2+O_2$), and thereby causes an augment of O_3 concentrations. Third: Due to the natural increase of insolation and temperatures from March to August in the northern hemisphere as a result of the northward migration of sun lead to an increase in O_3 when the maximum O_3 is usually recorded (Gorai et al. 2017). However, the role of the climate is not taken into consideration in this study.

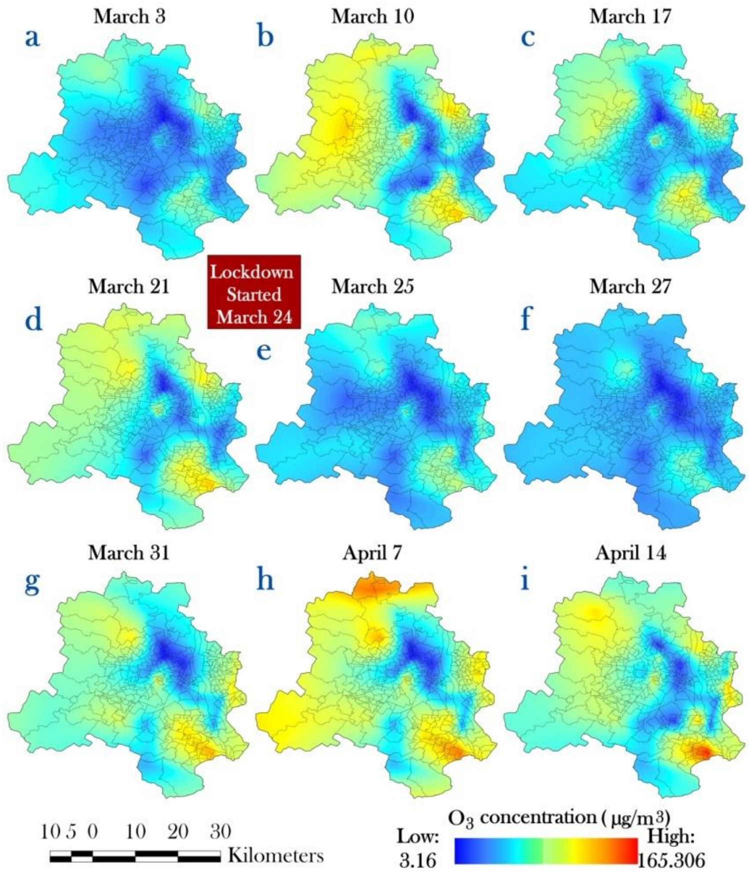


Figure 8. Status of O_3 concentration in pre-lockdown and during lockdown period over NCT Delhi

NCT Delhi is a low SO_2 city (Appendix 2) because of its interior location beyond the sea, since the majority of this pollutant starts off from shipping emissions (large cargo ships, cruises and ferries). For this reason concentration of SO_2 in NCT Delhi usually remains much below the acceptable limit (Figure 2c) and during this lockdown period SO_2 concentration has experienced slight decrease in comparison to the pre-lockdown phase. On the other hand it is a widely accepted fact that NH_3 originated from the non-agricultural sources is negligible (Sutton et al.

1995). Therefore, concentration of NH_3 is also much below the acceptable limit (Figure 2g). However, significant decrease in NH_3 concentration during the lockdown phase (Appendix 3) is due to the fact that petrol engine vehicles comprise a foremost cause of urban NH_3 (Kean et al. 2000; Kirchner et al. 2002) and during lockdown transportation activity strictly restricted.

5.4 Understanding the pattern of PM_{10} and $PM_{2.5}$ concentration over the last four years

In order to supplement the PM_{10} and $PM_{2.5}$ observations as highlighted in the earlier sub-sections, we have explored the 24hrs pattern of concentration of the two pollutants over the last four years (from 2017 to 2020) for the same two months window (i.e. March and April) (Figure 9). Continuous observations of PM_{10} and $PM_{2.5}$ concentrations are obtainable from the network of air quality monitoring stations maintained by the (CPCB 2016). Here we have used monitoring data at Neheru Nagar (site indicated in Figure 1) located in the central Delhi (Primarily residential location) as a representative station for the assessment.

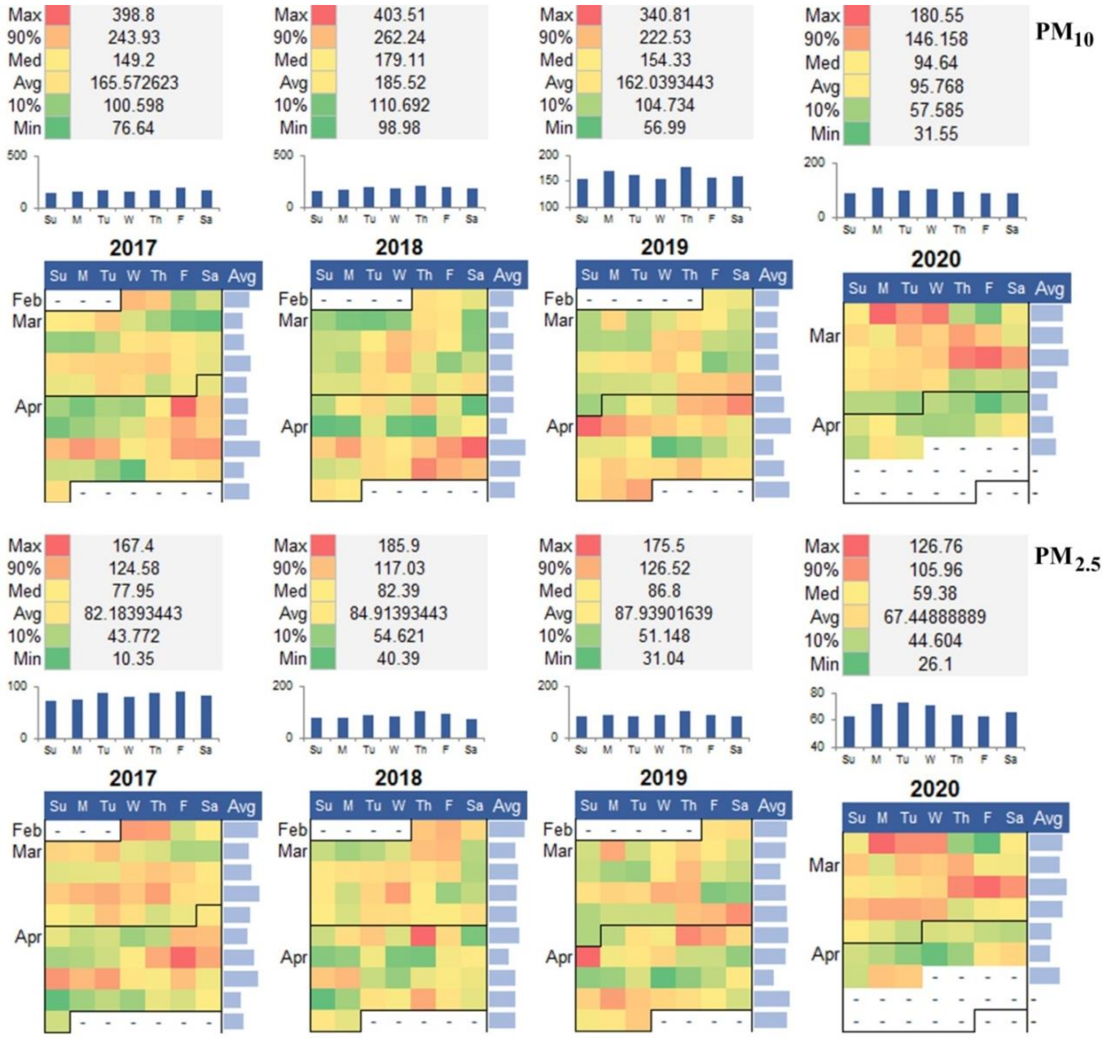


Figure 9. Daily (24hrs) profiles of the concentration of PM_{10} and $PM_{2.5}$ for the month of March and April during 2017 to 2020 in Neheru Nagar, NCT Delhi

Table 5 highlights the statistics concerning differences in the concentration of the two major pollutants during the lockdown period (i.e. from 24th of March to 14th of April, 2020) in compare to the previous three years (2017 to 2019) for the same period. It can be noticed that, over the previous three years during the period from March 24th to April 14th the concentration of PM_{10} was substantially higher counting 24 hrs average of about 168.32μg/m^3 (average of the year 2017, 2018 and 2019) in compare to 2020 average counting about 73.13μg/m^3 (about -56.55%

reduction). Likewise the $PM_{2.5}$ averaged concentrations for the preceding three years during the said months (2017 to 2019 year average 83.96µg/m^3) has decreased by about −32.62% during the year 2020 for the same period (56.57µg/m^3). In comparison to the last year (i.e. 2019) during the said time period the reduction of the two pollutants PM_{10} and $PM_{2.5}$ is as high as about -60.46% and -38.68% respectively. The maximum concentration of PM_{10} was during 2017 and that of $PM_{2.5}$ was during 2017 counting as high as 398.80µg/m^3 and 185.90µg/m^3 respectively. This has reduced to 110µg/m^3 (-72.42% maximum reduction) and 94µg/m^3 (-49.44% maximum reduction) respectively during 2020. The results again are a sign that implementation of lockdown may lead to substantial improvement of the air quality and could be put into practice as an alternative measure for pollution reduction.

Table 5. Basic statistics pertaining to 24 hrs average concentration of PM_{10} and $PM_{2.5}$ for the period of 24th March to 14th April during 2017 to 2020 in Neheru Nagar, NCT Delhi

Periods/Statistics	**24th of March to 14th of April**					**Variation (2020 and 2019)**		**Variation (2020 and avg. of 2017-2019)**	
	2017	2018	2019	Avg. of 2017-2019	2020	Net	%	Net	%
	PM_{10}								
Maximum	**398.8**	262.24	340.81	333.95	**110.00**	-230.81	-67.72	-223.95	-67.06
90%	218.08	211.43	263.99	231.17	101.67	-162.32	-61.49	-129.49	-56.02
Median	139.32	161.6	183.6	161.5	67.65	-115.95	-63.16	-93.86	-58.12
Average	157.49	162.53	**184.94**	**168.32**	**73.13**	-111.81	**-60.46**	-95.19	**-56.55**
10%	104.06	100.98	121.89	108.98	56.13	-65.77	-53.95	-52.85	-48.5
Minimum	86.26	98.98	96.2	93.81	31.55	-64.65	-67.2	-62.26	-66.37
Statistics	**$PM_{2.5}$**								
Maximum	167.4	**185.9**	175.5	176.27	**94**	-81.5	-46.44	-82.27	-46.67
90%	111.12	97.67	146.91	118.56	79.37	-67.53	-45.97	-39.19	-33.05
Median	73.7	80.84	83.45	79.33	52.21	-31.25	-37.44	-27.12	-34.19
Average	78.19	81.44	**92.24**	**83.96**	**56.57**	-35.68	**-38.68**	-27.39	**-32.62**
10%	45.42	48.37	58.8	50.86	39.47	-19.33	-32.88	-11.4	-22.4
Minimum	36.44	46.27	47.3	43.34	27.5	-19.8	-41.86	-15.84	-36.54

Aside from variation of pollutants concentration as assessed during the study period, concentrations of the pollutants may also fluctuate with the inter-seasonal disparity in the meteorological conditions. For example, during the monsoon season in Indian subcontinent (Mid June to September) the concentrations of PM_{10} and $PM_{2.5}$ remain much lower than that of the other seasons of a year. In late October the pollutants are augmented primarily due to the Dwali festival in India. From November onwards up to February winter season prevails in north India with subsequent development of stagnant weather condition and regular temperature inversions. This results in gathering of local and transported pollutants and augmentation of pollution level during the season. Therefore, in order to consider lockdown as an alternative policy measure once or twice a year in a long-distance race, examination of seasonal variation of pollutant concentration with respect to regional meteorological conditions is also necessary. Appendix 4, Appendix 5 and Appendix 6 may supplement this type of future research to the scientific community.

5.5 Co-relationship between the ambient air pollutants

The correlations between different air pollutants concentration in NCT Delhi during the study period (i.e. 3rd March to 14th of April) are shown in Figure 10. The daily (24hrs) average concentration of $PM_{2.5}$ is highly correlated with the daily average concentration of SO_2 ($r = 0.59$), NO_2 ($r = 0.35$) as well as 8hrs average concentration of CO ($r = 0.45$). Likewise, the daily average concentration of PM_{10} is also strongly correlated with the daily average concentration of SO_2 ($r = 0.47$), NO_2 ($r = 0.46$), NH_3 ($r = 0.30$) as well as 8hrs average concentration of CO ($r = 0.39$). This visibly implies that the augmented control of regional transport activity compared to local contributions in the mega city is the key responsible factor for the reduction of pollutants concentration (Sharma et al. 2020) as during the lockdown period the regional transportation has been restricted completely. Apart from these NO_2 is significantly correlated with CO (r = 0.57) and NH_3 (r = 0.42). There is no apparent correlation between O_3 & NO_2, O_3 & CO and O_3 & NH_3. This is also applicable in case of SO_2 & NH_3 and SO_2 & NO_2.

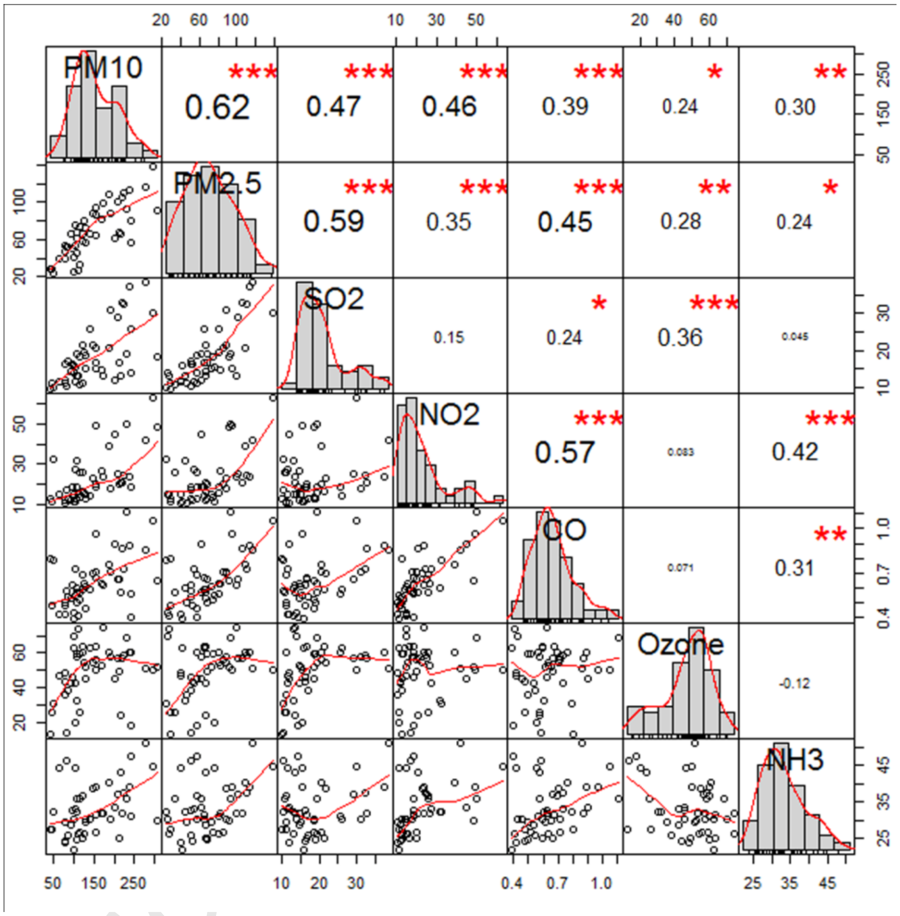


Figure 10. Co-relationships between different air pollutants

Note:*The correlations are expressed as Pearson's correlation coefficient, where *, ** and *** denote significant correlations at p<0.1, p<0.05 and p<0.01 (two-tailed) respectively.*

6.0 Discussion and conclusion

Mega cities of India are often listed within the world's topmost polluted cities that exceed the ambient air quality standard and therefore a comprehensive account of air quality improvement in the megacity Delhi has international relevance of its own. Lockdown measures in different parts of the world fortunately have brought opportunity to rationalize human impact on the environment. Therefore results of the present article may help to rethink how far we are responsible for our misery. It may also help to consider whether lockdown would be an unconventional measure for restoring the environment and providing a quality ecosystem to the urban people. Because in urban areas in aim of fulfilling the target economic growth often the sources of ecosystem services are ignored due to which people undergo health threat. The dreadful virus in one hand threatening our life and on the other hand the mechanism of the environmental restoration process is also going on. Hence, global concern for air pollution has lead to draw significant attention for analyzing air pollution in the course of the pandemic. In China about 30% NO_2 and 25% carbon emission have reduced in the lockdown state (Lauri 2020; Jeff 2020). Study conducted by Watts and Kommenda (2020) also reported a temporary cut of air pollutants amid industrial shutdown in this period. Cadotte (2020) also identified diminishing air pollutants over the major cities of the world where the outbreak of COVID 19 is very strong. Ogen (2020) found a strong linkage between the concentration of NO_2 and fatal outcome caused by COVID-19.Study of Coccia (2020) reveals that the acceleration and vast dispersion of COVID-19in north Italy province capitals has a high connection with air pollution particularly PM_{10} and Ozone. There are quite a few other study concerning changes in air quality during the lockdown amid SARS-CoV-2 epidemic with special reference to many areas throughout the globe listed in table 5.Therefore, the result outlined in the present swat is not an isolated one as improvement of air quality due to lockdown is also evident throughout the world.

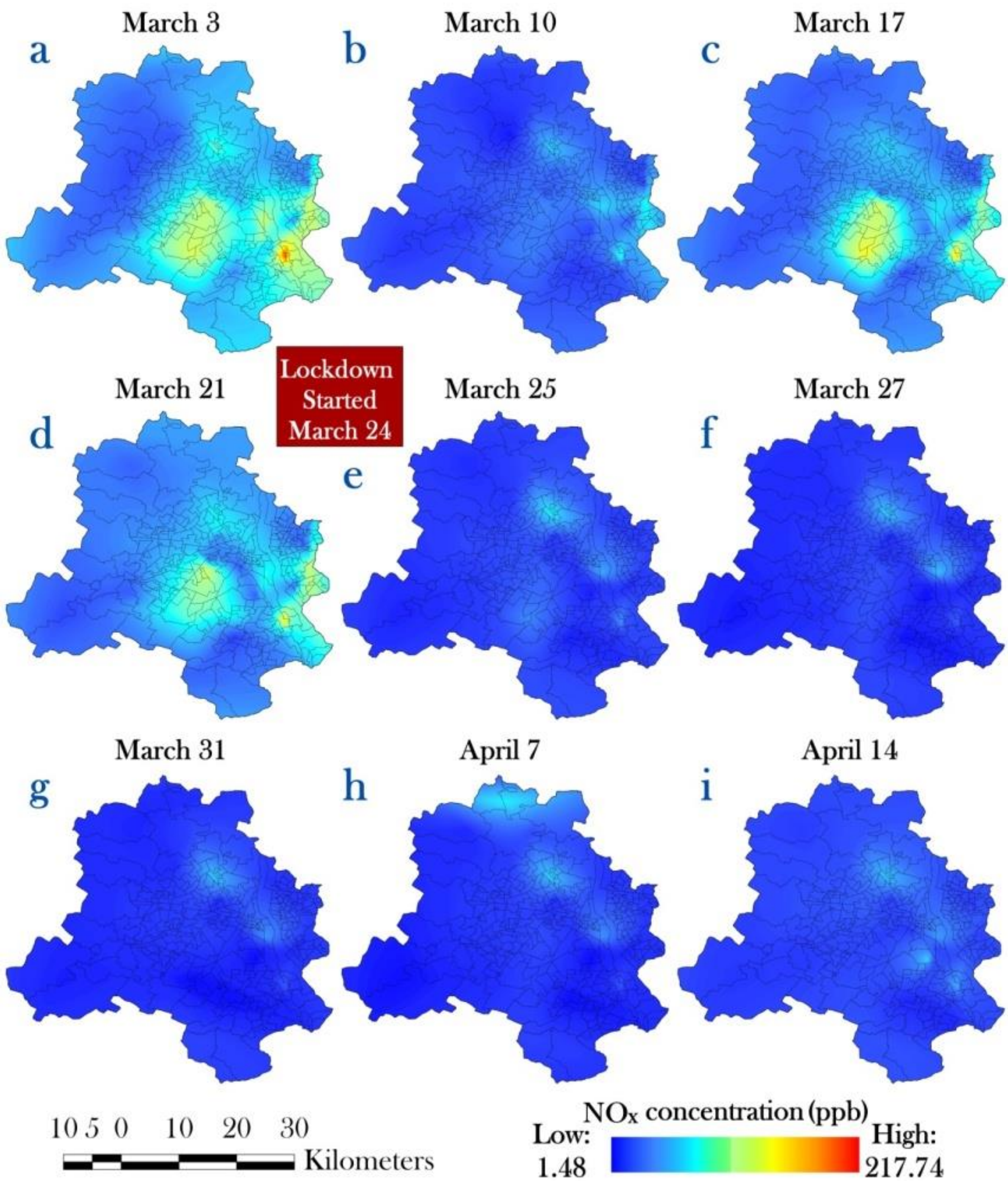
Table 5: Revisiting contemporary research related to air pollution amid COVID-19

Study region	**Issues addressed/ Major outcomes**	**References**
Cities across the globe	World's leading cities have experienced noticeable reduction of air pollution after lockdown	Saadat et. Al (2020); Muhammad et al (2020); Anjum (2020);Shrestha et al. (2020)
Eastern China	Reduction of primary emissions (like NOx) compensates enhanced secondary pollution (like O_3)during lockdown. Emissions reductions were overwhelmed by adverse meteorology.	- Huang et al. (2020) - Wang et al. (2020)
China	Regions with poor air quality are associated with higher mortality rate. Lockdown in some cities led to upgrading in air quality and lessened premature deaths. There is a considerable relationship between air pollution and COVID-19infection	- Isaifan (2020) - Wang and Su (2020), He et al. (2020) - Zhu and Xie (2020)
Major cities of India	Restricted human activities have lead up gradation of air quality and lessened allied excessive risk	Sharma et al. (2020)
New York, USA	Avg. temperature, minimum temperature and air quality were significantly associated with the COVID-19pandemic.	Bashir et al. (2020)
Barcelona, Spain	A significant reduction of most pollutants and increase in O_3 concentrations during lockdown	Tobías et al. (2020)
Italian province capitals	Accelerated transmissions of COVID-19are principally by means of "air pollution-to-human transmission" rather than "human-to-human transmission".	Coccia (2020)

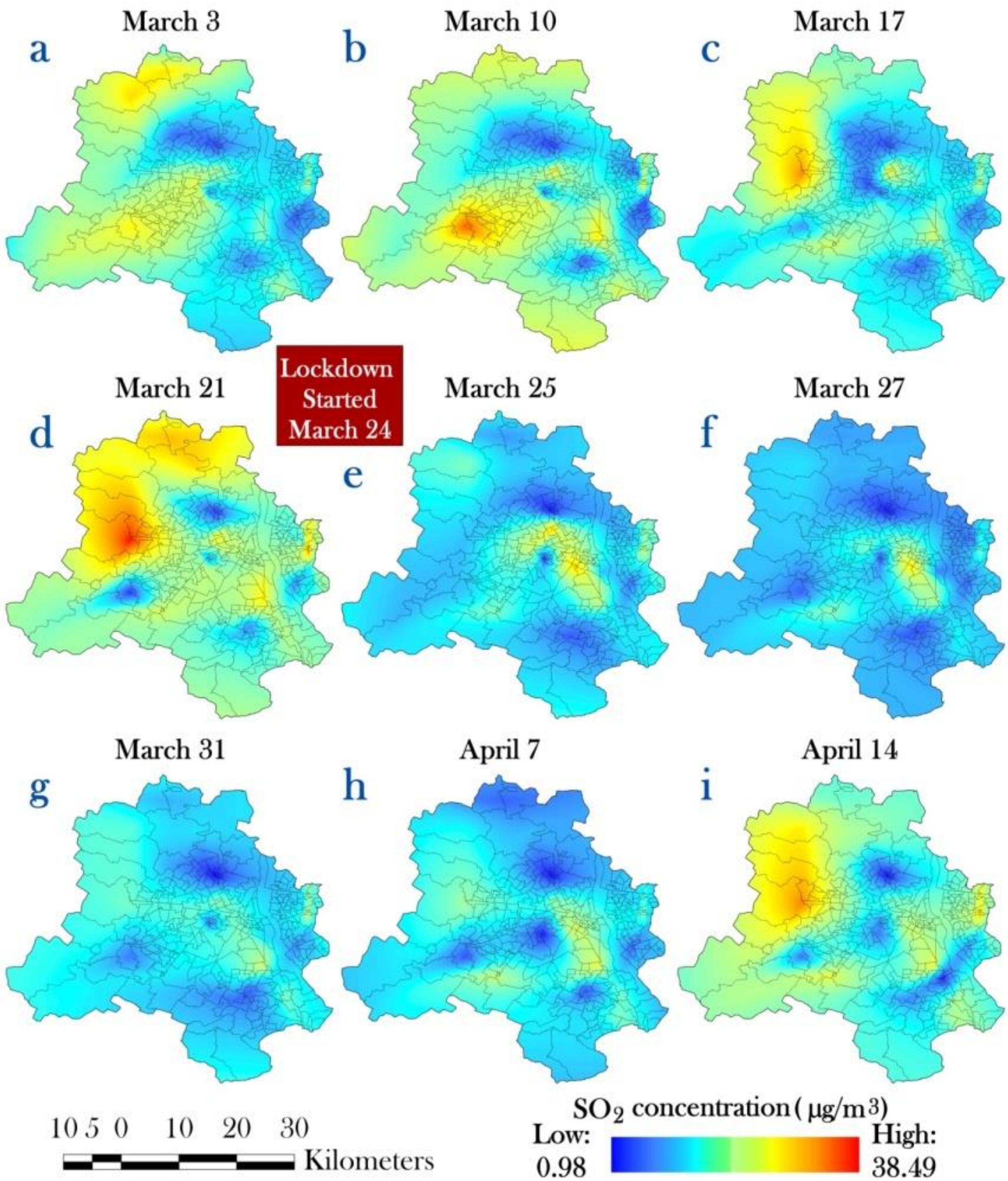
In the present article the effect of lockdown (since the third week of March 2020) imposed in order to restrict the rapid spread of COVID-19 pandemic in India on the air quality of the National Capital City Delhi has been assessed based on National Air Quality Index and concentration of seven major pollutants. Delhi is internationally recognized for its extreme pollution level. Among the selected pollutants PM_{10} and $PM_{2.5}$ have witnessed maximum reduction followed by NO_2, CO and NH_3. In compare to the past three year average concentration of PM_{10} and $PM_{2.5}$ has decreased by about -57% and -33% respectively. On a contrary there is a slight increase in O_3 concentration which is expected to be primarily due to the decrease in the concentration of NOx and particulate matter. Moreover, as anticipated, a considerable reduction in NAQI is observed during the window period of lockdown throughout the megacity. Just after 1 day of the commencement of lockdown (i.e. 25^{th} of March) there is about 40% improvement in air quality. Only on the 4^{th} day of lockdown (March 27^{th}) concentrations of PM_{10} and $PM_{2.5}$ have came within the permissible limit and there is about 51% reductions in NAQI. During the entire 3 week of lockdown there is an about 43% decrease in NAQI in compare to the first three week of March this year. About 54%, 49%, 43%, 37% and 31% reductions in NAQI are observed in Central, Eastern, Southern, Western and Northern regions of the NCT Delhi respectively. The region where energy footprint was high and guideline of lockdown has been obeying, the air quality improvement is found high there. Therefore study is thought to be a useful supplement to the regulatory authorities that may lead to rethinking of the existing regulatory plans and may provide assurance towards implementing strict alternative measures like short term (2 to 4 day) lockdown in aim to control air quality.

The study reported here is only highlighted the changes in air quality during the lockdown period. However, in order to implement short term (2-4 day) lockdown as an alternative policy measure for pollution reduction and its vis-à-vis effect on economy need to be study rigorously. Because cost effectiveness will be one of the key issue to the policy-makers while deciding such control measures. Moreover, with inter-seasonal disparity in the meteorological condition, concentrations of pollutants significantly differ in a region. Therefore, to facilitate fruitful implementation of this type of measures once or twice a year in a long-distance race in-depth analysis of the seasonal change in air quality in relation to regional meteorological condition is also required to be studied.

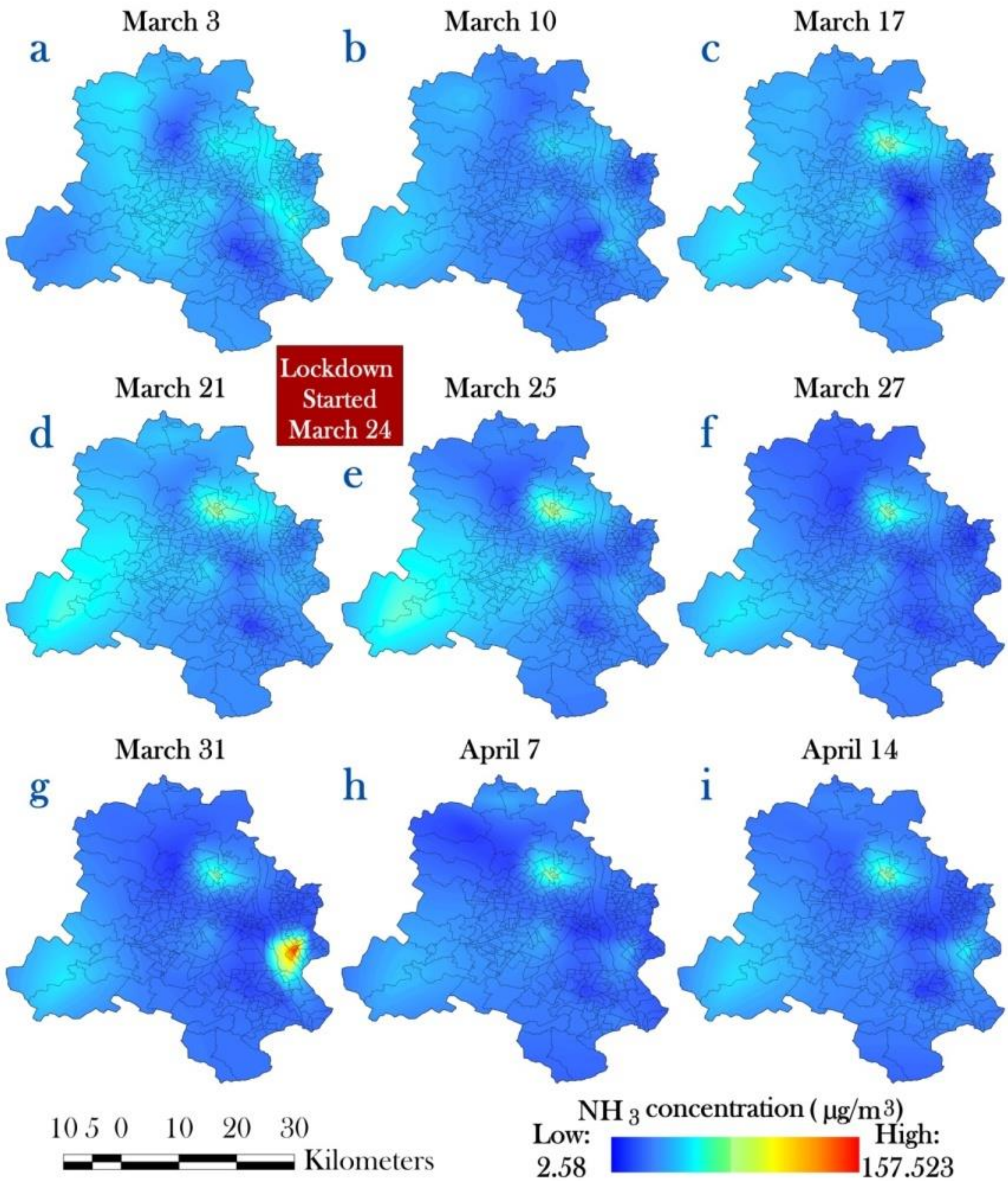
Appendix 1: Status of NO_x concentration in pre-lockdown and during lockdown period over NCT Delhi



Appendix 2: Status of SO_2 concentration in pre-lockdown and during lockdown period over NCT Delhi



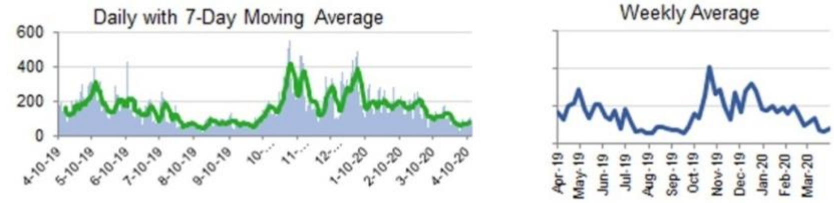
Appendix 3: Status of NH_3 concentration in pre-lockdown and during lockdown period over NCT Delhi



Appendix 4. Status of daily (24hrs) average PM_{10} concentration during April 2019 to April 2020 window period in Neheru Nagar of NCT Delhi

Status of PM_{10}

From 10-04-2019
To 14-04-2020



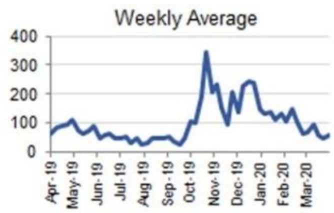
Avg:

	W Th F Sa Su M Tu	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Weekly Average
Apr	10 11 12 13 14 15 16	202.53	172.43	194.76	141.59	138.61	140.76	154.33	164
	17 18 19 20 21 22 23	56.99	76.47	109.85	137.8	158.66	202.18	171.97	131
	24 25 26 27 28 29 30	177.88	215.56	168.88	168	None	207.46	255.07	199
	1 2 3 4 5 6 7	296.68	221.89	134.46	169.07	183.45	209.5	286.53	215
May	8 9 10 11 12 13 14	312	319.19	268.99	257.11	398.06	328.49	124.85	287
	15 16 17 18 19 20 21	203.42	209.28	317.61	91.79	143.76	186.9	157.58	187
	22 23 24 25 26 27 28	148.09	172.91	107.6	94.2	114.78	150.25	146.19	133
	29 30 31 1 2 3 4	157.79	181.14	286.1	241.79	187.66	235.45	145.36	205
Jun	5 6 7 8 9 10 11	179.66	177.65	132.77	167.46	204.36	172.75	431.33	209
	12 13 14 15 16 17 18	194.19	147.99	149.66	212.65	113.51	104.6	69.35	142
	19 20 21 22 23 24 25	211.46	118.26	165.31	136.45	92.05	65.33	105.26	128
	26 27 28 29 30 1 2	125.53	172.9	166.48	195.08	211.59	150.78	191.11	173
Jul	3 4 5 6 7 8 9	75.95	82.98	89.47	67.48	78.91	112.22	81	84
	10 11 12 13 14 15 16	197.09	226.55	252.47	224.02	215.22	78.78	79.76	182
	17 18 19 20 21 22 23	78.9	71.99	135.49	110.04	113.6	121.98	172.89	115
	24 25 26 27 28 29 30	129.53	43.35	51.4	43.29	49.43	53.32	65.71	62
	31 1 2 3 4 5 6	62.42	70.64	67.91	63.99	81.59	76.3	68.81	70
Aug	7 8 9 10 11 12 13	78.15	64	48.3	40.85	51.28	38.51	45.84	52
	14 15 16 17 18 19 20	66.05	51.57	37.82	21.96	49.62	81.9	86.3	56
	21 22 23 24 25 26 27	96.86	98.28	118.18	97.32	58.69	57.82	84.05	87
	28 29 30 31 1 2 3	77.5	69.48	76.04	80	None	100.75	101.4	84
Sep	4 5 6 7 8 9 10	96.8	55.46	56.79	62.26	66.32	97.33	113.15	78
	11 12 13 14 15 16 17	134.52	88.29	47.92	39.2	52.98	70.56	97.49	76
	18 19 20 21 22 23 24	74.14	45.55	73.48	76.6	61.96	61.5	88.47	69
	25 26 27 28 29 30 1	75.95	47.85	34.09	46.52	38	65.09	64.23	53
Oct	2 3 4 5 6 7 8	76.43	102.58	79.56	82.5	106.36	105.01	87.15	91
	9 10 11 12 13 14 15	136.42	154.19	128.46	159.8	182.61	165.57	201.21	161
	16 17 18 19 20 21 22	183.43	142.73	121.15	123.67	137.37	151.49	114.68	139
	23 24 25 26 27 28 29	179.13	257.42	200.64	205.05	254.63	320.28	344.29	252
	30 31 1 2 3 4 5	332.81	401.73	477.94	505.61	555.79	333.68	243.44	407
Nov	6 7 8 9 10 11 12	137.83	256.85	211.75	189.83	262.09	341.45	462.77	266
	13 14 15 16 17 18 19	467.22	459.74	425.92	224.74	130.64	139.75	173.44	289
	20 21 22 23 24 25 26	231.29	302.75	244.52	152.93	130.48	158.55	150.33	196
	27 28 29 30 1 2 3	109.99	48.14	82.79	140.35	156.18	180.52	189.55	130
Dec	4 5 6 7 8 9 10	231.1	344.15	285.31	265.02	251.51	225.57	279.11	269
	11 12 13 14 15 16 17	337.86	304.67	96.89	101.89	110	97.32	114.24	166
	18 19 20 21 22 23 24	177.15	318.04	373.53	299.49	198.9	232.82	329.72	276
	25 26 27 28 29 30 31	204.15	246.97	304.88	373.24	435.83	396.99	270.22	319
	1 2 3 4 5 6 7	458.44	492.06	220.53	255.95	172.66	173.71	151.52	275
Jan	8 9 10 11 12 13 14	128.16	102.18	150.28	183.82	274.21	298.42	172.19	187
	15 16 17 18 19 20 21	158.59	160.05	123.81	172.62	152.58	198.69	267.96	176
	22 23 24 25 26 27 28	282.35	108.86	132.9	197.34	228.17	260.19	161.88	196
	29 30 31 1 2 3 4	135.93	134.98	130.75	145.36	159.56	192.86	282.49	169
Feb	5 6 7 8 9 10 11	191.47	154.9	206.72	185.8	172.57	175.87	229.69	188
	12 13 14 15 16 17 18	204.78	122.09	111.53	119.79	166.83	202.99	177.98	158
	19 20 21 22 23 24 25	212.71	187.9	99.37	181.1	246.04	191.12	255.58	196
	26 27 28 29 1 2 3	232.62	229.78	127.35	97.11	96.3	180.55	147.45	159
Mar	4 5 6 7 8 9 10	169.55	67.36	40.94	89.47	108.67	89.83	127.35	99
	11 12 13 14 15 16 17	112.92	142.94	117.34	84.69	95.97	103.56	108.84	109
	18 19 20 21 22 23 24	118.22	165.61	178.14	144.22	100.99	109.74	110	132
	25 26 27 28 29 30 31	103.28	61.87	72.54	68.76	66.25	66.31	53.51	70
	1 2 3 4 5 6 7	68.08	56.29	31.55	56.11	79.59	94.64	63.08	64
Apr	8 9 10 11 12 13 14	58.14	59.91	81.39	99.61	67.21	101.9	88.89	80

Appendix 5. Status of daily (24hrs) average $PM_{2.5}$ concentration during April 2019 to April 2020 window period in Neheru Nagar of NCT Delhi

Status of $PM_{2.5}$

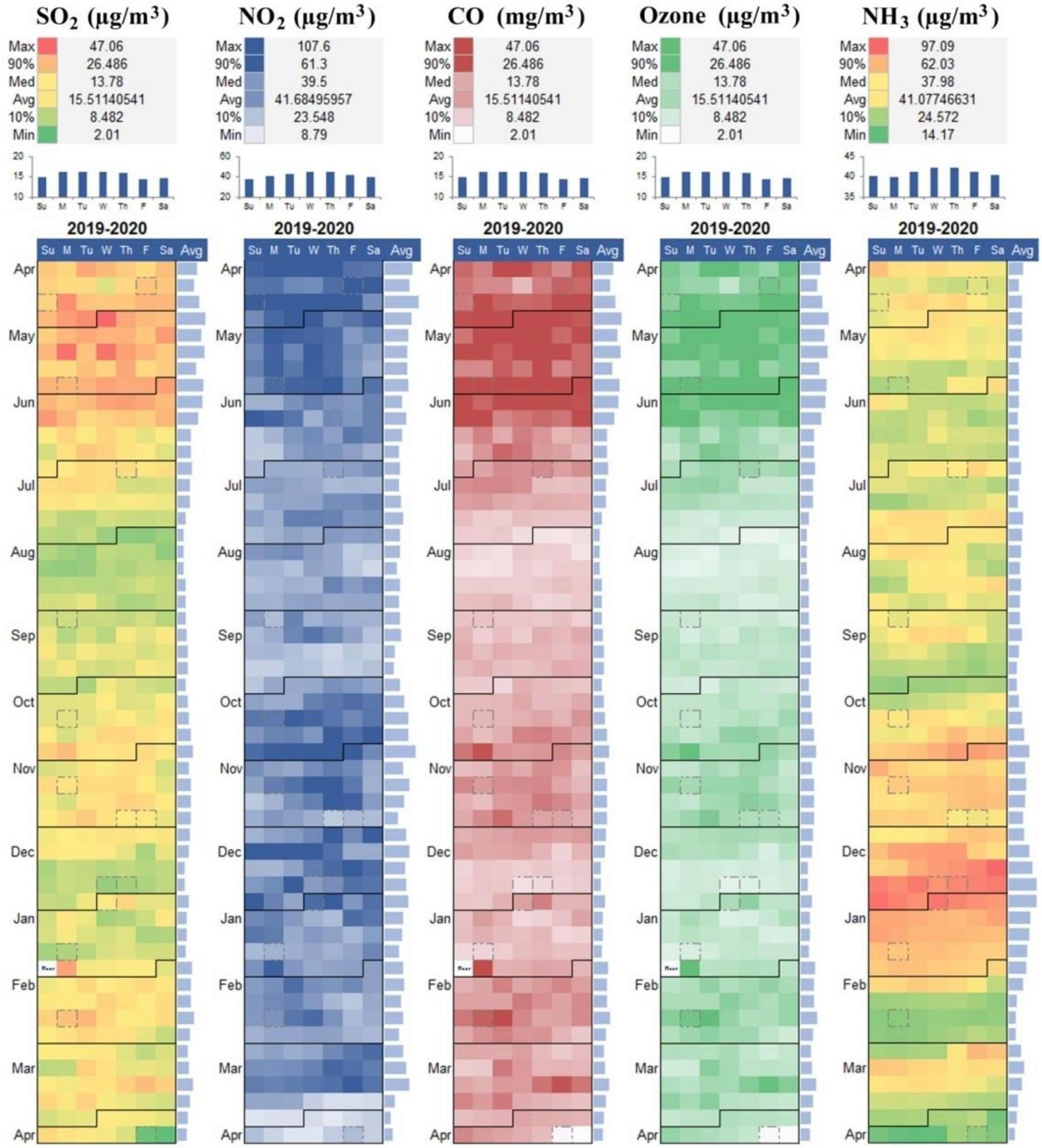
From 10-04-2019
To 14-04-2020



Avg:

	W Th F Sa Su M Tu	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Weekly Average
Apr	10 11 12 13 14 15 16	102.92	69.17	68.74	49.58	47.3	52.11	73.8	66
	17 18 19 20 21 22 23	31.04	46.82	64.06	88.94	104.5	138.06	111.83	84
	24 25 26 27 28 29 30	101.58	96.82	86.8	72	None	90.33	109.36	93
	1 2 3 4 5 6 7	130.71	79.73	58.18	76.05	96.98	107.66	107.68	94
May	8 9 10 11 12 13 14	110.08	112.89	76.03	103.48	143.6	186.24	60.53	113
	15 16 17 18 19 20 21	97.52	74.51	68.38	42.94	81.52	92.45	80.83	77
	22 23 24 25 26 27 28	62.8	90.56	44.88	41.7	57.46	68.21	66.71	62
	29 30 31 1 2 3 4	73.38	78.26	82.77	99.86	80.74	62.93	61.57	77
Jun	5 6 7 8 9 10 11	79.42	76.68	64.33	86.44	113.91	82.02	118.89	89
	12 13 14 15 16 17 18	62.03	54.94	50.91	70.01	32.44	32.92	27.64	47
	19 20 21 22 23 24 25	96.88	44.62	74.91	64.12	40.55	27.39	55.1	58
	26 27 28 29 30 1 2	69.06	73.32	53.73	49.2	60.61	56.31	75.7	63
Jul	3 4 5 6 7 8 9	39.91	47.3	56.99	37.91	45.2	53.71	37.48	46
	10 11 12 13 14 15 16	65.27	60.15	57.92	53.91	51.55	31.97	32.4	50
	17 18 19 20 21 22 23	40.59	35.15	60.74	51.89	55.26	58.35	82.73	55
	24 25 26 27 28 29 30	73.58	27.42	36.93	28.4	20.59	24.01	31.97	35
	31 1 2 3 4 5 6	30.69	41.03	44.89	44.08	57.39	61.05	42.37	46
Aug	7 8 9 10 11 12 13	42.68	30.09	18.64	21.53	28.42	23.5	25.05	27
	14 15 16 17 18 19 20	41.99	30.93	19.88	12.06	22.14	49.84	52.54	33
	21 22 23 24 25 26 27	51.93	50.31	55.89	56.76	35.46	28.79	46.64	47
	28 29 30 31 1 2 3	46.89	40.19	42.09	41.5	None	63.68	64.39	50
Sep	4 5 6 7 8 9 10	64.46	36.65	39.26	36.97	39.76	59.99	70.89	50
	11 12 13 14 15 16 17	80.34	62.98	35.07	31.15	42.4	57.95	63.24	53
	18 19 20 21 22 23 24	40.52	24.05	40.19	42.44	30.46	32.64	45.96	37
	25 26 27 28 29 30 1	38.25	23.27	16.4	23.9	19.61	35.46	34.81	27
Oct	2 3 4 5 6 7 8	43.94	61.04	48.17	41.66	57.97	54.24	46.55	51
	9 10 11 12 13 14 15	74.77	97.09	82.3	106.2	131.35	114.84	132.3	106
	16 17 18 19 20 21 22	138.71	109.93	81.56	83.22	93.33	109.07	73.47	98
	23 24 25 26 27 28 29	115.96	174.3	127.73	147.39	206.32	294.93	277.88	192
	30 31 1 2 3 4 5	276.12	321.46	379.64	415.62	514.36	294.14	213.25	345
Nov	6 7 8 9 10 11 12	100.72	204.47	156.25	140.15	206.36	269.74	388.7	209
	13 14 15 16 17 18 19	395.21	394.99	361.86	161.77	97.28	104.6	125.28	234
	20 21 22 23 24 25 26	172.46	238.67	190.07	123.33	103.6	125.11	106.76	151
	27 28 29 30 1 2 3	72.99	32.48	57.18	106.96	121.54	136.84	142.5	96
Dec	4 5 6 7 8 9 10	169.28	275.94	231.88	210.55	203.03	167.85	207.34	209
	11 12 13 14 15 16 17	264.06	258.75	85.48	83.44	92.39	79.33	92.2	137
	18 19 20 21 22 23 24	149	244.16	305.06	258.22	170.2	198.09	260.79	227
	25 26 27 28 29 30 31	151.52	189.05	234.39	271.84	321.26	303.08	230.08	243
	1 2 3 4 5 6 7	399.66	453.82	199.48	224.25	149.41	140.26	121.71	241
Jan	8 9 10 11 12 13 14	114.65	83.89	116.69	138.03	208.81	232.03	142.44	148
	15 16 17 18 19 20 21	123.21	132.7	97.86	128.3	119.79	146.69	192.91	134
	22 23 24 25 26 27 28	212.34	72.69	93.92	138.84	162.05	172.16	101.64	136
	29 30 31 1 2 3 4	74.18	83.14	90.17	98.79	116.28	130.61	194.51	113
Feb	5 6 7 8 9 10 11	138.31	117.72	152.96	144.03	130.96	110.13	153.85	135
	12 13 14 15 16 17 18	153.92	79.56	62.77	71.05	114.66	142.55	118.02	106
	19 20 21 22 23 24 25	136.39	133.53	79.42	139.53	206.67	147.03	190.02	148
	26 27 28 29 1 2 3	157.88	146.87	94.05	70.19	56.75	126.76	107.57	109
Mar	4 5 6 7 8 9 10	107.18	38.52	26.1	59.15	77.26	52.13	83.58	63
	11 12 13 14 15 16 17	76.73	90.95	57.43	56.89	62.97	56.97	66.43	67
	18 19 20 21 22 23 24	71.49	110.2	124.56	104.13	82.95	94.06	94	97
	25 26 27 28 29 30 31	88.89	51	57.9	60.48	59.38	53.58	46.62	60
	1 2 3 4 5 6 7	51.23	53.18	47.08	44.73	49.93	44.31	35.95	47
Apr	8 9 10 11 12 13 14	27.5	38.93	64.22	70.76	48.64	79.7	76.43	58

Appendix 6. Status of daily (24hrs in case of SO_2, NO_2 and NH_3 and 8Hrs in case of O_3 and CO) average concentration of during April 2019 to April 2020 window period in Neheru Nagar of NCT Delhi



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Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India

Credit author statement

Mahato S. collected the data, prepared maps and framework of the study; Pal S. visualized the work, wrote part of manuscript and performed revision and; Ghosh KG. conceived ideas, wrote the manuscript and performed revision.

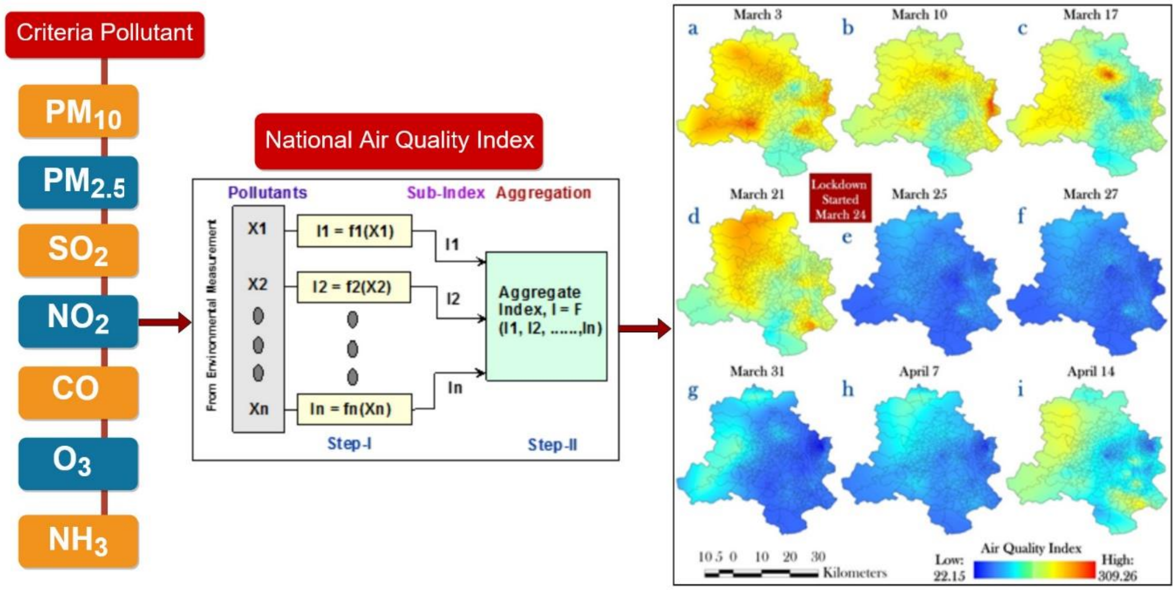
Declaration of interests

☒ 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.

Krishna Gopal Ghosh

(On behalf of all the authors)

Graphical Abstract



Highlights

- PM_{10} and $PM_{2.5}$ concentrations reduced by about half in compare to the pre-lockdown
- NO_2 and CO have also shown considerable decline during lockdown
- In the transportation and industrial location air quality have improved close to 60%
- The central and Eastern Delhi have experienced maximum improvement in air quality
- On the 2nd and 4th day of lockdown, about 40% to 50% improvement in air quality