VARIABILITY IN AIR QUALITY DURING LOCKDOWN AND UNLOCK PHASES IMPLEMENTED DUE TO PANDEMIC COVID 19 AND INFLUENCE OF PLANETARY BOUNDARY LAYER

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Abstract: The pandemic Covid 19 caused a worldwide lockdown during different time periods starting from late December 2019. In India, country wide lockdown namely lockdown 1 with subsequent lockdown phases was imposed from 25 March 2020 with closure of industries, educational institutes, offices and other activities restricting the vehicular movement completely. The present study considered the data of air quality for three years 2018-2020 at two cities of Rajasthan state namely Jaipur and Udaipur to evaluate the changes in air quality during lockdown and unlock phases. The results revealed a sharp decline in all the pollutants (PM2.5, PM10, SO2, NO2 and CO) during lockdown phase 1 as compared to concentration during Prelockdown phase except O3 which exhibited a reverse trend at both the sites with an increase in concentration during lock down phases. During the phase Unlock 1.0, pollutants showed an increase and then again a decrease during unlock 2.0. All the pollutants except O3 showed a negative and statistically significant (P>0.05) relationship with Planetary boundary layer (PBL). O3 showed a positive relationship with PBL significant at (P>0.05).The results indicate a need for formulation of new policies by the government with incorporation of planned restrictions on some activities to combat the problem of air pollution.
Key Words: Air Quality; Covid19; Lockdown; Pandemic.
Article History
Received: 17/11/2020; Accepted: 15/01/2021

Introduction

The pandemic, Severe Acute Respiratory Syndrome Coronavirus 2 (SARS Covid19) caused by the novel Coronavirus showed its effect worldwide with high mortality rates. In India, COVID 19 was reported in late December 2019 where the first confirmed case was reported in southern India in the state of Kerala on 30 January 2020 rapidly spreading all over the country in a very short period. According to medical science, the only way to prevent the spread of this deadly infection is social distancing. Keeping in view the rapid uncontrolled spread of the disease, the Indian government took robust steps to control the disease. By early to mid-March, different ministries of the country worked together to set up quarantine and medical treatment facilities across the country and prepared plans to arrest the spread of COVID 19. In addition to all other preparations, the most significant step to control the deteriorating situation led to a phase-wise lockdown in the country to maintain social distancing and checking the spread of the pandemic. There were restrictions implemented on various activities as per the lockdown phases and zones (Table 1). During phases 2, 3, and 4, cities were divided into zones as red with high-risk zone, orange with moderate risk, and green with low or no risk zone of the pandemic. Due to countrywide lockdown, industries, educational institutes, and other facilities came to a halt displaying two prominent effects; a sharp decline in the economy as a negative effect but improvement in environmental quality parameters as a positive effect indicating the resilience in the environment which has been adversely affected by the human activities. Rapid decline in air pollutants was evident all over the world. US space agency National Aeronautics and Space Administration (NASA) 2020, observed lower levels of aerosol through the satellite sensors in Northern India as during the lockdown phases compared to last 20 year. During the second lockdown, NASA data from space depicted that Particulate matter $PM_{2.5}$ and nitrogen dioxide (NO_2) levels had both reduced by at least 50 percent relative to average concentration in the same period during 2016-2019, as recorded by the same satellites. Other researchers have also reported an improvement in all the environmental quality parameters during the lockdown which could not be attained even after implementation of several action plans, protocols, technology interventions and other economic intensive methods (Zambrano- Monserrate *et al*., 2020). In India, the positive effect of lockdown was evident with improvement in the water quality of rivers Ganges which could not be done even after spending Rs.700 crores on the project Namami Gange implemented to improve the water quality of the river (Mani, 2020). Air quality also showed a significant improvement as the emissions from anthropogenic activities came to standstill. The air quality parameters showed drastic improvement which several air quality improvement programs like the National Clean Air Programme (NCAP) could not do. The Indian government allocated a budget of Rs 4,400 crore to deal with air pollution in Indian cities for the financial year 2020-21 which is much higher as compared to the amount of Rs 460 crores allocated for year 2019-20 (Nandi 2020). As a result of cessation all industrial activities and mass transportation during lockdown, the pollution level in 88 cities across the country drastically reduced down only after four days of commencing lockdown according to the official data from the Central Pollution Control Board (CPCB) leading to (~4 times) reduction of pollutants. These lowered pollution levels can reduce the risk of ~0.65 million deaths in India in a year (Sharma *et al*., 2020). Several publications all over the world reported enhancement in air quality during this lockdown phases for particulate matter, sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and volatile organic compounds (VOCs) (Li *et al*., 2020; Lal *et al*., 2020, Mahato *et al*., 2020). This brings some sigh of relief as deteriorating air quality has been one of the major causes of concern worldwide despite implementing several schemes and allocating a large amount of budget for improving the air quality.

The determination of the air quality parameters of any region, several factors need to be evaluated including the source and type of emission and the meteorological factors like temperature, wind speed, relative humidity which in turn affect the mixing heights. One such parameter for the determination of pollutant dispersion in an area is the planter boundary layer height. Planetary Boundary layer (PBL) or the atmospheric boundary layer (ABL) is the lower layer present in the troposphere that is in close contact with the surface of the earth where earth's surface strongly affects temperature, moisture, and wind through the turbulent transfer of air mass (Stull, 1988). The PBL has a profound effect on the concentration of pollutants in the troposphere (Quan *et al*., 2013; Athanassiadas *et al*., 2002). The boundary layer height (BLH) has been widely used to characterize the vertical dilution volume for pollutants (Li *et al*., 2019; Miao *et al*., 2019; Seidel *et al*., 2012; Stull, 1988).

Recently, the pandemic has led to a large number of publications related to changes in air quality during the lockdown. This paper is an attempt to evaluate the trend in changes in air quality during pre lockdown, lockdown and post lockdown phases(unlock phases) with reference to the major air pollutants, particulate matter with aerodynamic diameter less 2.5µm and diameter 10µm, Nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3). The relationship of PBL has also been calculated with the air pollutants at the different study sites to observe the concentration of pollutants with changing mixing heights in the atmosphere. For this purpose, two major objectives were considered for the present study i)Evaluation of percentage change in air quality parameters during a lockdown and Unlock phases in 2020 as compared to the concentration during 2019 and the average concentration of 2019 and 2018-19 ii) Study the relationship between the Planetary boundary layer and the concentration of air pollutants.

Table 1: Phases of Lockdown and Unlock with varying zone wise (red, Orange and Green) activities in India

Activities	**Phase 1 (25 March to 14))April 2020)**	**Phase 2 15 April – 3 May**			**Phase 3 (4–17 May)**			**Phase 4 (18–31 May)**			**Unlock 1.0 (1–30 June)**	**Unlock 2.0 (1–31 July)**
		Red	**Orang**	**Green**	**Red**	**Orang**	**Green**	**Red**	**Orang e**	**Green**		
Railway and Metro services	X	X	X	X	X	X	X	X	X	X	✓	✓
Educational institutions	X	X	X	X	X	X	X	X	X	X	X	X
Cinema halls, malls, etc.	X	X	X	X	X	X	X	X	X	X	X	X
Public gatherings and such events	X	X	X	X	X	X	X	X	X	X	X	X
Places of worship	X	X	X	X	X	X	X	X	X	X	X	X
Non-essential movement between 7 p.m. to 7 a.m.	X	X	X	X	X	X	X	X	X	X	X	X
Inter/intra-district buses with 50% capacity	X	X	X	X	X	X	X	X	X	X	✓	✓
Taxis with 1 driver and 2 passengers	X	X	X	X	X	X	X	X	X	X	✓	✓
Shops/e-commerce dealing essential goods	X	X	X	X	X	✓	✓	X	✓	X	X	✓
Industrial Activities	X	X	X	X	X	X	X	X	X	✓	✓	✓
Private offices with 33% capacity	X	X	X	X	X	X	X	X	X	X	✓	✓
Two-wheelers without pillion rider	X	X	X	X	X	✓	✓	X	✓	✓	✓	✓
Four-wheelers with 1 driver and 2 passengers	X	X	X	X	X	X	✓	X	✓	✓	✓	✓
Inter-state movement of goods	X	X	X	X	X	X	X	X	X	X	✓	✓

Methodology

Data Collection

The study focuses on two cities of Rajasthan state in India viz. Jaipur, and Udaipur. Jaipur, the capital of the state is a sub-humid region whereas Udaipur shows variation as the northeastern part being humid region and southwest part as a very humid region. The 24 hours average data for $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 has been obtained from Central Pollution Control Board (CPCB) New Delhi website for real-time air quality data (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing). Data for all the air quality parameters were collected for three monitoring stations in Jaipur namely Adarsh Nagar (Residential area), Police Commissioner ate (Commercial area) and Shastri Nagar (Industrial area),the mean for which for calculated for further analysis.Whereas for Udaipur only one monitoring station is available namely Ashok Nagar. Data was collected according to the different phases of lockdown and Unlock namely pre lockdown (1st February and 24th March), lockdown Phase 1(25 March- 14 April), Phase 2 (15 April- 3 May), Phase 3(4- 17 May), Phase 4(18- 31 May) and Unlock 1.0 (1-30 June) and Unlock 2.0 (1-31 July). For comparing the effect of lockdown on air quality, periods of three years has been considered, from February 2018 to July 2020 as per the lockdown and unlock phases.

The satellite images showing variation in air pollutants over the study area has been obtained from the website https://earth.nullschool.net/#2020/03/30/1800Z/particulates/surface/level/overlay=pm10/orthographic=75.75,26.82,873/loc=72.048,24.014

Calculation of Planetary Boundary layer

The Planetary boundary layer height for both the cities was calculated using archived data of NOAA's Air Resources Laboratory (https://ready.arl.noaa.gov). NOAA Hysplit trajectory model (https://www.ready.noaa.gov/HYSPLIT.php) considering data for 24 hours for each sampling day.

Statistical Analysis

The correlation between the PBL and air pollutants was derived using the software SPSS version 2019 considering PBL as the independent and air pollutants as the dependent variables.

Results and Discussion

Variability in Concentration of Pollutants during Phases of Lockdown and Unlock

The concentration of most of the pollutants was found to decline during lockdown phase1 as compared to Prelockdown phase at both the study sites; Jaipur and Udaipur. Pollutants were observed to increase with uplitment of some of the restrictions on industrial and transportation activities during Lockdown phase 3 and 4. Pollutants further decreased during Unlock 2.0 as compared to lockdown phase 4.

Particulate Matter ($PM_{2.5}$ and PM_{10})

A complete lockdown was implemented during Phase 1 and 2 with restriction on all the activities like industrial activities and transportation whereas during Phase 2 and 3 restriction on some of the activities was lifted as per the categorization of areas as Green, Orange and Red zones (Table 1).When the percentage change in pollutant concentration was calculated for each phase as compared to the previous phase, a distinct fluctuation in concentration of pollutants was observed.

The results of changes in PM concentration at both the sites in different phases of lockdown and unlock as compared to the previous phase are depicted in Table 2 and Figure 1and 2. $PM_{2.5}$ and PM_{10} at both the sites declined by (-36.48% and -21.38%) at Jaipur and

Table 2: Percentage change in pollutants during different phases of lockdown and unlock

	% change between Prelockdown and Lockdown 1	% change between Lockdown1 and Lockdown 2	% change between Lockdown 2 and Lockdown 3	% change between Lockdown3 andLockdown4	% change between Lockdown4 and Unlock 1.0	% change between Unlock 1.0 and Unlock 2.0
Jaipur						
$PM_{2.5}$	-36.48	23.76	16.40	-17.97	18.56	-13.78
PM_{10}	-21.38	33.21	-4.27	-2.65	9.84	3.80
NO_2	-8.49	11.57	41.07	-15.45	4.48	-5.56
SO_2	-24.94	142.22	24.05	7.53	17.14	-2.95
CO	-11.01	-37.67	-2.04	0.00	-17.07	-6.71
O_3	-23.27	-62.88	-18.75	34.00	475.00	-34.73
Udaipur						
$PM_{2.5}$	-33.16	-3.49	24.74	16.55	-25.83	-5.77
PM_{10}	-34.57	10.56	4.11	48.26	-39.09	-3.10
NO_2	-67.42	14.75	36.16	21.06	25.62	0.95
SO_2	-29.89	-26.87	59.38	-21.79	-23.51	50.57
CO	-51.49	-22.45	31.58	-6.00	65.96	-3.85
O_3	7.55	11.19	4.68	-8.74	-12.88	-27.69

(-33.16% and -34.57%) at Udaipur respectively during lockdown phase 1 as compared to Prelockdown phase. Similar results have been reported by Dantas et.al., 2020 at Brazil where the levels of PM reduced sharply at the initial phase of lockdown. The levels of PM then increased during lockdown phase 3 and 4 and Unlock 1. Further, the levels of $PM_{2.5}$ lowered by (-13.78%) and (-5.77%) at Jaipur and Udaipur respectively and PM_{10} decreased by (-3.10%) at Udaipur during Unlock phase 2. This reduction can be attributed to the onset of monsoon during this period leading to wash down of pollutants from the atmosphere.

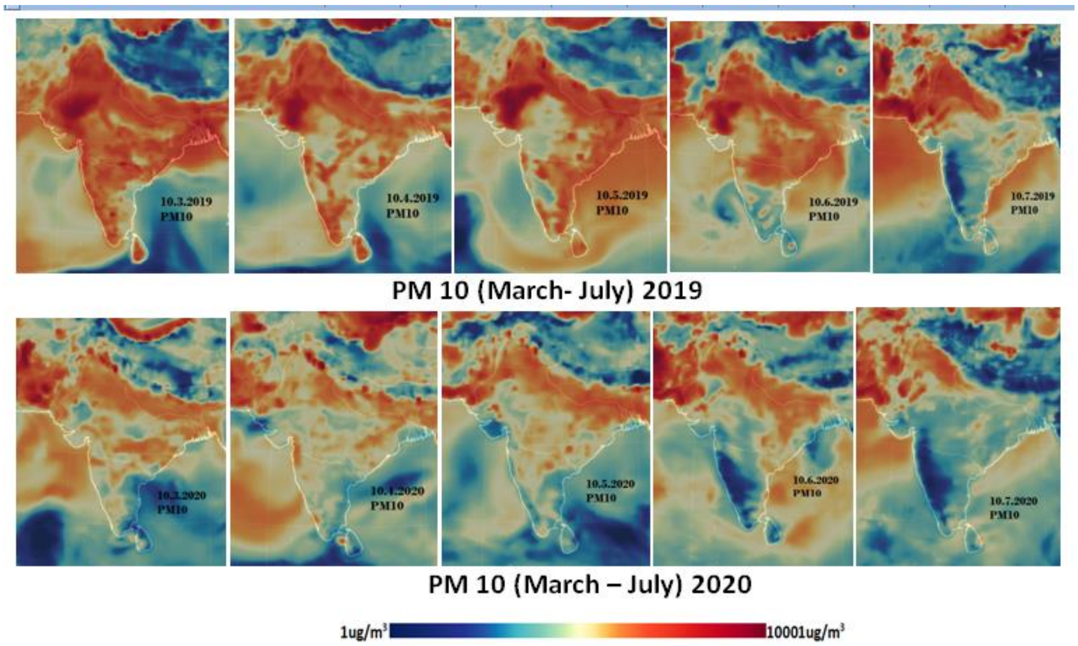


Figure 1: Variability in PM_{10} during March –July (2019 -2020)

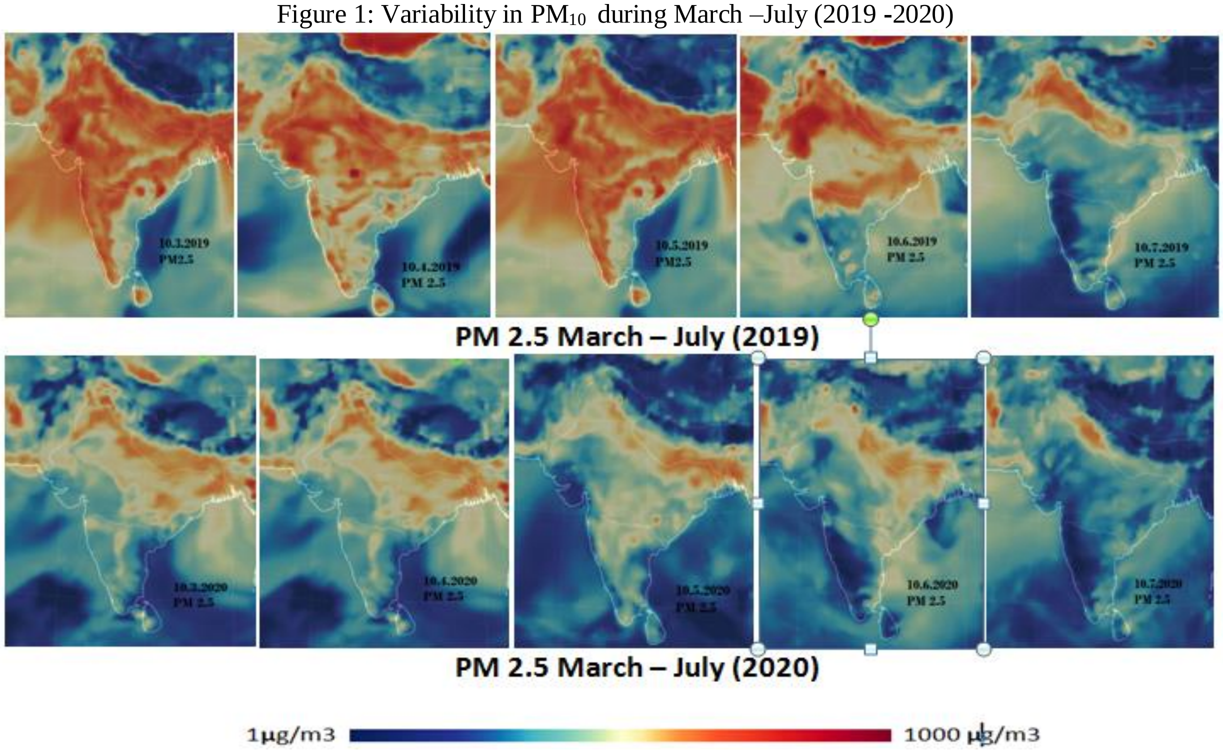


Figure 2: Variability in $PM_{2.5}$ during March –July (2019 -2020)

Gaseous Pollutants

The gaseous pollutants also showed a decrease during the lockdown phase 1 as compared to Prelockdown phase. The percentage decrease of pollutants was NO_2 (-8.49% and -67.42%), SO_2 (-24.94% and -29.89%) and CO (-11.01% and -51.49%) at Jaipur and

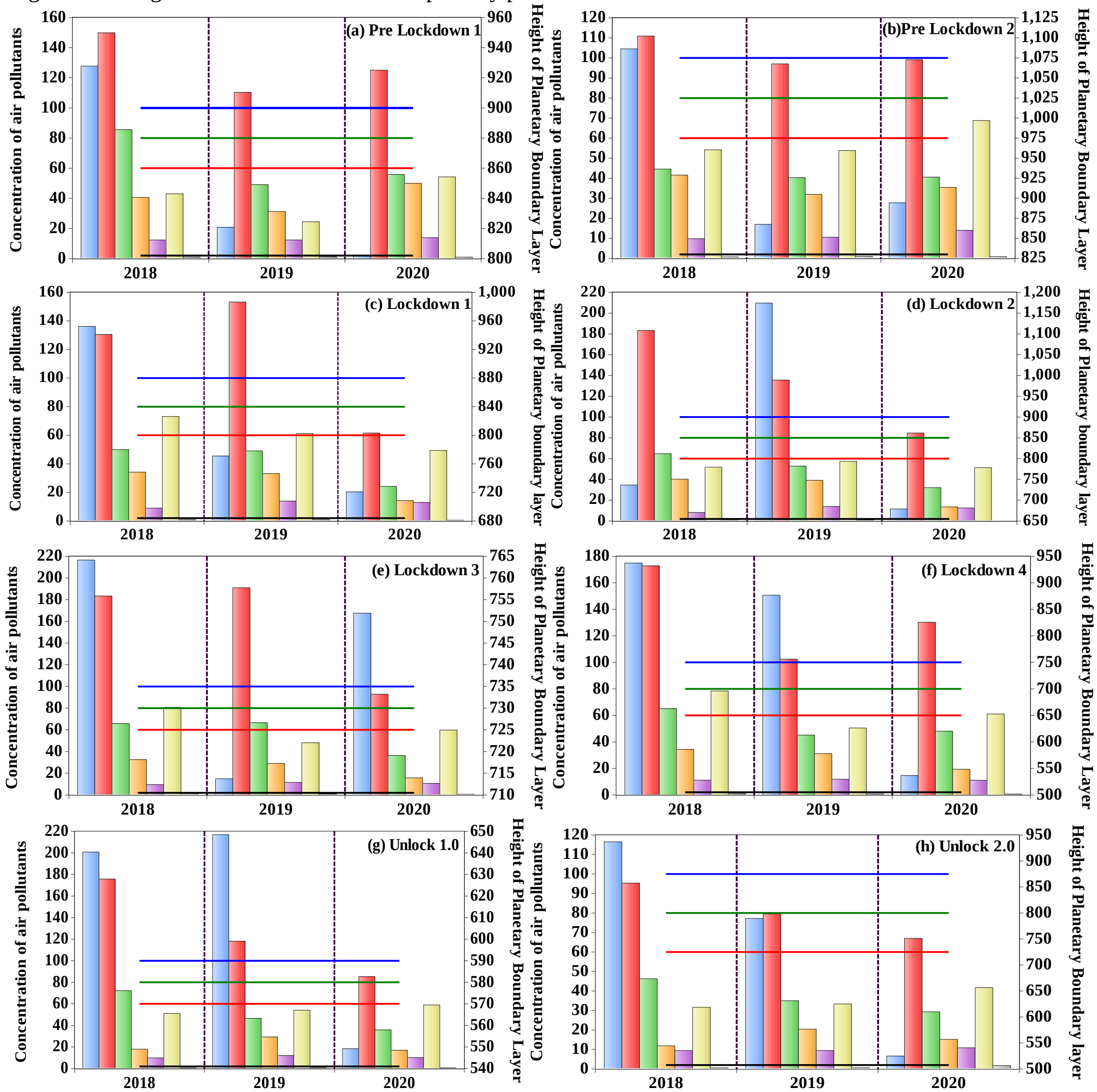
Udaipur respectively. The concentration then gradually increased with upliftment of restrictions during lock down phase 2, 3, and 4. (Table 2)

The concentration of O_3 at both the cities showed a reverse trend (Table 2) with an increase during the lockdown phase and a decrease in concentration during the unlock phase. Similar trend has been reported by Huang et. al., 2020 in China , Tobias et.al, 2020 in Spain and Kerimray et.al., 2020 at Kazakhstan during the Covid 19 lockdown.

There can be two reasons for this trend of ozone Firstly, the increase in O_3 can be attributed to the decrease in particulate matter in the atmosphere leading to increase in the solar activity assisting in the photochemical reaction and in turn enhanced formation of O_3. Secondly, the decreases in nitrogen oxide (NO) leads to lowering of the O_3 consumption in the troposphere as per the reaction titration, (NO=O3=NO2+O2) and cause an increase in O_3 concentration (Mahato et.al., 2020).

Variability of pollutant concentration between 2018-19 and 2020

While comparing the means of all the pollutants during 2018-19 and 2020 (Table 3-5 and figure 3 and 4) during similar time durations (Lockdown and Unlock phases) at both the sites, most of pollutants were found to reduce except the levels of Ozone which has shown a increasing trend during lockdown with decrease in primary pollutants and increase in solar irradiation.



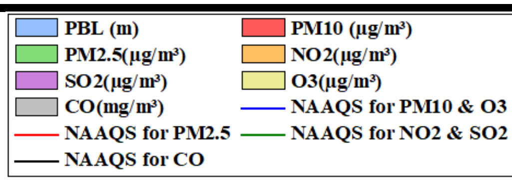


Figure 3:Mean Concentration of air pollutants and Height of Planetary boundary layer in different phases of lockdown in Jaipur.(a) Pre- Lock down 1 (1-28 Feb 2018 to 2020);(b) Pre- Lock down 2 (1-22 March 2018 to 2020); (C)Lock down 1 (23 March- 15 April 2018 to 2020); (d)Lock down 2 (16 April-3 may 2018 to 2020);(e) Lockdown 3 (4 -17 May 2018-2020);(f) Lockdown 4 (18-31 May 2018 to 2020);(g) Unlock 1.0 (1-30 June 2018 to 2020); (h) unlock 2.0 (1-7 July 2018 to 2020)

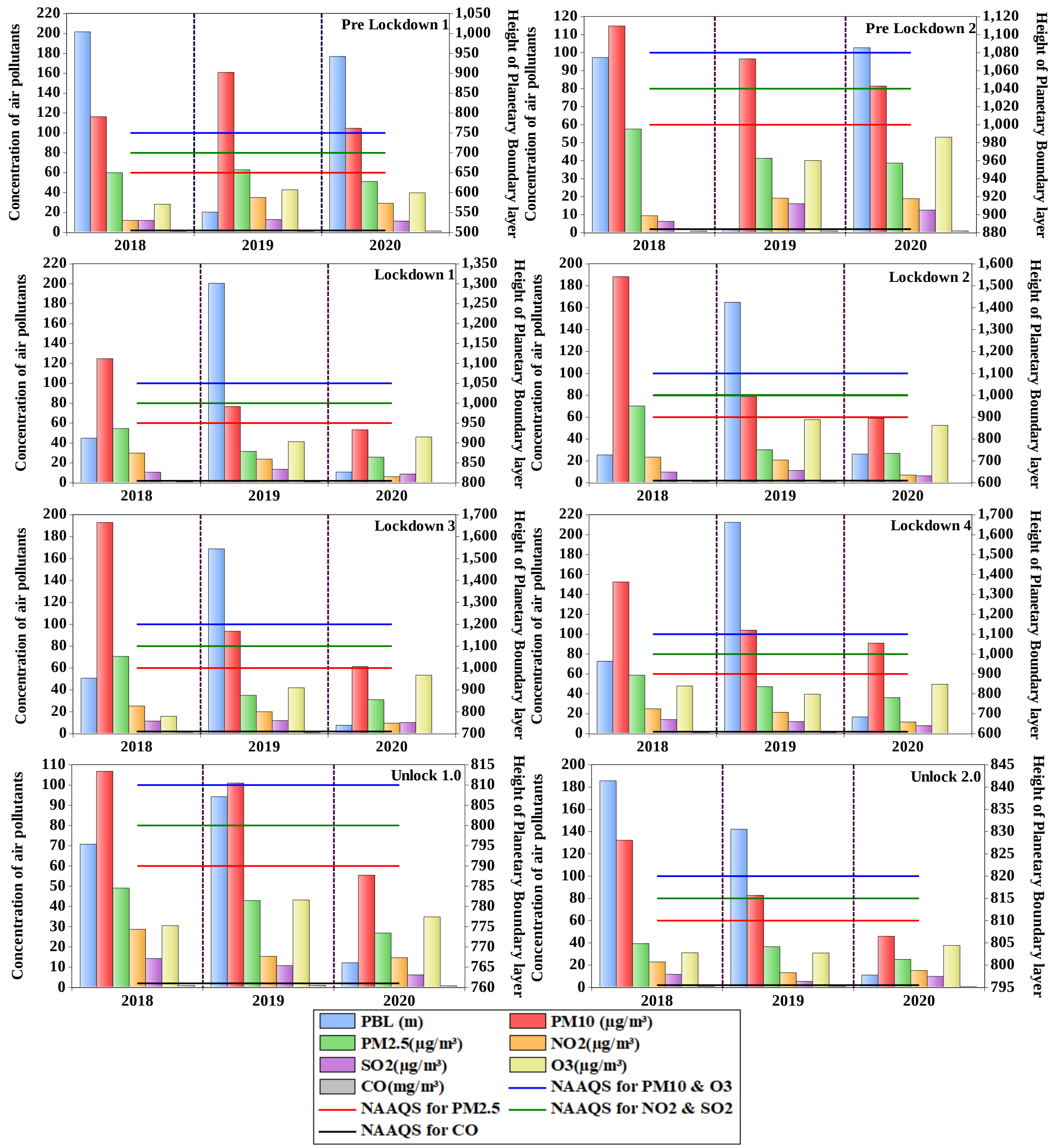


Figure 4: Mean Concentration of air pollutants and Height of Planetary boundary layer in different phases of lockdown in Udaipur.(a)

Pre- Lock down 1 (1-28 Feb 2018 to 2020);(b) Pre- Lock down 2 (1-22 March 2018 to 2020); (C)Lock down 1 (23 March- 15 April 2); (d)Lock down 2 (16 April-3 may 2018 to 2020);(e) Lockdown 3 (4 -17 May 2018-2020);(f) Lockdown 4 (18-31 May 2018 to 2020);(g) Unlock 1.0 (1-30 June 2018 to 2020); (h) unlock 2.0 (1-7 July 2018 to 2020)

Table 3: Concentration of Particulate Matter (PM) (2018-2020) and percentage variation during different phases of Lockdown and Unlock

	Jaipur								**Udaipur**							
	PM 2.5(µg/m3)				**PM10(µg/m3)**				**PM 2.5(µg/m3)**				**PM10(µg/m3)**			
Lockdown phases	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**
Pre-Lockdown (1Feb -22 March)	36.3 ±6.30	31.8 ±8.71	-12.29	6.83	99.6 ±15.68	86.7 ±40.32	-12.93	7.25	49.5 ±18.71	38.6 ±6.876	-21.84	-6.47	105.7 ±39.61	81.49 ±15.57	-22.90	-15.59
Lockdown 1 (25 March - 15 April)	42.8 ±10.37	20.2 ±7.08	-52.72	-48.26	137.8 ±89.06	54.5 ±24.16	-60.43	-62.58	43.1± 4.733	25.8 ±6.01	-39.99	-18.19	100.6 ±12.37	53.32 ±14.07	-47.01	-30.35
Lockdown 2 (16 April-3 may)	49.8 ±13.52	25.0 ±8.65	-49.73	-43.44	160.5 ±46.64	72.6 ±40.73	-54.78	-40.61	50.1 ±12.98	24.9 ±6.43	-50.25	-10.84	133.47 ±46.92	58.95 ±21.3	-55.83	-25.10
Lockdown 3 (24 -17 May)	56.3 ±21.877	29.1 ±13.51	-48.23	-49.50	188.01 ±88.24	81.0 ±37.13	-56.92	-55.83	52.9 ±11.16	31.06 ±6.20	-41.30	-11.58	143.35 ±33.24	61.37 ±10.98	-57.19	-34.51
Lockdown4 (18 -31 May)	63.4 ±4.59	23.87 ±8.51	-33.29	15.13	98.8 ±12.85	196.21 ±44.75	-2.64	9.71	53.0 ±13.95	36.2 ±11.48	-31.62	-23.23	128.28 ±44.52	90.99 ±50.32	-29.07	-12.52
Unlock 1- (1-30 June)	58.0 ±12.96	28.3 ±7.16	-51.23	-28.63	142.0 ±48.82	122.32 ±31.27	-13.89	19.32	46.0 ±12.77	26.85 ±5.19	-41.64	-37.45	103.8 ±27.85	55.42 ±14.12	-46.64	-45.11
Unlock 2 (1-31 July)	41.5 ±10.56	24.4 ±11.19	-41.12	-19.32	86.5 ±30.62	45.4 ±29.68	-47.41	-36.22	35.2 ±11.59	25.3 ±4.83	-27.96	-15.23	92.31 ±34.46	53.7 ±11.71	-41.82	-23.28

Table: 4 Concentration of gaseous pollutants (2018-2020) and percentage variation during different phases of Lockdown and Unlock at Jaipur

	NO2(µg/m3)	**SO2(µg/m3)**	**CO(µg/m3)**	**O3(µg/m3)**

Lockdown phases	Mean and SD 2018-2019	Mean and SD 2020	Percent variation 2020 and Avg of 2018-2019	Percent Variation 2020-2019	Mean and SD 2018-2019	Mean and SD 2020	Percent variation 2020 and Avg of 2018-2019	Percent Variation 2020-2019	Mean and SD 2018-2019	Mean and SD 2020	Percent variation 2020 and Avg of 2018-2019	Percent Variation 2020-2019	Mean and SD 2018-2019	Mean and SD 2020	Percent variation 2020 and Avg of 2018-2019	Percent Variation 2020-2019
Pre-Lockdown (1Feb -22 March)	36.7 ±10.49	30.2 ±10.16	-17.63	-9.39	8.9 ±2.18	12.3 ±2.17	39.19	22.26	0.65 ±0.173	0.77 ±0.24	15.06	10.95	65.0 ±11.39	52.6 ±13.22	-19.08	3.92
Lockdown 1 (25 March - 15 April)	35.3 ±10.27	11.7 ±3.67	-66.59	-68.63	10.4 ±2.57	11.3 ±2.23	8.19	-7.15	0.83 ±0.265	0.61 ±0.17	-36.36	-30.30	68.0 ±11.59	65.8 ±9.21	-3.23	16.71
Lockdown 2 (16 April-3 may)	37.5 ±12.12	11.2 ±2.39	-70.08	-73.74	9.4 ±2.96	11.0 ±2.62	16.76	-0.34	0.79 ±0.24	0.67 ±0.16	-18.47	-31.99	55.9 ±15.20	68.3 ±12.06	22.18	11.48
Lockdown 3 (24 -17 May)	35.0 ±11.64	15.8 ±3.88	-54.83	-58.26	8.1 ±0.907	9.3 ±2.76	14.49	9.39	0.91 ±0.23	0.7 ±0.25	-18.72	-27.24	59.2 ±8.82	64.5 ±11.15	8.95	26.66
Lockdown4 (18 -31 May)	35.6 ±10.10	19.6 ±4.32	-44.85	-58.77	8.4 ±1.93	10.0 ±2.89	18.62	-6.25	0.82 ±0.16	0.82 ±0.23	-0.18	-17.75	55.2 ±13.91	62.6 ±15.23	13.41	11.44
Unlock 1- (1-30 June)	27.0 ±8.99	19.2 ±3.05	-28.96	-43.21	8.7 ±1.61	10.0 ±1.69	15.03	-7.73	0.7 ±0.22	0.68 ±0.15	-12.97	-23.52	54.7 ±16.88	58.4 ±14.49	6.76	3.06
Unlock 2 (1-31 July)	21.2 ±7.56	15.6 ±7.71	-26.19	-32.03	8.8 ±0.96	13.4 ±10.58	52.73	42.70	0.81 ±0.123	3.91 ±7.70	79.16	33.60	29.4 ±12.13	38.12 ±17.03	29.66	39.96

Table 5: Concentration of gaseous pollutants (2018-2020) and percentage variation during different phases of Lockdown and Unlock at Udaipur

	NO_2(μg/m3)				SO_2(μg/m3)				CO(μg/m3)				O_3(μg/m3)			
Lockdown phases	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**	**Mean and SD 2018-2019**	**Mean and SD 2020**	**Percent variation 2020 and Avg of 2018-2019**	**Percent Variation 2020-2019**

Pre-Lockdown (1Feb - 22 March)	14.33 ±5.24	18.94 ±9.21	32.15	-1.35	11.22 ±5.62	12.58 ±2.41	12.15	-22.01	0.94 ±0.302	1.01 ±0.36	7.95	3.25	40.08 ±10.94	53.08 ±11.16	32.44	32.44
Lockdown 1 (25 March-15 April)	26.87 ±8.82	6.17 ±1.257	-77.04	-74.10	12.19 ±2.541	8.82 ±2.21	-27.57	-35.24	0.97 ±0.179	0.49 ±0.138	-49.49	-45.38	41.28 ±8.334	46.09 ±9.861	11.65	11.65
Lockdown 2 (16 April-23 may)	22.21 ±3.301	7.08 ±3.14	-68.13	-66.16	10.61 ±1.57	6.45 ±1.341	-39.19	-43.29	0.98 ±0.19	0.38 ±0.1	-61.28	-49.60	37.74 ±15.88	59.48 ±9.78	57.61	57.61
Lockdown 3 (24 -17 May)	22.67 ±3.96	9.64 ±2.17	-57.45	-51.92	11.82 ±1.48	10.28 ±1.94	-12.96	-14.80	1.04 ±0.19	0.50 ±0.11	-51.34	-44.07	28.9 ±9.7	53.45 ±10.96	84.46	27.40
Lockdown4 (18 -31 May)	23.22 ±6.28	11.67 ±2.66	-49.72	-45.65	13.17 ±2.34	8.04 ±1.34	-38.93	-33.72	0.94 ±0.19	0.47 ±0.132	-49.49	-37.50	43.79 ±7.64	49.64 ±8.47	13.37	25.09
Unlock 1- (1-30 June)	22.04 ±5.11	14.66 ±4.106	-33.46	-4.53	12.51 ±3.57	6.15 ±0.41	-50.78	-42.80	0.98 ±0.199	0.78 ±0.17	-19.86	-24.54	44.83 ±9.01	46.83 ±10.17	4.47	8.48
Unlock 2 (1-31 July)	14.03 ±4.72	14.80 ±5.92	5.44	48.29	6.73 ±1.695	9.26 ±0.66	37.52	92.84	0.82 ±0.330	0.75 ±0.14	-9.31	-10.18	28.72 ±11.48	29.2 ±7.20	1.66	10.55

Relationship between PBL and air pollutants

The strength of the statistical association between the pollutants and PBL height was calculated using linear regression taking PBL as Independent variable and air pollutants as the dependent variables. The mean height of PBL was 989.68 meters from February to May and 523.45 meters from June to July at Jaipur whereas the mean height was 1045 meters and 499.86 meters from February to May and June to July respectively at Udaipur.

To find the relationship between Planetary Boundary layer (PBL) and air pollutants, the months of June and July were considered separately as the monsoon period. During monsoon period there is sufficient variation in, meteorological parameters like precipitation, temperature, relative humidity wind speed affecting the height of PBL layer as compared to winter and summer seasons. At Jaipur, a strong significant ($P>0.05$) negative correlation was found between $PM_{2.5}$($R=-0.42$), PM_{10}($R=-0.46$), NO_2($R=-0.36$), SO_2($R=-0.26$) Whereas CO showed a non-significant but negative relationship CO($R=-0.22$)($P< 0.05$) with Planetary Boundary Layer Height. Opposite to this, O_3 showed a Positive and a non-significant relationship with PBL height ($R=0.12$) ($P<0.05$). The negative relationship can be explained with the fact that as the mixing heights increase, pollutants are easily dispersed. In the atmosphere, the fate of pollutants (e.g., dispersion, mixing, transport, transformation, deposition) is strongly dependent on the height of PBL (Miao *et al*., 2019). While considering the movement of pollutants in a vertical direction, the thermal stratification controls the intensity of thermal buoyancy and the PBL. Wind and surface roughness in combination establishes the strength of mechanical turbulence (Stull, 1988). Together they are responsible for regulating the upward dispersion of pollutants.

The positive correlation between PBL and O_3 can be explained because increasing temperature increases the photolysis efficiency and in turn O_3 concentration. These findings can be corroborated with the findings of Dey et.al, (2018).

Similarly, at Udaipur a strong significant ($P>0.05$) negative correlation was found between $PM_{2.5}$ ($R=-0.46$), PM_{10} ($R=-0.42$), NO_2 ($R=-0.33$), SO_2 ($R=-0.27$), CO($R=-0.23$).Whereas O_3 showed a positive ($R=0.20$) and significant ($P>0.05$) relationship with PBL Height. These results are in line with the findings of Liu *et al*., (2018) where an anti-correlation was reported with $PM_{2.5}$ in Central

China between the years 2013-2016 (Tiwari et al., 2014 and Yadav et al., 2014).Where a negative relationship was found between $PM_{2.5}$ in Delhi and Udaipur in India.
During the monsoon season (June-July) at both the study sites, a weak positive relationship with PBL height was observed for $PM_{2.5}$ and PM_{10} (R=0.21) and (R=0.31) respectively at (P>0.05) significance at Jaipur and (R=0.19) and (R=0.21) at (p< 0.05) at Udaipur. Other pollutants showed a weak negative relationship with PBL height NO_2 (R=-12), SO_2 (R=-0.19), CO (R=-0.13) with (P>0.05) with an exception to O_3 with a positive relationship (R=0.20) with (P>0.05) at Jaipur. Similarly, at Udaipur the relationship with PBL height was positive for $PM_{2.5}$ (R=0.19), PM_{10} (R=0.24), O_3 (R=0.30) with (P<0.05) whereas other pollutants shows a negative relationship NO_2 (R=-0.16), SO_2(R=-0.17) with (P<0.05) and CO(R=-0.23) with (P>0.05). The results obtained are in agreement with the observations of (Tiwari et al., 2014 and Yadav et al., 2014).

Conclusion

The poor quality of air in India is a result of unplanned development and population explosion. Air quality has always been being a serious cause of concern for scientists and policymakers where no efforts worked to improve the quality of air and in turn quality of life. The outcome of the present study clearly shows the capacity of nature to restore itself as soon as human interference is reduced. This is evident from the rapid improvement of the air quality within 21 days of complete restriction of activities in the country. Thus this indicates a serious need to reframe our policies for industrial and other activities leading to emissions. It is recommended to plan policies for such intermittent lockdown which would not only upgrade the environmental quality parameters but also help to further conserve the natural resource and make the earth a better place to live on.

Acknowledgments

The authors are thankful to the Central pollution Control Board(CPCB), New Delhi and NASA Earth Observatory for making the air quality data available for the study period.

Disclaimer

The authors have no conflicts of interest.

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