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Air quality index and criteria pollutants in ambient atmosphere over selected sites:

Impact and lessons to learn from COVID-19

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15.1 Introduction

The disease COVID-19 caused by novel virus SARS-CoV-2 (until now known to originate from Wuhan, China) spread from local through regional and national to global level, and affected human health causing severe mortality as well as economic slowdown (Liu et al., 2020a; Chinazzi et al., 2020; Muhammad et al., 2020; Tian et al., 2020; Lian et al., 2020). Impact of COVID-19 was such that World Health Organization (WHO) declared it as pandemic on 12th March 2020 and suggested each country to take appropriate action to control the spread of virus and to save human lives (Liu et al., 2020b). To avoid transmission of virus through human to human and to create desired medical infrastructure, restrictions on public transport (road/rail/air), outdoor movement, industrial, and construction activities were considered as immediate measure by different countries in their own way at different times (Li and Tartarini, 2020; Otmani et al., 2020).

The Union Government of India too implemented complete lockdown from 24th March 2020 to 14th April 2020. This was termed as lockdown phase 1 (LD 1) wherein there was complete restriction on public transport (road/rail/air), academic institutions (school/college/university), shopping mall/complexes, industrial, and construction activities except for essential services (medical, hospital, milk, grocery store). Considering the success of LD 1, lockdown was extended further from 15th April 2020 to 3rd May 2020, marked as lockdown phase 2 (LD 2), from 4th May to 17th May 2020 (LD 3), and from 18th May to 31st May 2020 (LD 4) across the country (<https://www.mha.gov.in/>). Later from June 1st onward, unlock process started with more relaxations on intra- and interstate movements, opening up of necessary activities such as construction, staggered opening of shops/markets. Anthropogenic emissions in ambient atmosphere were substantially reduced during lockdown phases, which positively influenced air quality and air quality index (AQI) in ambient atmosphere (Muhammad et al., 2020; Wang et al., 2020; Dhaka et al., 2020; Navinya et al., 2020). The atmospheric concentrations of particles and gaseous pollutants over urban environments are directly linked with vehicular emission, industrial emission, resuspension of road dust and biomass burning (Tandon et al., 2008; Kotnala et al., 2020). Implementation of lockdown has put a limit to the such emission sources and influenced atmospheric budget of pollutants at local/regional and global scales (Venter et al., 2020; Chinazzi et al., 2020; Sharma et al., 2020). To understand the impacts of lockdown on air quality and AQI, variations in concentrations of criteria pollutants viz. NO_x , CO , SO_2 , O_3 , $\text{PM}_{2.5}$, PM_{10} during before lockdown period (1st March 2020 to 24th March 2020) and during lockdown phases (25th March 2020 to 31st May 2020) at 15 representative monitoring stations over New Delhi are analyzed in this study. The variations and impacts on AQI at multiple locations in the country, depending on availability of data, are also discussed. The observational analysis is attempted to explore the possibilities of implementation such lockdown measures in future to improve air quality.

15.1.1 Air pollution

Air, a homogenous mixture of gases (oxygen- O_2 , nitrogen- N_2 , carbon dioxide- CO_2 , argon-Ar, and trace gases), is lifeline for life forms to survive on the planet Earth. Any change in its composition that can affect human health and human welfare directly or indirectly on immediate or chronic basis will be termed as case of air pollution. In order to maintain the ambient air (surrounding us, i.e., in ambient atmosphere and not indoor air) quality for human beings and its suitability for human welfare, emission limits have been prescribed by several agencies over across the world. Some of them are listed such as the United States Environmental Protection Agency, European Environment Agency, and Central Pollution Control Boards (CPCB) in India. There are primary air quality standards, which are also termed criteria pollutants, that ambient air must meet with ample margin of safety to safeguard human health. These standards includes CO, NO_x , SO_2 , O_3 , Pb, and PM_{10} and $PM_{2.5}$ for which prescribed limits of different areas such as industrial, residential, and sensitive are provided by the CPCB, New Delhi. The details related to sources, impact, and prescribed limits for criteria pollutants are provided in Table 15.1. The criteria pollutants are part of primary National Ambient Air Quality Standards (NAAQS) which are periodically reviewed after every 5 years. The secondary NAAQS, which ambient air must met to safeguard human welfare including ecosystem, includes more than 180 pollutants and are required to monitor on case-to-case and need basis. It is important to note that Criteria pollutants in NAAQS include the pollutants emitted by combustion activities (fossil fuel or biomass), industrial and construction activities. Carbon monoxide (CO) and NO_x are released by all fossil fuel and biomass combustion, whereas SO_2 is largely contributed by coal combustion in thermal power plants. Lead (Pb) was added as tetraethyl lead in fossil fuel and was part of vehicular emissions. However, it is banned since more than two decades but still stays in environment as metal persist for long time in environment unlike organic compounds.

Troposphere ozone (O_3) is a secondary pollutant as it is not released directly in atmosphere rather it is formed via photochemical reactions among NO_x and volatile organic compounds (VOCs) released from combustion activities. PM_{10} and $PM_{2.5}$ refers to particles of diameter less than 10 μm and less than 2.5 μm , respectively. Note that the term diameter refers to aerodynamic diameter and not necessarily indicate that all particles are spherical in nature. Aerodynamic diameter is diameter of an imaginary sphere having unit density and same falling velocity as the particle in consideration for which diameter is determined.

TABLE 15.1 National Ambient Air Quality Standard for criteria pollutants along with their sources, prescribed limits and impacts on human health.

Pollutant	Source	Impact	Time-weighted average	Residential/ industrial	Ecologically sensitive
CO (mg/m^3)	Incomplete combustion	Risk for cardiovascular	8 Hours	2	2
NO_x ($\mu g/m^3$)	Lightening, high temperature burning, biomass burning, fossils fuel burning	Cause of pulmonary disorder, increase the risk of respiratory diseases	Annual	40	30
			24 Hours	80	80
SO_x ($\mu g/m^3$)	Coal burning, volcanic emission, petrochemical burning	Affect upper respiratory system, affect nose mucous, bronchoconstriction	Annual	50	20
			24 Hours	80	80
O_3 ($\mu g/m^3$)	Photochemical reaction	Irritation in respiratory track, cause of cough, mild chest pain, sensitive toward allergens	8 Hours	100	100
Pb ($\mu g/m^3$)	Vehicular exhaust, coal burning, waste burning	Acute effect on central nervous system, affect soft tissue and bone, anemia	Annual	0.50	0.50
			24 Hours	1.0	1.0
$PM_{2.5}$ ($\mu g/m^3$)	Windblown dust, construction activity, vehicular, and industrial emission	Premature death, chronic respiratory diseases, asthma, toxic metal	Annual	40	40
			24 Hours	60	60
PM_{10} ($\mu g/m^3$)	Dust storm, construction activity, sea salt spray	Breathing problem, respiratory symptom	Annual	60	60
			24 Hours	100	100

Source: <http://cpcbenvvis.nic.in>.

The concentrations of criteria pollutants are used to monitor the ambient air quality in general and to monitor the emission sources. A region is considered in attainment if it meets the NAAQS for criteria pollutant and is considered out of attainment, if the NAAQS are not met by the ambient air in that region. The control agency takes a call on emission sources if they exceed the NAAQS and issue advisories/notice to emitters and take action to bring the pollutant levels within the prescribed NAAQS.

15.1.2 Air quality index

AQI is a numerical representation of complex data set of criteria pollutants (NO_x, CO, O₃, SO_x, PM_{2.5}, PM₁₀) to understand the air quality situation for public information purposes at local and regional scale. It makes easy for communication with public using single number and color code compared to concentrations of criteria pollutants. Based on numerical values, AQI has been categorized in six categories such as good (0–50), satisfactory (51–100), moderately polluted (101–200), poor (201–300), very poor (301–400), and severe (401–500; Table 15.2). The subindices for each pollutant at given locations are calculated using 24 hours average concentration (8 hours monitoring for CO and O₃) following health breakthrough points and empirical equation. The AQI calculations must contain minimum three criteria pollutants in which PM_{2.5} or PM₁₀ is mandatory one and minimum time duration required to calculate the AQI is 16 hours.

The following algorithm is applied to calculate AQI using continuous real-time criteria pollutant data sets.

$$I_i = \left[\left\{ (I_{HI} - I_{LO}) / (B_{HI} - B_{LO}) \right\} \times (C_P - B_{LO}) \right] + I_{LO}$$

where,

I_i = Sub index for pollutant i (eg. PM_{2.5}, SO_x, NO_x, O₃)

I_{HI} = AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}

B_{HI} = Breakpoint mass concentration > or equal to given concentration

B_{LO} = Breakpoint mass concentration < or equal to given concentration

C_P = Pollutant concentration (eg. PM_{2.5} = 90 µg m⁻³)

Only 24 hours average value of all pollutants has been taken except 8 hours value for CO and O₃. Source: https://app.cpcbcr.com/AQI_India.

The AQI is used for public advisory purposes for children, elderly people and persons already suffering from any chronic disease such as pulmonary, heart or other. Based on the forecasted AQI, children and old age persons and persons with other disease are advised not come out of the house unless it is very necessary. The lockdown periods followed by unlock provided an opportunity to estimate the effects of closure of emission sources on criteria pollutants and AQI (Figs. 15.2 and 15.3).

15.2 Data source and data collection point

The real time data of PM_{2.5}, PM₁₀, NO_x, NH₃, CO, O₃, SO₂ were accessed from Environment Information System Resource partner on Control of Water, Air and Noise pollution hosted by CPCB and sponsored by (Ministry of Environment, Forests and Climate Change, Government of India <http://www.cpcbenviis.nic.in/>). The data

TABLE 15.2 Details of air quality index along with range of concentrations of criteria pollutant (PM_{2.5}, PM₁₀, NO_x, SO_x, O₃, CO, Pb) and NH₃.

AQI category	AQI range	Pollutant concentration range (in µg/m ³ unit except that CO is in mg/m ³ unit)							
		PM _{2.5}	PM ₁₀	NO _x	SO _x	O ₃	CO	Pb	NH ₃
Good	0–50	0–30	0–50	0–40	0–40	0–50	0–1.0	0–0.5	0–200
Satisfactory	51–100	31–60	51–100	41–80	41–80	51–100	1.1–2.0	0.5–1.0	201–400
Moderately polluted	101–200	61–90	101–250	81–180	81–380	101–168	2.1–10	1.1–2.0	401–800
Poor	201–300	91–120	251–350	181–280	381–800	169–208	10–17	2.1–3.0	801–1200
Very poor	301–400	121–250	351–430	281–400	801–1600	209–748	17–34	3.1–3.5	1200–1800
Severe	401–500	250+	430+	400+	1600+	748+	34+	3.5+	1800+

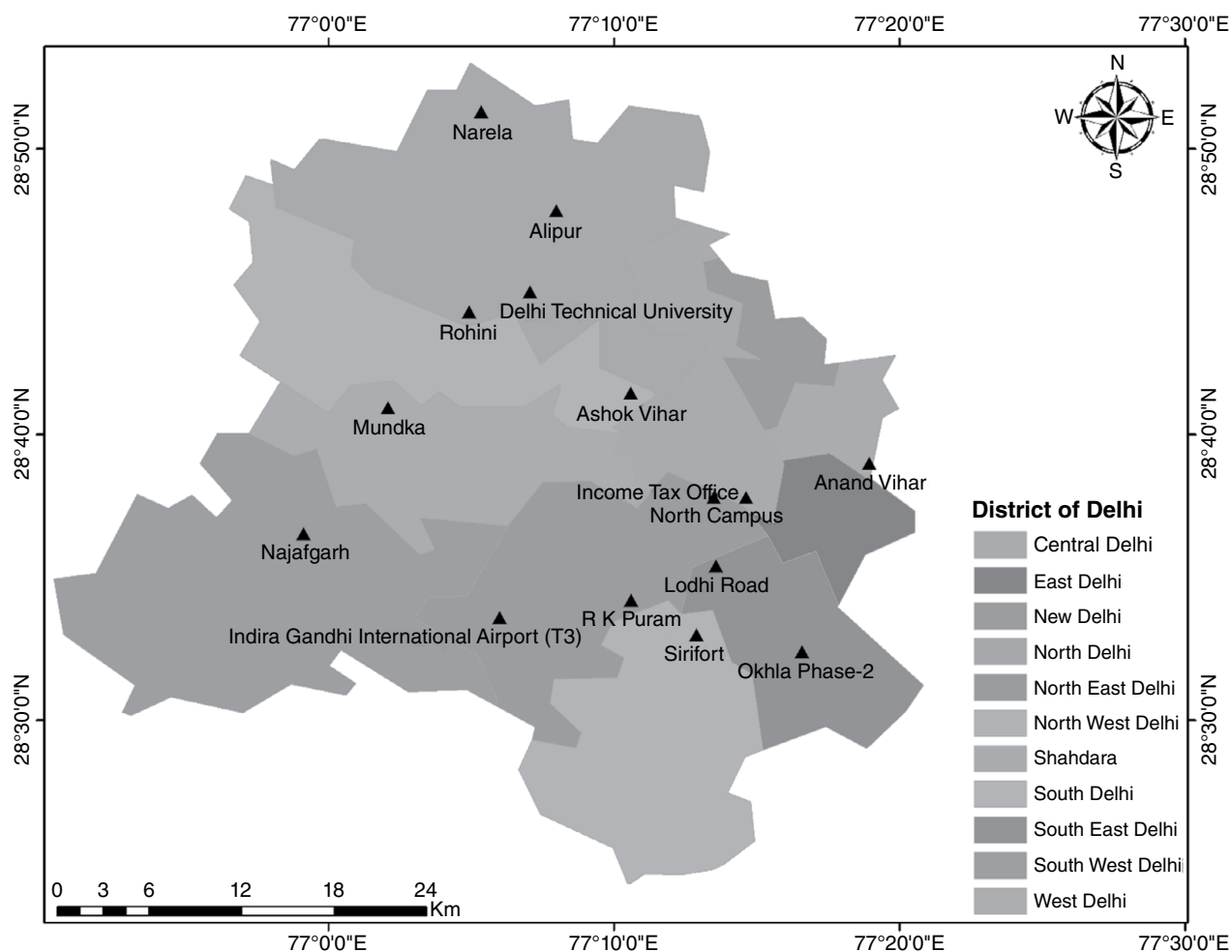


FIG. 15.1 Map showing the real-time data monitoring stations across New Delhi used in this study.

Source: Environment Information System (ENVIS) Resource partner on Control of Pollution Water, Air and Noise hosted by Central Pollution Control Board (CPCB) sponsored by Ministry of Environment and Forests (MOEF), Government of India (<http://www.cpcbenvvis.nic.in/>).

collected from 1st March 2020 to 30th June 2020 for 24-hour duration have been categorized in before lockdown period (1st March to 24th March 2020), during lockdown (25th March to 31st May 2020), and Unlock 1.0 (1st June to 30th June 2020). Based on availability of data, a total of 15 monitoring stations covering all districts of New Delhi, viz. North, North-East, North-West, West, South, South-West, South-East, New-Delhi, Central, Shahdara, and East Delhi, were selected for analysis of concentrations of criteria pollutants (Fig. 15.1). The monitoring stations included Anand Vihar, Delhi Technical University (DTU), Indira Gandhi International Airport-T3, Income Tax Office (ITO), Lodhi Road, North Campus, Okhla Phase-2, R K Puram, Siri Fort, Alipur, Ashok Vihar, Mundka, Najafgarh, Narela, Rohini in New Delhi (Fig. 15.1). Similarly, AQI data were also accessed from CPCB website for 24 monitoring stations across 18 states and two union territories of India covering metro cities, desert and coastal regions, northeast India (hilly terrains), landlocked areas, foothills of Himalayas, Gangetic plains (Fig. 15.3).

15.2.1 Study area

Delhi, the capital of India is one of the rapid growing metropolitan city with more than 16 million inhabitants and more than 10 million registered vehicles with Transport Department of New Delhi. Vehicular emissions, two coal-based thermal power stations, construction activities, small scale industries and resuspension of surface and road side dust are major contributors to criteria pollutants in ambient atmosphere of New Delhi. New Delhi, by virtue of its location, receives particles from the Thar Desert during summer month (March to June). More details about demographic and climatic regimes over New Delhi can be accessed from Yadav and Rajamani (2004), Kumar and Yadav (2020). New Delhi has dubious distinction of having its own pollution sources and of receiving

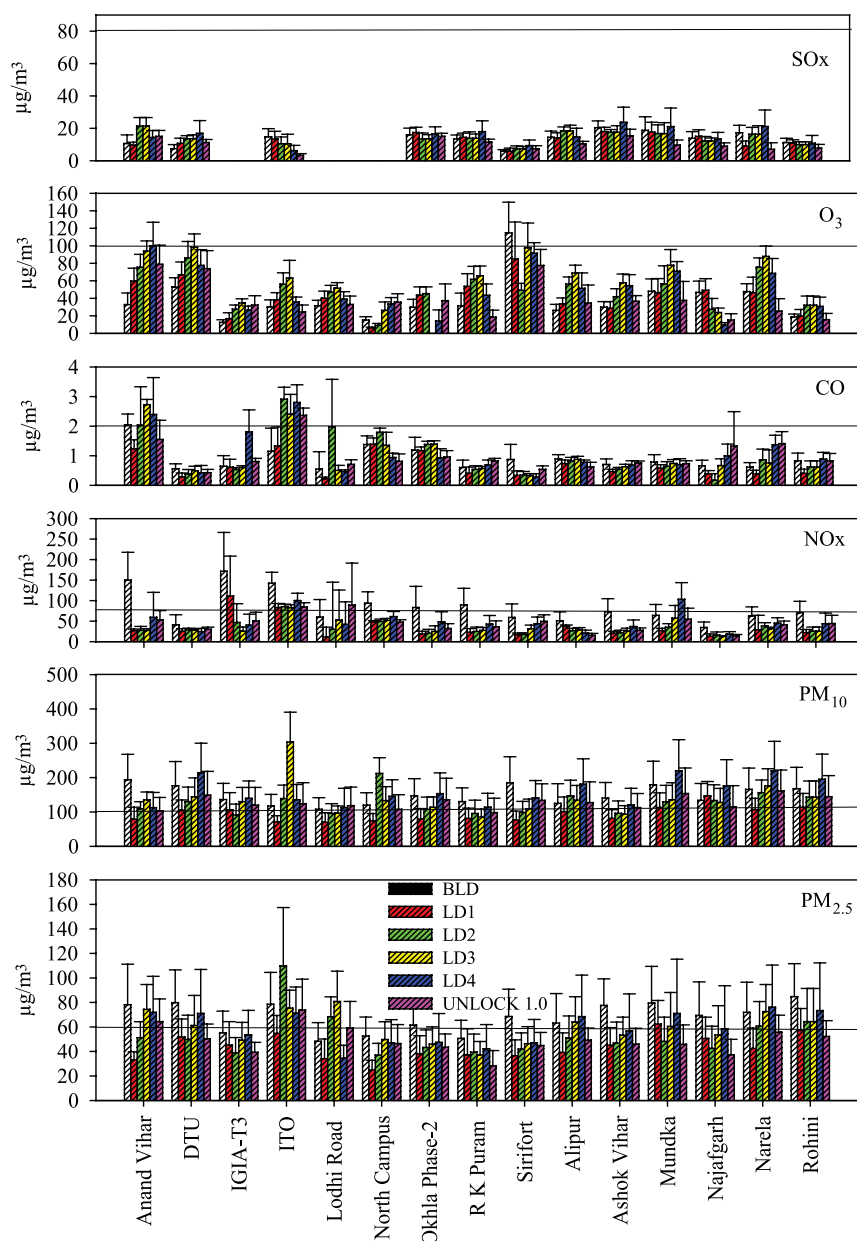


FIG. 15.2 Average mass concentrations of PM_{2.5}, PM₁₀, NO_x, SO₂, CO, and O₃ during before lockdown period (BLD: 1st March 2020 to 24th March 2020), during lockdown period (LD: 25th March to 31st May 2020) and Unlock 1.0 (1st June to 30th June 2020) over New Delhi. Horizontal line represents National Ambient Air Quality Standard (NAAQS). LD 1: 25th March to 14th April 2020; LD 2: 15th April to 3rd May 2020; LD 3: 4th May to 17th May 2020; LD 4: 18th May to 31 May 2020.

pollutants from dust storms from western parts of India during summer season, from Gangetic plains during monsoon period, from northern states during post monsoon and winter season. A significant amount of pollutants come from the vehicles that pass through New Delhi during their movements from north to south India and west to east India or vice versa.

15.3 Results

15.3.1 Air quality before lockdown

The average mass concentrations of PM_{2.5}, PM₁₀, NO_x, CO, O₃, SO₂ from 15 real time monitoring stations before lockdown (BLD) and lockdown phases (LD 1, 2, 3, and 4) and unlock phase 1.0 are provided in Supplementary Table (ST 15.1)

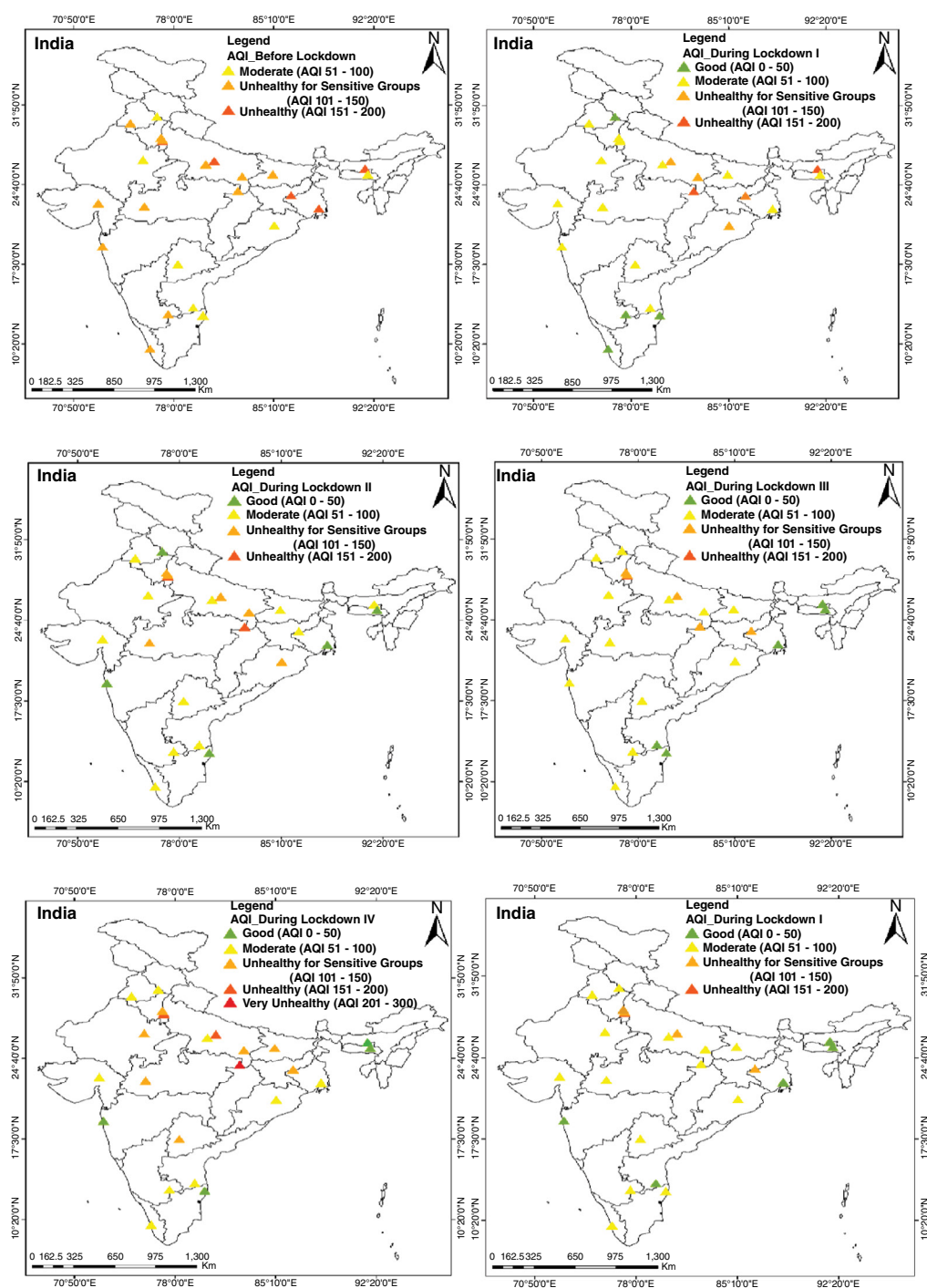


FIG. 15.3 Air quality index (AQI) over selected locations in India during before lockdown (BLD: 1st March 2020 to 24th March 2020) and during lockdown (LD: 25th March to 31st May 2020) and Unlock 1.0 (1st June to 30th June 2020) over India. LD 1: 25th March to 14th April 2020; LD 2: 15th April to 3rd May 2020; LD 3: 4th May to 17th May 2020; LD 4: 18th May to 31 May 2020.

and are plotted in Fig. 15.2. The $PM_{2.5}$ concentrations during BLD over Anand Vihar, DTU, ITO, and Siri Fort, Ashok Vihar, Mundka, Najafgarh, Narela, Rohini stations were quite high compared to IGI-T3, Lodhi Road, R K Puram, North Campus and exceeded NAAQS of $60 \mu\text{g}/\text{m}^3$. High $PM_{2.5}$ concentrations over these monitoring stations were associated with high traffic load, resuspension of road dust and industrial emissions (Yadav et al., 2016; Chen et al., 2020) compared to other stations, which had lower emissions and were located in sensitive zones. The ITO station is surrounded by several government office and encounter heavy traffic congestion (Krishan et al., 2019).

Further, Anand Vihar is located near to railway station and interstate bus stand terminal (ISBT) and faces high particle concentration due to direct sources and resuspension by heavy vehicle movements. Moreover, PM_{2.5} concentrations over New Delhi are also influenced by local and regional emission around national capital region (NCR) (Chen et al., 2020).

Contrary to PM_{2.5}, average PM₁₀ concentrations were high over all monitoring stations except Lodhi Road which is surrounded by lush green garden and is a diplomatic area. All monitoring stations except Lodhi Road exceeded the NAAQS (PM₁₀; 100 µg/m³). Maximally polluted stations included Anand Vihar, Siri fort, and Mundka, where PM₁₀ concentrations exceeded the NAAQS (PM₁₀; 100 µg/m³ for 24 hours) by a factor of two. High PM₁₀ concentrations showed the site specific variations and appeared to be affected by the local emission and resuspension of road dust (Tandon et al., 2008; Kumar and Yadav, 2016).

NO_x (NO + NO₂) emitted over urban environment is indicator of high temperature burning, vehicular emission and industrial activity. Among all monitoring station, Anand Vihar, IGI-T3, ITO showed high load of NO_x compared to other monitoring stations (Fig. 15.2). High NO_x concentrations over the region are strongly related with traffic emission (Krishan et al., 2019). This was also true here as the monitoring stations close ISBT, IGI-T3 and highway intersects experienced high NO_x concentrations. The NO_x emissions from multiple sources get converted into NO₃ through gas to particle conversion (GPC) and confined in coarse particles. In addition, NO₃ also contributed through crustal emission through geochemical processes (Gao et al., 2016). SO₂ emitted mainly from coal burning and several other stationary sources (Guttikunda et al., 2014). SO₂ gas gets converted into SO₄²⁻ through GPC and remains confined in fine particles. Okhala Phase 2, Ashok Vihar, Mundka, and Narela stations showed quite high concentrations of SO₂ compared to other monitoring stations. SO₂ data was not available for three monitoring station (IGI-T3, Lodhi road, North Campus). Coal-based thermal power points were static source of SO₂ whereas domestic coal burning appeared to be diffused source. Use of coal in industries is important source of SO₂ in industrial area (Sharma et al., 2019). Carbon monoxide is a byproduct of incomplete combustion of fossil fuel and biomass burning. The CO emissions from vehicles have been drastically reduced by usage of catalytic convertors, which oxidize CO to CO₂. Thus, the high CO at Anand Vihar followed by North Campus and Okhala Phase 2 could be linked to diffuse biomass burning like road side eateries etc. Ozone, a secondary pollutant, showed site specific variations with highest load at Siri fort followed by DTU, Ashok Vihar, Mundka, Najafgarh, Narela stations.

15.3.2 Air quality during lockdown and unlock period

Since the direct emission sources of pollutants were bare minimum during LD 1 and LD 2, average PM_{2.5} concentrations at all monitoring stations were lower than that observed before lockdown as well as lower than NAAQS (PM_{2.5}; 60 µg/m³ on 24 hours basis). As the restrictions were eased for government offices, PM_{2.5} concentrations showed increments at ITO station due to traffic movements and resuspension of dust. Previous studies also suggested that New Delhi is mainly influenced with high particle load on account of vehicular emission, GPC, and resuspension of surface dust (Kumar and Yadav, 2016; Sharma et al., 2019). Particle concentrations during LD 1 and LD 2, which was lower than before lockdown showed an increase during LD 3 and LD 4. It was interesting to note that PM_{2.5} concentrations were either nearly same or lower than that in LD 3 and LD 4 at nearly all stations. This could be extra caution shown by public and restricted movements (fear factor) even in Unlock 1. The impact of lockdown was quite visible at Anand Vihar station where PM₁₀ was reduced by factor of 1.1–2.5 compared to before lockdown because vehicular movement induced resuspension of road side dust was minimum. The reduction in particle concentrations at all monitoring stations reemphasized that vehicular emission, construction activity, resuspension of road dust are main sources of particles in New Delhi (Yadav et al., 2016). NO_x, an indicator of high temperature burning and vehicular emission showed pronounced reduction at all monitoring stations (Shehzad et al., 2020). The ratio of NO_x concentrations during before lockdown and all four phase of lockdown varied between 0.8 and 6.8 across monitoring stations. Maximum reduction in NO_x was observed at IGI-T3 (6.8), Anand Vihar (5.6) followed by Lodhi Road (5.4) and other monitoring stations. The ITO, DTU, North Campus and Alipur showed quite similar ratio (2 to 3) suggesting minimum reduction in NO_x. The NO_x concentrations were reduced to greater extent during LD 1 and LD 2 compared to that in LD 3 and LD 4 as restriction were slightly eased during later phases of lockdown. Similar concentrations of NO_x during LD 4 and Unlock 1.0 indicate increase in vehicular movements as restriction started easing out.

Sulfur dioxide showed minimum variation across monitoring stations and across the observation period. Sulfur dioxide also was much lower compared to NAAQS at all stations (Fig. 15.2). This was so as coal burning, dominant source of SO₂ in New Delhi, was bare minimum as poor people who use coal for domestic purposes left New Delhi

for their native places during pandemic. Further, lockdown period coincided with summer season and therefore, diffused coal burning, which picks in winter by local people for warming purpose, was lower. This was also reflected in lower CO concentrations at all stations except Anand Vihar and ITO. These stations had high CO due to heavy-duty diesel driven vehicles or by local domestic burning as people gathered at these places and stayed in open before leaving New Delhi. There could also be some impact from nearby coal-based thermal power plant at Anand Vihar and ITO stations. Consistently uniform concentrations of SO₂ and CO during BLD and all phases of lockdown over New Delhi could be due to domestic combustion of biomass, coal, and cow dung.

Ozone concentrations at all monitoring stations behaved differently compared to other criteria pollutants. Ozone concentrations increased during LD 1, LD 2, LD 3, and LD 4 compared to before lockdown and Unlock 1.0 period at all monitoring station. Among the all phase of lockdown, O₃ concentrations were high during LD 3 and LD 4 compared to LD 1 and LD 2 due to gradual relaxation on vehicular transport. The exemption in road transport in third and fourth lockdown phases provided ample amount of precursor gases for formation of O₃. High O₃ concentrations over Siri Fort could be due to emissions of ozone forming precursor gases (NO_x and VOC). In addition, the lockdown phases 3 and 4 and Unlock 1.0 period (May and June months) encountered high solar flux compared to LD 1 and LD 2 periods. This increased solar flux could be responsible for more ozone formation following photochemical reactions. The quite high formation of O₃ during lockdown period enhanced in the presence of VOC.

There is one paradoxical observation in the data about lowering of NO_x concentrations and increase concentrations of tropospheric ozone at many stations during lockdown phases. This requires an explanation. Ozone in troposphere, termed as bad ozone, is formed via photochemical reactions among NO_x and VOCs in addition to flux from stratosphere. Oxidation of CO and CH₄ is major photochemical pathway for ozone formation in troposphere, which includes conversion of NO to NO₂. The NO₂ molecules (formed or directly released), upon dissociation at ≤ 420 nm, releases NO and O (³P). Molecular oxygen combines with this atomic O to form O₃. But the net concentration of O₃ in troposphere is the steady state (SS) concentrations as O₃ also undergo dissociation by combining with NO. Thus, SS ozone will depend on the ratio of NO₂/NO, increase in numerator will lead of formation of O₃ and increase in denominator will result in loss of O₃ molecules. Therefore, a general understanding is developed that O₃ concentration should peak with NO emissions in ambient atmosphere. But the observations made across the country and world indicate low NO₂ concentrations and higher O₃ concentration in ambient atmosphere during lockdown periods. Low NO₂ levels can be directly attributed limited vehicular activity during lockdown. Then, the reasons for increase in O₃ need to be explored. These observations reiterate the nonlinear relationship among NO_x and O₃ in ambient atmosphere (Cazorla et al., 2020). The limited direct emissions of NO from vehicles could restrict the dissociation of O₃ and O₃ could build up in atmosphere, i.e., formation exceeded dissociation but it will not represent the SS concentration of O₃ rather represent absolute measured O₃ at a given time and place. The additional sources of NO₂ could be from agricultural fields and surface soils, which could become source of atomic O to form Ozone (Xia et al., 2020). Here, NO₂ levels were too low. The VOCs (isoprene mainly) released from forest could provide alternate pathway to form ozone in NO_x poor atmosphere (Wu et al., 2020). It is expected that the O₃ levels may go down because of change in whether and generation of chlorine radicals from excessive use of HOCl for disinfection purposes across places. In addition, reduced photochemical reactions and lower VOC emissions from forest in winter compared to dry season, which coincides with lockdown in India, will further expected to bring down tropospheric ozone.

15.3.3 Air quality index

The average AQI data (on 24 hours average basis from 6 AM to 6 AM) for the period of BDL (1st March to 24th March 2020), LD (25th March to 31st May 2020) and Unlock 1.0 (1st June to 30th June 2020) over 24 monitoring stations across the country are shown in Fig. 15.3 (accessed from Central Pollution Control Board, Ministry of Environment Forest and Climate Change; https://app.cpcbcr.com/AQI_India/). The LD period has been divided in LD 1, 2, 3 and 4 as stated before (<https://www.mha.gov.in/>).

The AQI value remained between moderate (51–100), unhealthy for sensitive group (101–150), and unhealthy (151–200) over all monitoring station across the country during before lockdown (Fig. 15.3). However, interesting observations are found in trends of AQI on implementation of lockdown (LD 1 and LD 2) over all monitoring stations and AQI shifted toward moderate range except some monitoring stations such as Singrauli (Madhya Pradesh), Jharkhand. The unhealthy AQI values over Singrauli station and in the state of Jharkhand are associated Thermal power plant, coal mining which were operational during LD phases. These observations clearly suggest that even complete restriction on anthropogenic activity was unable to reduce the AQI values to green zone across the country (Sharma et al., 2020). However, on implementation of LD 3 and LD 4, AQI values again shifted toward unhealthy (except northeast region and coastal region) because of onset of south-westerly monsoon in the country. The

staggered relaxations on transportation and social activities during LD 3 and LD 4 could have added pollutants and raised AQI values. The slight improvement in AQI values during Unlock 1.0 with more relaxations could be due to intermittent rain events. Maximum impact of heavy rains on AQI was visible in coastal areas and northeast regions (Fig. 15.3). However, constant vehicular emissions, biomass burning, industrial, and construction activities affect AQI over across the country (Dhaka et al., 2020). Moreover, it could be suggested that air quality across the country is not totally governed by anthropogenic activity rather it is linked to geographical locations, meteorological factors (Sharma et al., 2020).

15.4 Summary

In line of expectations, concentrations of criteria pollutants over New Delhi were reduced during lockdown phases compared to before lockdown. However, reduction was not uniform for all criteria pollutants as well as for all monitoring stations in New Delhi. The PM_{10} and $PM_{2.5}$ remained very close to the NAAQS limits, probably suggesting the impact of dust storm as period of lockdown coincided with onset of summer season in North India when the prevailing south-south westerly winds brings particles from the Great Indian Thar desert toward Indo-Gangetic plains. The increase in temperature too creates low pressure conditions locally and local winds resuspend the loose surface materials back to atmosphere. Therefore, the lockdown appears to impact and lower the particles in ambient atmosphere but the particles still stayed very close to NAAQS by virtue of meteorological conditions. The restrictions on vehicular emission and other combustion activities too did yield lowering of CO and NO_x but at places, the secondary pollutant O_3 showed marginal increments. Limited dissociation of O_3 in NO_x poor environment and oxidation of NO to NO_2 by VOCs emitted from forest/vegetation could be possible reasons for ozone build up in ambient atmosphere. Low energy demand from coal-based thermal power plants and limited diffused coal burning due to summer season and people's migration resulted in consistent and lower SO_2 concentrations compared to NAAQS. The AQI across the country remained in marginal to unhealthy for unhealthy person barring in the good zone at costal area and north east states of the country. The intermittent rains and onset of monsoon season could offset the impact of emissions during Unlock 1.0 on the AQI.

The observations clearly indicate that lockdown of services is not a viable options to bring down the pollutant concentrations in limits of NAAQS and AQI in green zone although it yielded some improvement. It is suggested that ambient air quality is governed by metrological conditions and local minor sources in addition to uniform sources such as vehicles, construction and industrial activity, biomass burning. We suggest from the observations that: (1) No uniform strategy can bring down the criteria pollutants and AQI in green zone rather measures should be geographical location linked and on micro scale; (2) Closure of development/transport and other activities is no viable solution even in short term rather has implications on countries economy and social fabric; and (3) Long-term measures such as people's awareness, attitude, and active participation coupled with policy restrictions on emissions seems to be viable option and may yield desired results. Participation of stakeholders (societies and citizens) is mandatory to achieve goals for better air quality for blue skies.

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