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Understanding the changes in untangled drivers of air pollution during and after COVID -19 pandemic lock down in Central India

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ABSTRACT

COVID 19 pandemic was declared by World Health Organization on 11th March, 2020 and from 25th March Indian government implemented a nationwide lockdown, initially for 21 days which was extended till 31st May 2020. During this period of this lockdown, there was almost a standstill in all human activities for a period of 68 days, including the transport of vehicles, shutting down the industries and all establishments. The present study has assessed the impact of lockdowns on certain air quality parameters in Central India before and during the period of COVID-19 calamity. Concentrations of 7 pollutants $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3 and NH_3 were analysed during 16th January to 23rd March, 2020 (before lockdown) and 25th March to 31st May, 2020 (during lockdown) in six major cities of Central India were analysed. The results indicated that the quality of air was significantly improved during lockdown period. Overall reduction in concentrations of $PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, and CO was 36.27%, 25.6%, 58.31%, 30.65%, 23.79%, and 37.87% respectively. Air quality index (AQI) in pre lockdown and during lockdown phases in districts of Indore, Bhopal, Jabalpur, Gwalior, Ujjain and Sagar was found to be reduced by -21.69%, -28.88%, -40.67%, -40.46%, -15.57%, -9.11% respectively. Concentration of ozone (O_3) in all the six cities under study was found to decrease in unlock periods 2.0 and 3.0 which had more relaxations as compared to 1.0. Our study is thought to be a functional supplement to the regulatory bodies that significant improvement in air quality could be expected if execution of pollution source control would be implemented in a suitable time interval. Use of traffic management system on the lines of GPS is suggested to relieve the air quality burden.
Keywords: *COVID 19, air pollution, lockdown, AQI, unlock, particulate matters*
Abbreviations: *$PM_{2.5}$: Fine particulate matter less than 2.5 micrometre in size; PM_{10}: Fine particulate matter less than 10 micrometre in size; NO_2: Nitrogen dioxide; SO_2: Sulphur dioxide; CO: carbon mono-oxide; O_3: Ozone; NH_3: Ammonia; (COVID-19): coronavirus disease 19; AQI: Air quality index.*

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INTRODUCTION

Air pollution is a serious public health and environmental problem worldwide and has become major environmental issue in both developed and developing countries. On an average over 1.2 million early deaths have been recorded due to environmental pollution, especially in major Indian cities [1]. In India, high population growth has triggered industrialization, and rapid increase in vehicular traffic, which adversely affects the air quality [2]. Among air pollutants, particulate matter is the most dominating pollutant in major areas of India including Central India [3,4]. The exasperated concentrations of air pollutants such as particulate matter pose serious threat to human health and environment. Dust and vehicle emissions are the main source of particulate matter in Central India. In Bhopal and Indore, two major cities of Madhya Pradesh (Largest state of Central India), the total concentration of particulate matters has always found to be beyond the permissible limits [5,6,7,8]. Accordingly, Indore is the 68th most polluted city in the world [9]. The novel coronavirus disease 19 (COVID-19) is highly contagious and is of great public health concern globally. It was first observed in Wuhan city of China in December, 2019. But the exact origin of the virus continues to remain as mystery [10,11,12]. On March 11, 2020, WHO has declared COVID-19 as pandemic and as of 1st June 2020, the world health Organisation has reported 97,008 positive cases and 5608 death cases in India due to COVID-19[13]. But regrettably, India has now become the epicentre of COVID 19 with 5,640,496 positive cases and 90021 death cases as of 22nd September 2020. In India, the nationwide lockdown for fourteen hours in the name of 'Janta curfew' was imposed on 22nd March 2020, followed by 21 days of complete lockdown from 25th March, to 3rd May 2020. This was the second phase of lockdown in India. On May 1st, the period of lockdown was further extended to 17th May with some relaxations, being the third phase of lockdown. It was further extended to the fourth phase, from 18th May to 31st May 2020. Due to this lockdown, the industrial operations, constructions and even transportations were prohibited. Thus, there was almost a standstill in all human activities for a period of 68 days. As a result, there has been a reduction in emission of air pollutants from industries and transportation and the pollution level in many cities of India has been surprisingly reduced down according to the official data from Central pollution control board (CPCB) [14,15]. Thus, the social lockdown presumed to be an alternative measure to control air pollution and the present study has been aimed to analyse the degree of change in important air quality parameters during the lockdown period of 68 days in six major cities of Central India. Consequently, a quantitative measurement of major air pollutants such as $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3 and NH_3 during the lockdown period has been carried out to understand the impact and significance of long-term lockdown on air quality in six major cities (Indore, Bhopal Jabalpur, Gwalior, Ujjain, Sagar) of Central India. The locations of these cities are encircled in the map of Madhya Pradesh, India showing that they are geographically apart and have significant distances among them. They almost cover an area of 1001 Km^2 of the state of Madhya Pradesh [Figure 1].

MATERIALS AND METHODS

In order to study the air quality status during the lockdown period of cities of central India including Indore, Bhopal Jabalpur, Gwalior, Ujjain, Sagar, data from their respective air quality monitoring stations have been taken into consideration. The concentration of different air pollutants for the time period of 16th January to 23rd March 2020 (Before lockdown), 25th March 2020 to 31st May 2020 (During lockdown) and from 1st June 2020 to 30th June 2020 (unlock 1.0), unlock 2.0 (1st to 31st July 2020) and unlock 3.0 (1st to 31st August 2020) were analysed. The daily concentration of seven air pollutants including particulate matters ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_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/data)Air quality index (AQI) has been calculated in order to understand the improvement in air quality. The AQI details are available in CPCB (2014) report, [16] and briefly outlined here. The AQI is divided into six categories as good, satisfactory, moderate, poor, very poor and severe. **[Table 1].** The Indian national air quality standard (INAQS) has considered eight parameters namely $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3, NH_3, Pb, having short term standard for near real-time dissemination of air quality index. It has been recognised that concentrations of lead (Pb) in air are not known in real time and cannot contribute to AQI [16]. Hence, in the present study seven pollutant parameters ($PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3 and NH_3) have been studied individually to investigate the positive impact of unconventional policy intervention in the form of lockdown on air quality. The sub-indices of each pollutant at the monitoring stations of the cities under study have been calculated for 24-hour mean data (8h for CO and O_3). Although all the seven pollutants may not be monitored in all the stations but the overall AQI can be calculated only if the data are available for minimum three pollutants, of which one should necessarily be either $PM_{2.5}$, or PM_{10}. Presently, CPCB provides web-based system for AQI calculation. This web-based system has been programmed in continuously monitoring stations whereas for manual monitoring stations; air quality index calculator has been developed. The procedure of AQI calculation was carried out following the method of CPCB [16].

RESULTS AND DISCUSSION

In India, strict measures have been taken by the government to minimize the movement of vehicles and social contact in order to execute the complete lockdown during the pandemic. This action has consequently reduced the emission of major air pollutants as hotels, restaurants, industries, administrative centres and many others were closed by strict administrative order. As a result, air quality of different regions including major cities of Central India got improved and the concentration of most dominating pollutants: PM_{10}, $PM_{2.5}$, NO_2, and SO_2 during the study period (25th March to 31st May, 2020; lockdown phase of 68 days) were found to drastically decrease as compared to the same period of 68 days of pre-lockdown phase (16th January to 23rd March, 2020). We observed significant decrease in concentrations of PM_{10} by -26.84%, -31.05%, -40.28%, -28.66%, -17.93%, and $PM_{2.5}$ by -44.94%, -38.33%, -47.07%, -55.28%, -30.35%, in Indore, Bhopal, Jabalpur, Gwalior, and Ujjain respectively during lockdown period in comparison to the period of before lockdown. But in Sagar there was a less significant decline in PM_{10} (-8.84%) and $PM_{2.5}$ (-1.67%) concentrations [Table 2]. Our results of reduction in particulate matters (PM_{10} and $PM_{2.5}$) are similar to the findings reported by Zambrano-Monserrate *et al,*[17]. The findings of Nakada [18] and Bera *et al.* [19] have also reported 29.8% and 17.5% reduction in $PM_{2.5}$ concentrations in Sao Paulo state, Brazil and Kolkata, India respectively.

In all the six cities under study, we have found high reduction in concentration of NO_2 during lockdown period as compared to the period before the lockdown. It has been reduced by-52.18%, -73.34%, -54.49%, -54.94%, -61.94%, -52.98% in Indore, Bhopal, Jabalpur, Gwalior, Ujjain and Sagar respectively. A recent study by He *et al.* [20] has demonstrated that the major source of nitrogen compounds is the traffic emission from heavy vehicles. So, during lockdown period, vehicle traffic was reduced and hence considerable decrease in NO_2 concentration was observed. Similar to our results, the findings of Shehzad *et al.* [21] have also found decrease in NO_2 concentration of Delhi and Mumbai, India during lock down phase. Other pollutants such as SO_2, NH_3 and CO were also drastically reduced in all the regions under study. **[Table 2].** By contrast, we observed an increase of 70.81%,11.78%, 64.13%, 6.91% in concentration of ozone in Indore, Bhopal, Jabalpur, Gwalior respectively during lockdown period as compared to prelockdown period. Our results are consistent with the study of Tobias *et al.* [22] who have observed 57.77% increase in ozone concentration in Barcelona, Spain. There may be either of the two reasons of increase in ozone concentration. First, increased concentration of ozone has been associated with the decrease of NO which may cause a decrease in ozone consumption and ultimately results in higher ozone concentration [22,23,24]. Second, maximum ozone is generally recorded from March to August in northern hemisphere due to northward migration of sun lead to an increase of ozone [23]. However, change in climate was not considered in this study. **Table 3** shows the change in air quality index of Indore, Bhopal, Jabalpur, Gwalior, Ujjain and Sagar. Overall, a significant improvement was observed in AQI in all the cities under study during lockdown period as compared to pre-lockdown phase. AQI was reduced by -21.69%, -28.88%, -40.66%, -40.46%, -15.57% and -9.11% in Indore, Bhopal, Jabalpur, Gwalior, Ujjain and Sagar respectively. This reduction in AQI is predominantly associated with the change in dominating pollutants such as $PM_{2.5}$, PM_{10}, NO_2, and SO_2 during lockdown period. Similar to our results Sharma *et al.* [25] have also reported reduction in AQI in various regions of India during the lockdown periods as compared to the same period in previous years of normal human activities. Analogously, Mahato *et al.* [26] have also reported 54%, 49%, 43%, 37% and 31% reduction in AQI of Central, Eastern, Southern, Western, and Northern parts of the megacity of India, Delhi. All such studies including our study clearly indicate that the quality of air has been improved if such kind of restrictions to the transportations and industrial processes are implemented. As reopening or unlock in India has started from June 1st 2020, ease from various restrictions has been provided. Hotels, shops, restaurants were opened and other activities such as gymnasium, swimming pools, auditorium, shopping malls and all inter or intrastate travel with limited international travel were permitted in subsequent phases of unlock. **Figure 2** shows the mean concentration of pollutants during phases of unlock in Indore, Bhopal, Jabalpur, Gwalior, Ujjain and Sagar. We observed very surprising results, as PM_{10} and $PM_{2.5}$ were found decreased in unlock 2 and 3 as compare to unlock 1 in all the six cities under study. Similar in case of NO_2 and NH_3 concentration (except in Sagar, as there was no data found for NH_3 in Sagar) which were also decreased but there was increase in SO_2 concentration in Indore, Jabalpur and Ujjain. On the contrary, ozone concentration was decreased significantly in all six cities (except in Sagar, as there was no data found for O_3 in Sagar) in unlock 2 and 3 in comparison to unlock 1 as shown in **figure 3.** The decrease in ozone concentration is clearly explained by the unprecedented increase in NO_x emission mainly due to augmented road transport, leading to a higher ozone titration by the NO_x. High significant reduction in O_3 concentration was found in Jabalpur and Gwalior as compare to other four cities.

Table 1: AQI categories, range, health breakpoints for seven pollutants and associated health impacts. (Source: CPCB, 2014). [16]

AQI category (range)	Concentration range of pollutants							Associated Health impacts
	PM_{10} 24 h (μg/m³)	$PM_{2.5}$ 24 h (μg/m³)	NO_2 24 h (μg/m³)	SO_2 24 h (μg/m³)	O_3 8 h (μg/m³)	CO 8h (mg/m³)	NH_3 24 h (μg/m³)	
Good (0-50)	0-50	0-30	0-40	0-40	0-50	0-1	0-200	Minimal impact
Satisfactory (51-100)	51-100	31-60	41-80	41-80	51-100	1.1-2	201-400	Minor breathing discomfort to sensitive people
Moderately polluted (101-200)	101-250	61-90	81-180	81-380	101-168	2.1-10	401-800	Breathing discomfort to people with lung disease and discomfort to people with heart disease, children and others

Poor (201-300)	251-350	91-120	181-280	381-800	169-208	10.1-17	801-1200	Breathing discomfort to people on prolonged exposure and people with heart disease on short exposure
Very poor (301-400)	351-430	121-250	281-400	801-1600	209-748	17.1-34	1201-1800	Respiratory illness to the people on prolonged exposure
Severe (401-500)	430+	250+	400+	1600+	748+	34+	1800+	Respiratory impacts on healthy people and serious health effect on people with lung and heart diseases

Table 2: Daily mean concentration and variation of seven pollutants during the period of 16th January to 23rd March, 2020 (before lockdown) and 25th March to 31st May, 2020 (during lockdown)

Cities	Air Pollutants	Mean concentration (in µg/m³ and mg/m³ for CO) of pollutants before lockdown (16th January to 23rd March, 2020)	Mean concentration (in µg/m³ and mg/m³ for CO) of pollutants during lockdown (25th March to 31st May, 2020)	Relative change (in %)
Indore	$PM_{2.5}$	50.27	27.68	-44.94
	PM_{10}	134.48	98.38	-26.84
	NO_2	78.4	37.49	-52.18
	NH_3	24.21	12.73	-47.42
	SO_2	11.46	7.52	-34.39
	CO	0.91	0.38	-58.24
	O_3	32.37	55.29	70.81
Bhopal	$PM_{2.5}$	49.52	30.54	-38.33
	PM_{10}	133.57	92.09	-31.05
	NO_2	36.27	9.67	-73.34
	NH_3	17.1	14.03	-17.95
	SO_2	15.91	12.03	-24.39
	CO	0.88	0.47	-46.59
	O_3	62.55	69.92	11.78
Jabalpur	$PM_{2.5}$	59.19	31.33	-47.07
	PM_{10}	137.97	82.4	-40.28
	NO_2	47.73	21.72	-54.49
	NH_3	11.88	9.44	-20.54
	SO_2	8.7	6.94	-20.23
	CO	0.95	0.48	-49.47
	O_3	41.37	67.9	64.13
Gwalior	$PM_{2.5}$	66.04	29.53	-55.28
	PM_{10}	131.15	93.56	-28.66
	NO_2	26.5	11.94	-54.94
	NH_3	22.16	16.88	-23.83
	SO_2	23.15	17.83	-22.98
	CO	0.52	0.49	-5.76
	O_3	73.42	78.5	6.91
Ujjain	$PM_{2.5}$	53.5	37.26	-30.35
	PM_{10}	115.41	94.72	-17.93
	NO_2	23.78	9.05	-61.94
	NH_3	21.13	11.93	-43.54
	SO_2	9.66	8.1	-16.15
	CO	0.95	0.62	-34.74
	O_3	72.02	71.96	-0.083
Sagar	$PM_{2.5}$	28.13	27.66	-1.67
	PM_{10}	74.87	68.25	-8.84

	NO_2	25.16	11.83	-52.98
	NH_3	-	-	-
	SO_2	2.52	1.9	-24.60
	CO	0.74	0.5	-32.43
	O_3	-	-	-

Table 3: Mean AQI of cities of Central India during the period of 16th January to 23rd March, 2020 (before lockdown) and 25th March to 31st May, 2020 (during lockdown)

S. No.	Cities	Mean AQI before lockdown period (16th January to 23rd March, 2020)	Mean AQI during lockdown period (25th March to 31st May, 2020)	Relative change in Percentage (%)
1	Indore	124.07	97.16	-21.69
2	Bhopal	126.77	90.16	-28.88
3	Jabalpur	136.33	80.89	-40.67
4	Gwalior	150.03	89.32	-40.46
5	Ujjain	115.75	97.73	-15.57
6	Sagar	74.28	67.51	-9.11

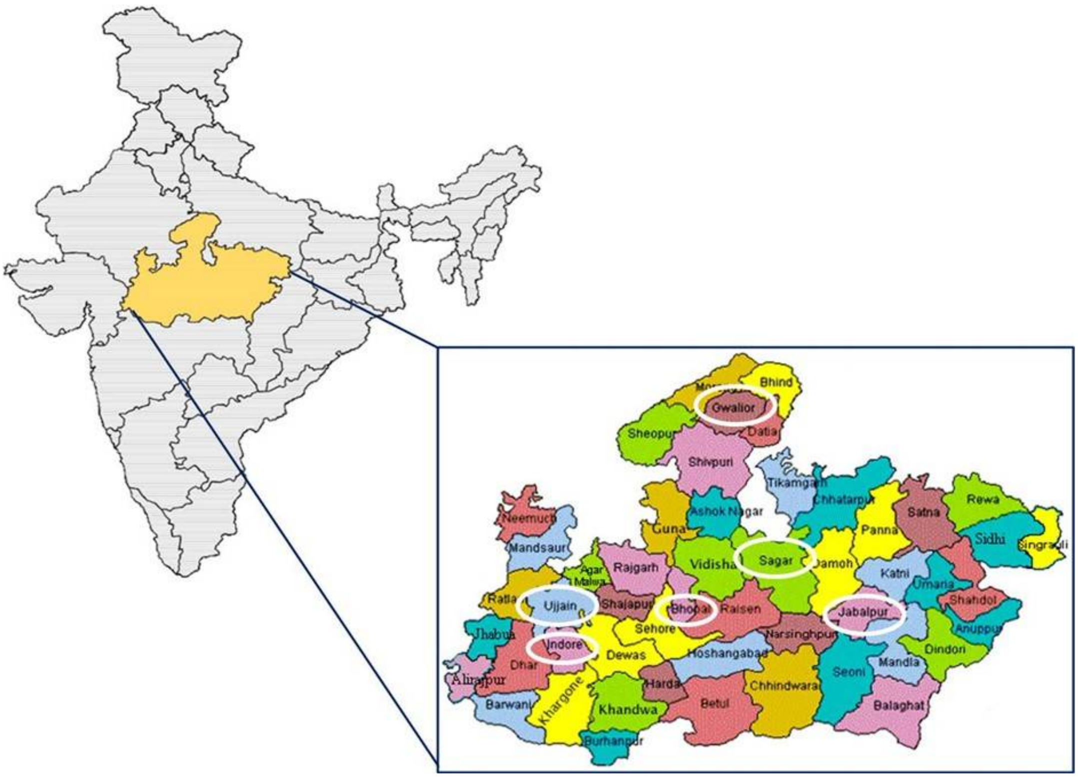

Figure 1: Reference map of Madhya Pradesh, India, showing locations of 6 major cities under study, covering 1001 km^2 of the state.

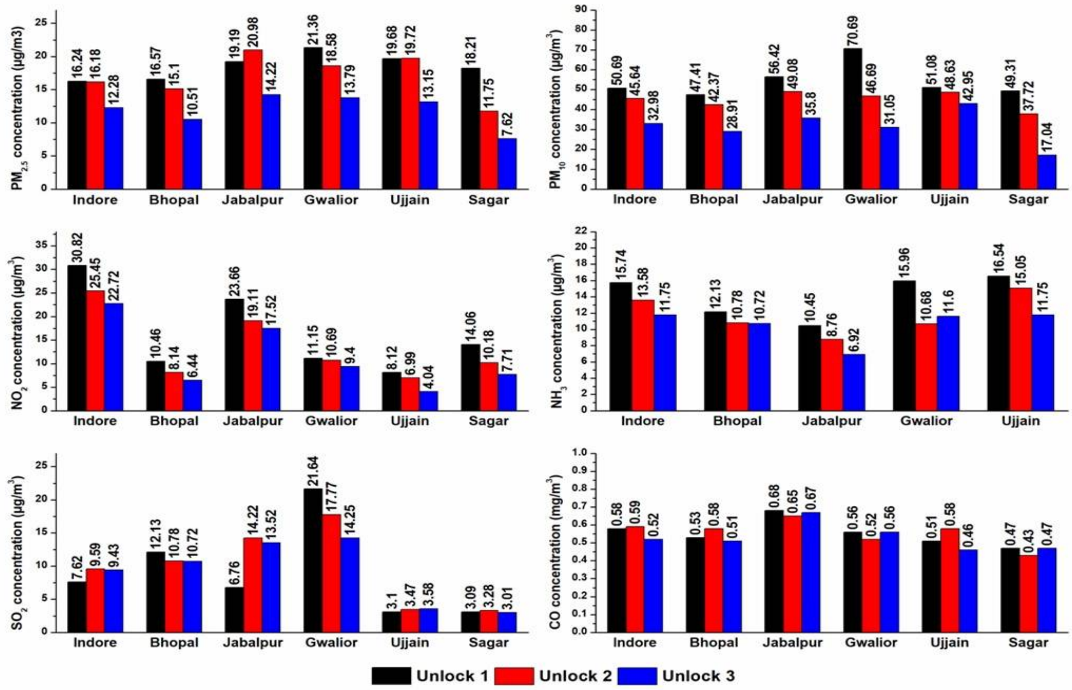

Figure 2: Mean concentration of pollutants during the period of 1st June 2020 to 30th June 2020 (unlock 1.0), 1st to 31st July 2020 (unlock 2.0) and 1st to 31st August 2020 (unlock 3.0).

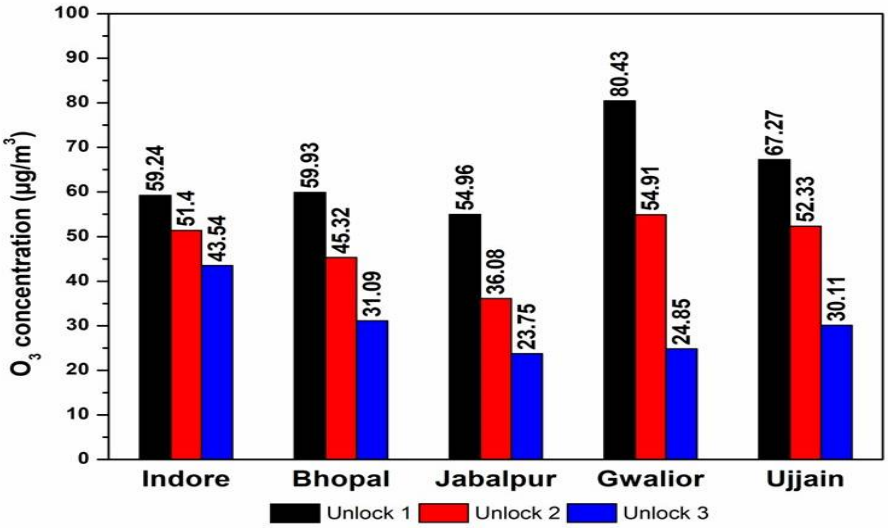

Figure 3: Mean concentration of Ozone during the period of 1st June 2020 to 30th June 2020 (unlock 1.0), 1st to 31st July 2020 (unlock 2.0) and 1st to 31st August 2020 (unlock 3.0).

CONCLUSION

As the stringent lockdown measures have been implemented in India in the framework of the COVID 19 pandemic, there was considerable reduction in road, railway and air transport, industrial activities and other non-essential businesses. This has led to significant decline in concentrations of pollutants such as $PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2 etc in different cities of Central India. There was overall 36.27%, 58.31%, 30.65%, 23.79%, and 37.87% % reduction in concentrations of $PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, CO respectively during the lockdown phase as compared to the pre-lockdown phase. The AQI was also found to be reduced by -21.69%, -28.88%, -40.66%, -40.46%, -15.57% and -9.11% in Indore, Bhopal, Jabalpur, Gwalior, Ujjain and Sagar respectively. Concentration of air pollutants during the three phases of unlock was also analysed and was found that the ozone concentration was significantly reduced in later unlock phases (unlock 2.0 and 3.0) in comparison to early unlock phase (unlock 1.0). Ozone reduction clearly indicates that the increased NO_x emission was mainly due to increase in road transport. Our study gives thought to the regulatory bodies that significant improvement in air quality could be achieved if execution of pollution source control would be implemented; in controlling the number of vehicles per day by a traffic management system using GPS in future, by applying even odd system or total restriction on vehicles on weekend.

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