



Examining the impact of lockdown (due to COVID-19) on ambient aerosols (PM_{2.5}): A study on Indo-Gangetic Plain (IGP) Cities, India

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Abstract

The outbreak of COVID-19 pandemic has impacted all the aspects of environment. The numbers of COVID-19 cases and deaths are increasing across the globe. In many countries lockdown has been imposed at local, regional as well as national level to combat with this global pandemic that caused the improvement of air quality. In India also lockdown was imposed on 25th March, 2020 and it was further extended in different phases. The lockdown due to outbreak of COVID-19 pandemic has showed substantial reduction of PM_{2.5} concentrations across the cities of India. The present study aims to assess concentration of PM_{2.5} across 12 cities located in different spatial segments Indo-Gangetic Plain (IGP). The result showed that there was substantial decrease of PM_{2.5} concentrations across the cities located in IGP after implementation of lockdown. Before 30 days of lockdown, average PM_{2.5} across cities was 65.77 µg/m³ that reached to 42.72 µg/m³ during lockdown periods (decreased by 35%). Maximum decrease of PM_{2.5} concentrations has been documented in Lower Gangetic Plain (LGP) cities (57%) followed by Middle Gangetic Plain (MGP) cities (34%) and Upper Gangetic Plain (UGP) cities (27%) respectively. Among all the cities of IGP, maximum decrease of PM_{2.5} concentrations was recorded in Kolkata (64%) (LGP) followed by Muzaffarpur (53%) (MGP), Asansol (51%) (LGP), Patna (43%) (MGP) and Varanasi (33%) (MGP). Therefore, this study has an immense potentiality to understand the impact of lockdown on a physical region (Ganga River Basin) and it may be also helpful for planners and policy makers to implement effective measures at regional level to control air pollution.

Keywords Lockdown · COVID-19 · Indo-Gangetic Plain (IGP) · Particle matter (PM_{2.5}) · Upper Gangetic Plain (UGP)

1 Introduction

COVID-19 has emerged as a serious global public health threats (Das et al. 2020). Due to outbreak of COVID-19, nationwide lockdown was implemented for the first time

from 25th March to 14th April, 2020 for the first phase and lockdown was extended in different phases since 31st May, 2020. The functions of all industries and transportations that are the main source of air quality deteriorations were strictly prohibited. Thus lockout due to lockdown of industries and transpirations brought an immense alteration in pollution level across the cities of India. The pollution level started declining rapidly during first phases (25th March to 14th April, 2020) and more rapidly during third phase (4–17th May, 2020) respectively (CPCB, 2020). Many regions of the world experienced a dramatic reduction of air pollution due to implementation of lockdown. Wang et al. (2020) found that there was a significant decline of PM_{2.5} concentrations due to suspension of transportation and industrial activities. In India a number of research studies were performed to assess the concentration of PM_{2.5} across the cities previously (Nagar et al. 2019; Mahesh et al. 2019; Guttikunda et al. 2014; Chowdhury

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Table 1 Categorization of Indo-Gangetic Plain (IGP) cities considered in this study

Region	Cities	No of cities studied
Upper Gangetic Plain (UGP)	Delhi, Gurugram, Faridabad, Agra	4
Middle Gangetic Plain (MGP)	Kanpur, Lucknow, Varanasi, Patna, Gaya, Muzaffarpur	6
Lower Gangetic Plain (LGP)	Kolkata, Asansol	2

Table 2 Brief profile of cities located in IGP of India

Cities	Area (km ²) (2011)	Pop. density (km ²) (2011)	Total population (2011)	World air quality report (2018) PM _{2.5} (µg/m ³)*	WHO's report (2016)
UGP Delhi UA	561	11,312	16.31	113.5	143
Gurugram	738	4803	0.87	135.8	113
Agra	121	13,152	1.74	104.8	131
Faridabad	204	6932	1.40	130.4	172
MGP Kanpur	403	10,377	2.92	120.3	173
Lucknow	349	8077	2.90	115.7	138
Varanasi	163	14,598	1.43	105.3	151
Patna	136	15,640	2.04	119.7	144
Gaya	308	9450	0.47	96.6	149
Muzaffarpur	93	13,411	0.35	110.3	120
LGP Asansol	326	3500	1.24	–	–
Kolkata	1851	7950	14.11	–	–

*Average annual PM_{2.5}

et al. 2019) but very few studies were conducted to examine the impact of lockdown on air quality. Particularly the concentration of aerosols (PM_{2.5}) across the most polluted cities of India remains unexplored during COVID-19 pandemic. Considering this research gap, present study aims to assess the impact lockdown on the concentration of PM_{2.5} across the most polluted cities of India.

As per as report published by World Health Organization (WHO) (2018), a number of the cities of India were the most polluted that exceeded the tolerate limits. Out of 15 most polluted cities of the world, 14 cities are located in India in terms of PM_{2.5} concentrations. These most polluted cities are Kanpur (in Bihar) followed by Faridabad (in Haryana), Varanasi (in Uttar Pradesh), Gaya, Patna (in Bihar), Delhi, Lucknow (in Uttar Pradesh). The World Air Quality Report (2018) recorded the similar fact that Indian cities were the most polluted cities in the world. The report highlighted that out of 10 most polluted cities of the world seven cities were located in India (on the basis of average annual concentration). As per as this report, Gurugram was the most polluted city in the world (135.8 µg/m³) followed by Faridabad (129.1 µg/m³), Patna (119.7 µg/m³), Lucknow (115.7 µg/m³), Delhi (113.5 µg/m³). Even Delhi was the most polluted capital city of the world (average annual

PM_{2.5} was 113.8 µg/m³). Most of these cities are located in Upper Gangetic Plain (UGP) and Middle Gangetic Plain (MGP). The cities (Kolkata, Asansol) located in Lower Gangetic Plain (LGP) are relatively least polluted. In addition to this, out of 20 most polluted cities in south-east Asia, 18 most polluted cities were in India. From the above global reports, it was clear that the pollution level of Indian cities is not acceptable for environmental sustainability. But after the implementation of lockdown substantial reduction of air pollutants in the atmosphere have been observed across many cities of the world. The most of the cities of the world experienced significant improvement of air quality after lockdown down. Recently a number of studies already have been performed to examine the impact of lockdown on air pollution level and result showed that there was substantial improvement of air pollution level (He et al. 2020; Liu et al. 2020; Watts and Kommenda 2020; Cadotte 2020; Ogen 2020; Coccia 2020). Such outcomes of the previous studies really inspired to formulate few research questions- (a) how far the most polluted cities of IGP gets impacted during lockdown in PM_{2.5} concentrations? (b) Is there any variation of PM_{2.5} concentrations across cities in different spatial segments of IGP? To address these research questions, this mainly focuses on the

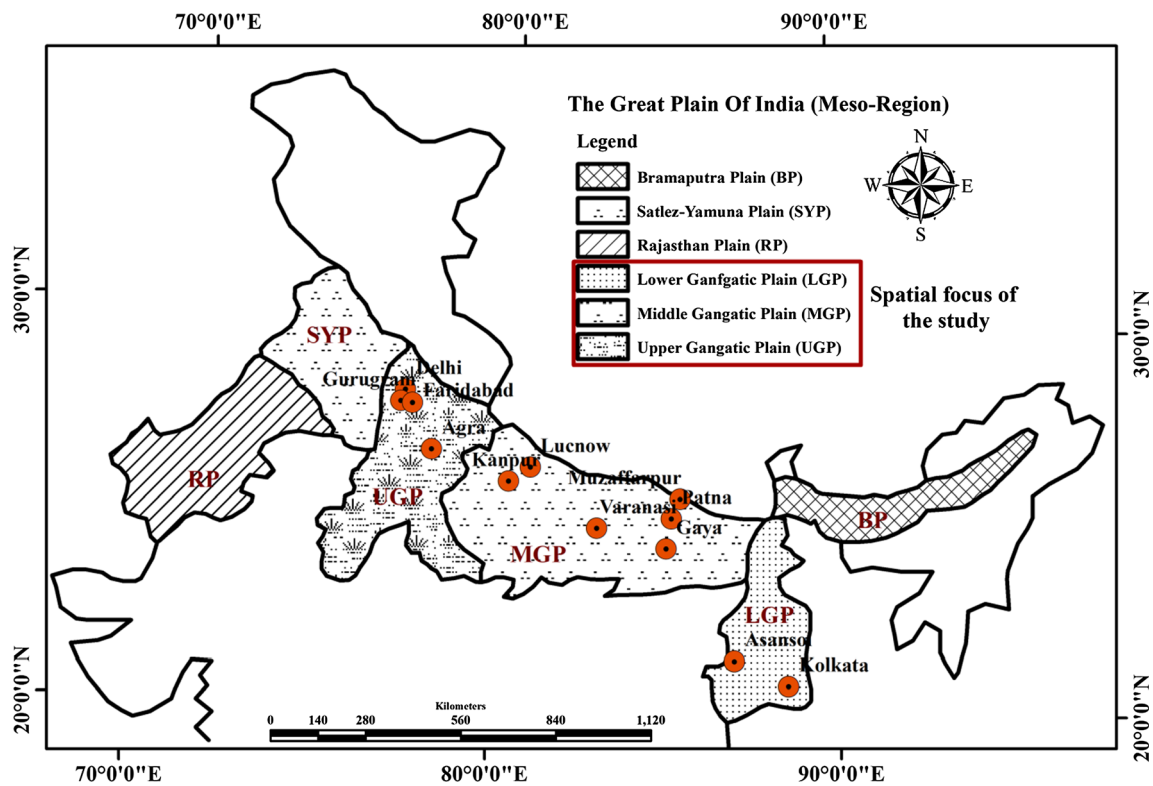


Fig. 1 Location map of the study area (shown in brown color)

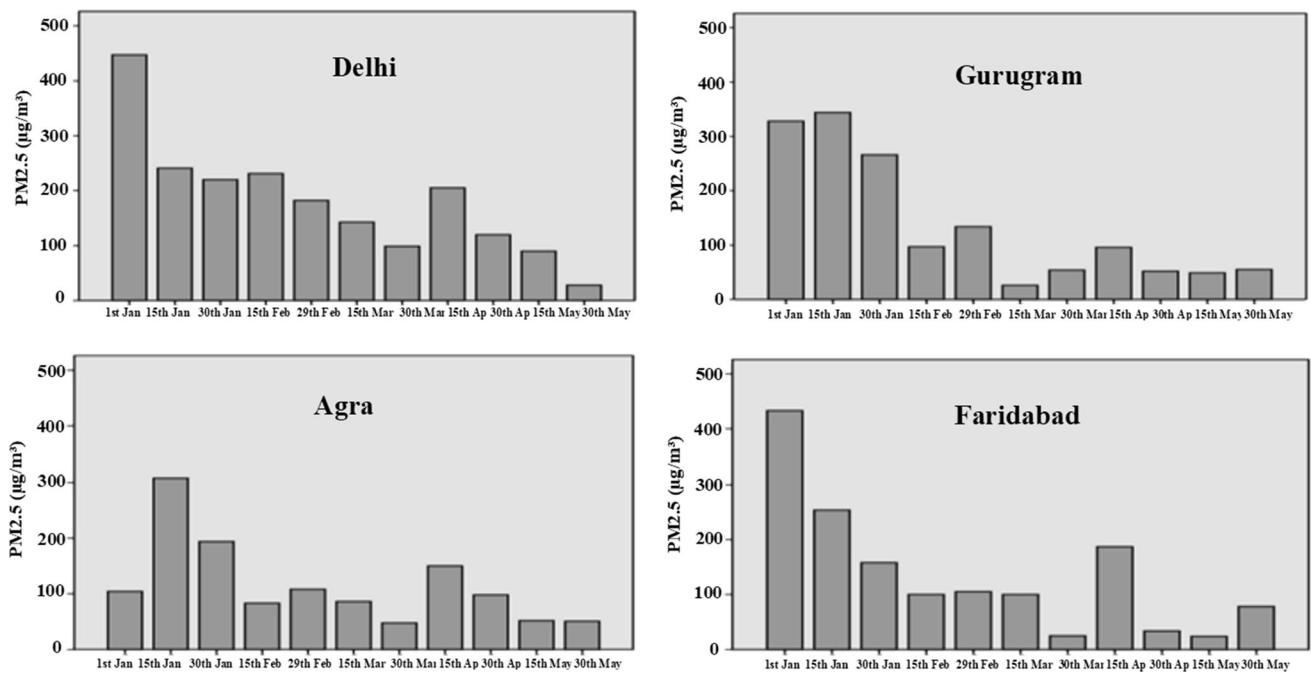


Fig. 2 Concentration of PM_{2.5} across cities of UGP (since 1st January to 30th May, 2020)

assessment impact of lockdown due to COVID-19 across the cities of Indo-Gangetic Plain (IGP) of India. To validate the impact, the concentration of PM_{2.5} across the cities of IGP has been assessed in last two years (2018–2020).

The result of the study surely assists planner and policy makers to understand the scenario of PM_{2.5} concentrations during non-pandemic (2018 and 2019) as well as present pandemic (COVID-19) situation during same periods. Thus



Fig. 3 Daily concentration of PM_{2.5} across cities during January–February, 2020 (pre-lockdown periods)

this study may be also helpful to implement policies at regional level to fight with air pollution level in India.

2 Material and methods

2.1 Study area

In this study, concentration of PM_{2.5} has been assessed across 12 cities located Indo-Gangetic Plain (IGP) in India. The entire IGP has been categorized into three regions namely- (i) Upper Gangetic Plain (UGP), (ii) Middle Gangetic Plain (MGP) and Lower Gangetic Plain (LGP) respectively (Details of the cities are presented in Table 1 and 2). These 12 cities stretch over four union territories (UT)/ states namely Delhi UT, Uttarpradesh, Bihar and West Bengal. In many reports and literatures, it was well recognized that these cities (particularly UGP and MGP cities) are one of the polluted cities of India. In this region relatively higher concentration of PM_{2.5} was recorded due

to industries, power plants, transportations, construction activities etc. (Pant et al. 2016; Srimuruganandam and Nagendra 2012; Liu et al. 2013; Villalobos et al. 2015). As per as WHO's report published in 2018 on PM_{2.5} concentrations, out of ten most polluted cities of the world, seven most polluted cities were located in India and the capital city of India i.e. Delhi was the most polluted city of the world. The report also showed that Gurugram was the most polluted city in the world (135 µg/m³). The profile of the cities is presented in Table 2 in details (Fig. 1).

2.2 PM_{2.5} data

Data to assess the impact of lockdown on concentration of PM_{2.5} was collected from different air quality monitoring stations across the cities. The daily hourly air quality data were extracted from Central Pollution Control Board (CPCB) online portal (https://app.cpcbcr.com/AQI_India/). CPCB provides data regarding the concentration of major seven air pollutants (such as Sulphur Dioxide (SO₂),

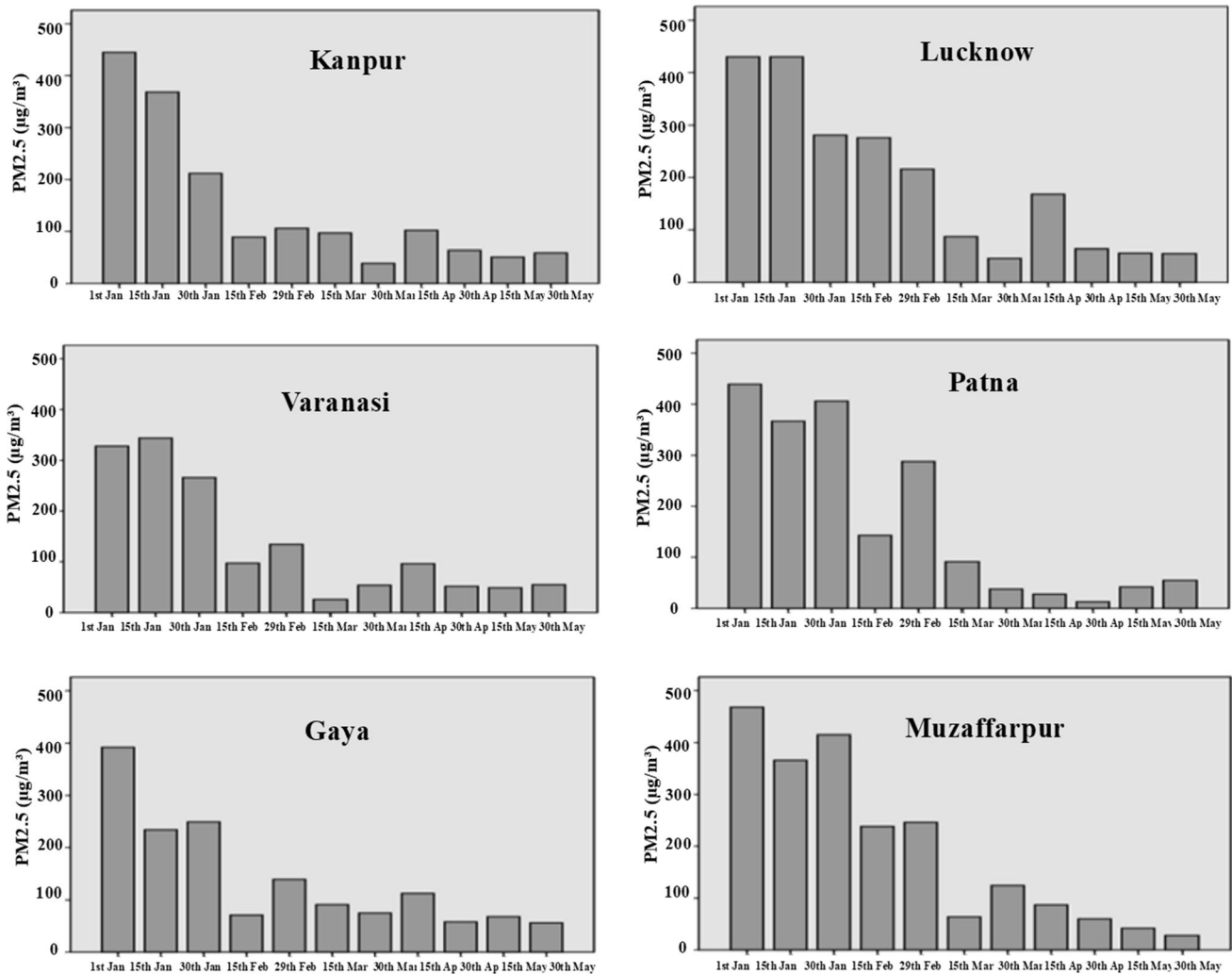


Fig. 4 Concentration of PM_{2.5} across cities of MGP (since 1st January to 30th May, 2020)

Nitrogen Dioxide (NO₂), Carbon Monoxide (CO), Ozone (O₃) and Ammonia (NH₃) as well as concentration of fine particles matter (PM_{2.5} and PM₁₀) respectively. From CPCB on line portal, PM_{2.5} data were collected from 1st January to 17th May, 2020 to compare PM_{2.5} concentrations before and during lockdown periods. In addition to this, to examine the spatial scenario of PM_{2.5} over the region (across cities), data were collected in last two years (2018 to 2020).

2.3 Statistical analysis

In this study, Coefficient of Variation (CV) has been used to find out the spatial variation of PM_{2.5} concentration in different phases of lockdown. In addition to this, one way ANOVA has also been used to examine the significant difference of PM_{2.5} concentrations across cities in different phases of lockdown.

3 Result

3.1 Regional scenario of PM_{2.5} (µg/m³) concentration in Indo-Gangetic Plain (IGP)

In this present study, the spatial concentration of PM_{2.5} has been assessed at regional (in different spatial segments of Gangetic Plain).

3.1.1 Upper Gangetic Plain (UGP)

From this region of IGP, four major cities have been selected which comprises 33% of total cities of the study area. These major cities are- Delhi, Gurugram, Agra and Faridabad. These cities are located in Delhi UT (1) (Union Territory), Haryana (1) and Uttar Pradesh (2) respectively. These cities are the most polluted cities of the country (discussed in previous literatures).



Fig. 5 Daily concentrations of PM_{2.5} across cities during March to April, 2020

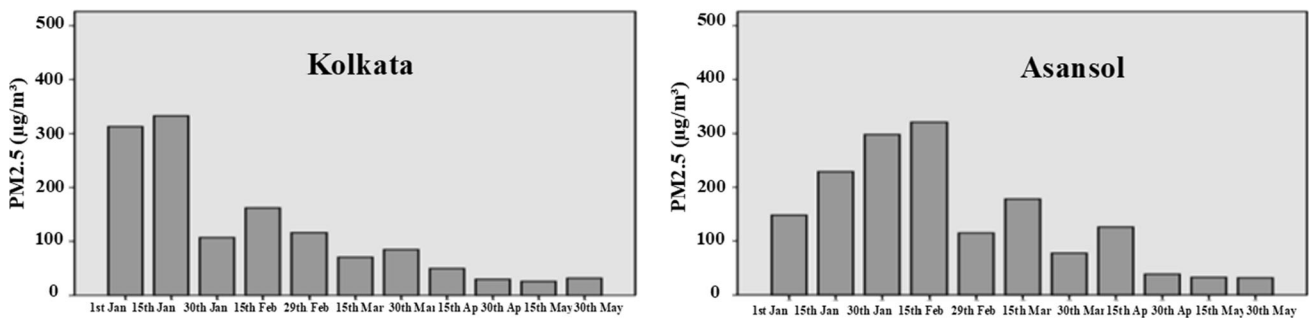


Fig. 6 Concentration of PM_{2.5} across cities of LGP (since 1st January to 30th May, 2020)

As per as result, it has been observed that before 30 days of lockdown, the average concentration of PM_{2.5} was 66.73 that reached to 39.63 during phase I and slightly increased during second phase (45.45) and third phase (51.15) of lockdown respectively. Before lockdown highest concentration of PM_{2.5} has been found in Delhi (75.00) followed by Faridabad (69.5), Gurugram (63.4) and Agra (59.00) respectively.

During entire phase of lockdown (from phase I to phase IV), the average concentration of PM_{2.5} was 48.74 with

highest concentration of PM_{2.5} reported from Delhi (51.15), Agra (50.05) followed by, Faridabad (47.93), Gurugram (45.83) respectively (Figs. 2, 3).

3.1.2 Middle Gangetic Plain (MGP)

From this part of IGP, six major cities have been considered in this study. These cities are stretched over Uttar Pradesh (3) and Bihar (3). These major cities are—Kanpur, Lucknow, Varanasi, Patna, Gaya, Muzaffarpur. In many

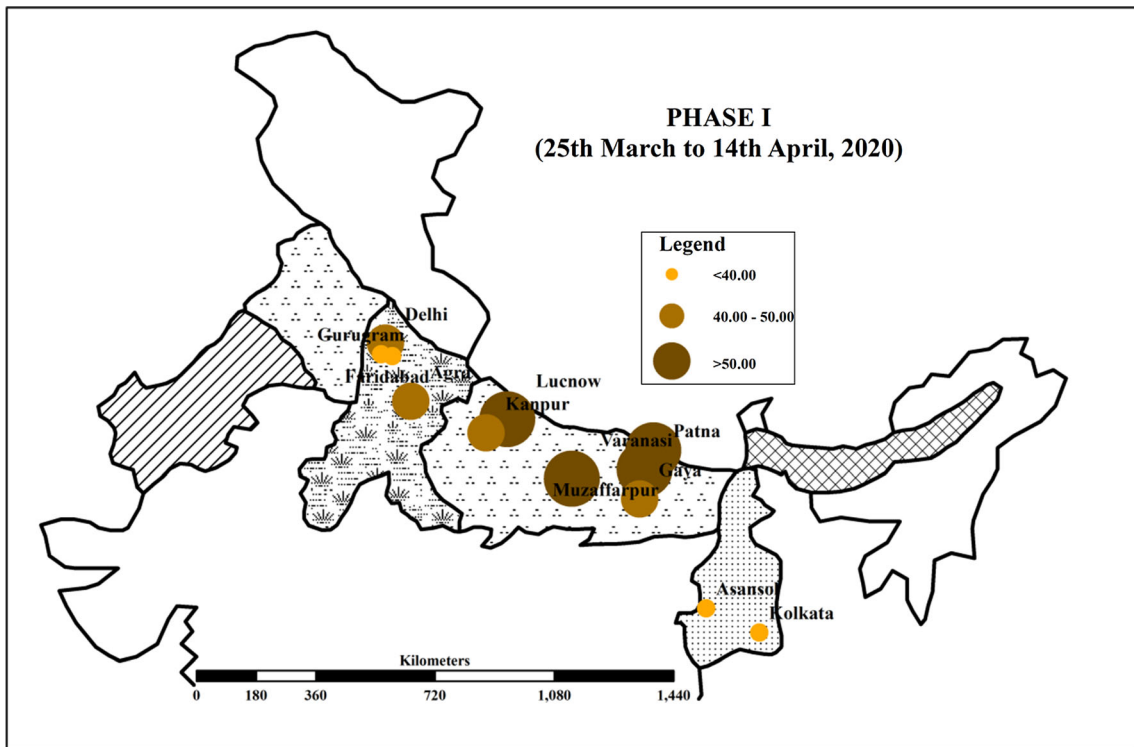


Fig. 7 Concentration of PM_{2.5} across cities of IGP (Phase I)

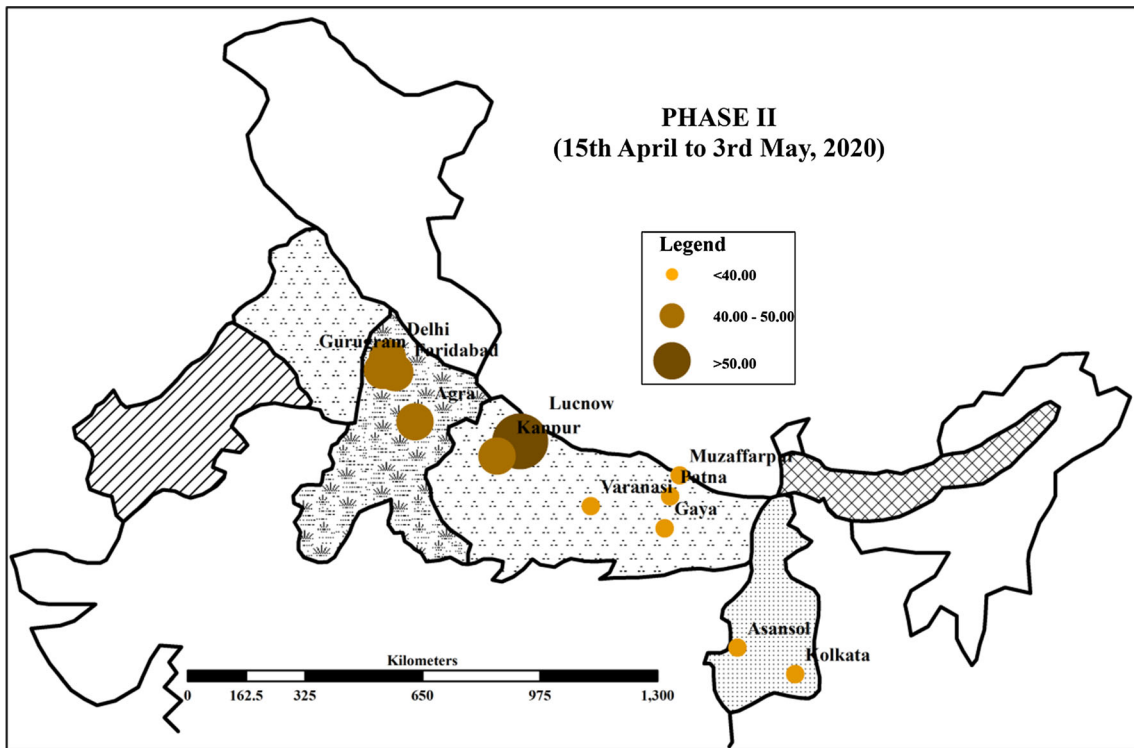


Fig. 8 Concentration of PM_{2.5} across cities of IGP (Phase II)

reports and previous literatures, it has been highlighted that

these cities are one of the most polluted in India (discussed in above section).

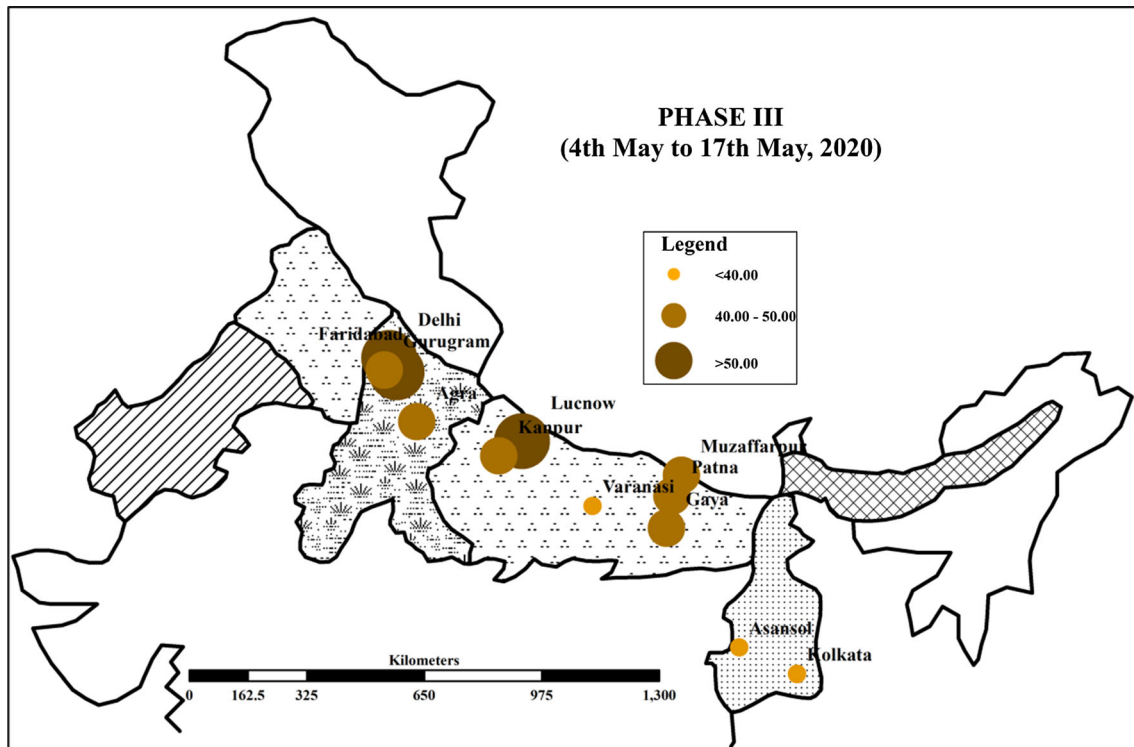


Fig. 9 Concentration of $PM_{2.5}$ across cities of IGP (Phase III)

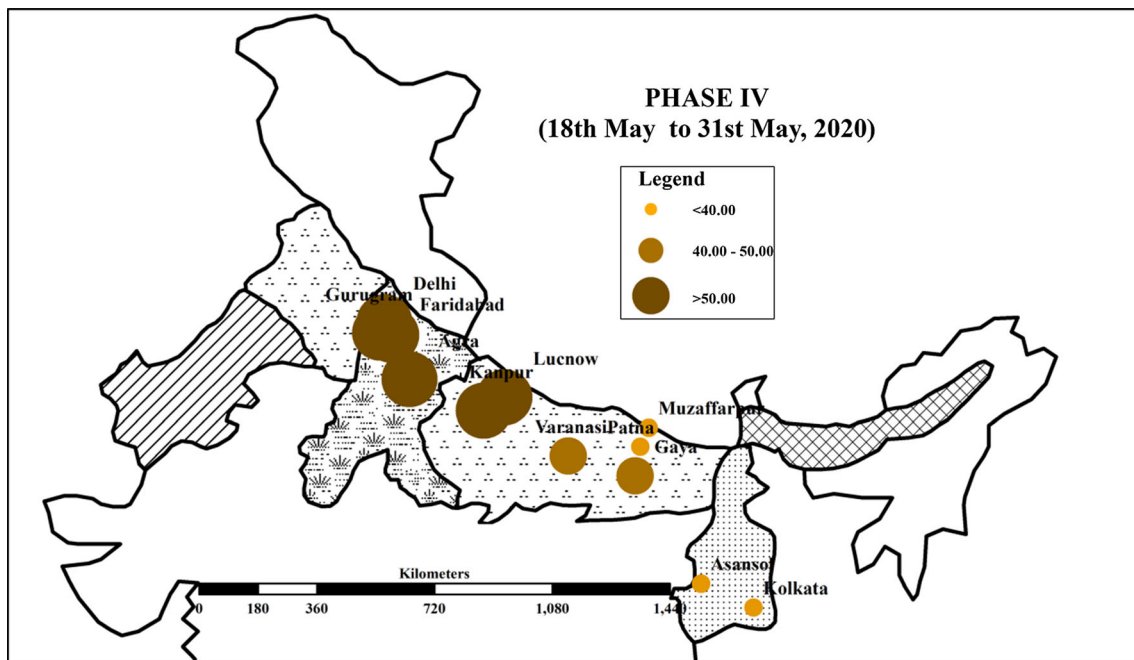


Fig. 10 Concentration of $PM_{2.5}$ across cities of IGP (Phase IV)

In this region of IGP, the average concentration of $PM_{2.5}$ was 66.42 before 30 days of lockdown whereas it declined to 52 during first phase of lockdown and 42.57 during fourth phase of lockdown. The average concentration of $PM_{2.5}$ during entire phase of lockdown (from phase I to

phase IV), the average concentration of $PM_{2.5}$ was 44.16 (it was higher than UGP and LGP) with highest average concentration of 57.45 in Lucknow followed by Kanpur (47.10), Varanasi (41.5), Gaya (40.58) respectively (Fig. 4).

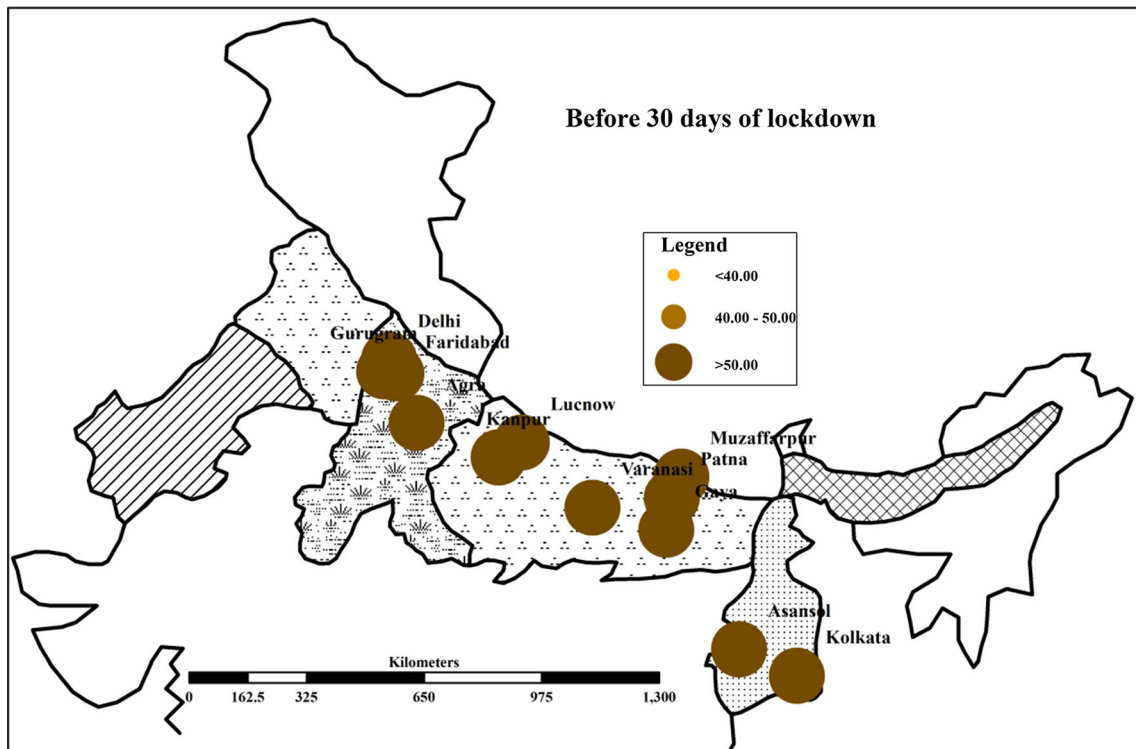


Fig. 11 Concentration of PM_{2.5} across cities of IGP (30 days before lockdown)

Table 3 Number of cities based on average PM_{2.5} (µg/m³) concentration

PM _{2.5}	30 days before lockdown	Phase I	Phase II	Phase III	Phase IV
< 40	0	4	6	3	4
40–50	0	4	5	6	2
> 50	12	4	1	3	6

3.1.3 Lower Gangetic Plain (LGP)

Lower Gangetic Plain (LGP) mainly covers a vast geographical area of West Bengal. From this region, two major cities have been studied namely—Kolkata and Asansol. In these cities, the average concentration of PM_{2.5} was 61.90 with highest concentration of 63.3 in Asansol and 60.5 in Kolkata before 30 days of lockdown and average concentration of PM_{2.5} declined to 35.05 during first pahse and 21.90 during second phase of lockdown. During entire periods of lockdown, average concentration of PM_{2.5} was 26.39 with highest concentration in Asansol (30.88) and Kolkata (21.90) (Figs. 5, 6).

3.2 Regional variation of PM_{2.5} (µg/m³) in IGP

The result of the study showed that there was substantial regional variation of PM_{2.5} concentration in IGP across the cities. The concentration of PM_{2.5} was relatively high over the cities located in UGP as compared to MGP and LGP

during different periods of lockdown and even 30 days before lockdown. Before 30 days of lockdown, average concentration of PM_{2.5} in IGP was 65.01 with highest concentration of 66.73 in UGP followed by MGP (65.42) and LGP (61.90) respectively. During lockdown phases also, highest average concentration of PM_{2.5} has been recorded from UGP. The result showed that during entire phases of lockdown, average concentration of PM_{2.5} was 39.76 with highest concentration of 48.74 again in UGP followed by MGP (44.16) and LGP (26.39) respectively. Thus from the result it is clear that PM_{2.5} concentrations was relatively higher over the cities located in UGP such as Delhi, Gurugram, Agra and Faridabad as compare to those cities located in MGP and LGP respectively. During fourth phase of lockdown, average concentration across most of the cities increased due to relaxation of guidelines implemented by Central as well as State government.

There were substantial variations of PM_{2.5} concentrations in different phases of lockdown and before 30 days of lockdown (Figs. 7, 8, 9, 10, 11). Table 3 represents the

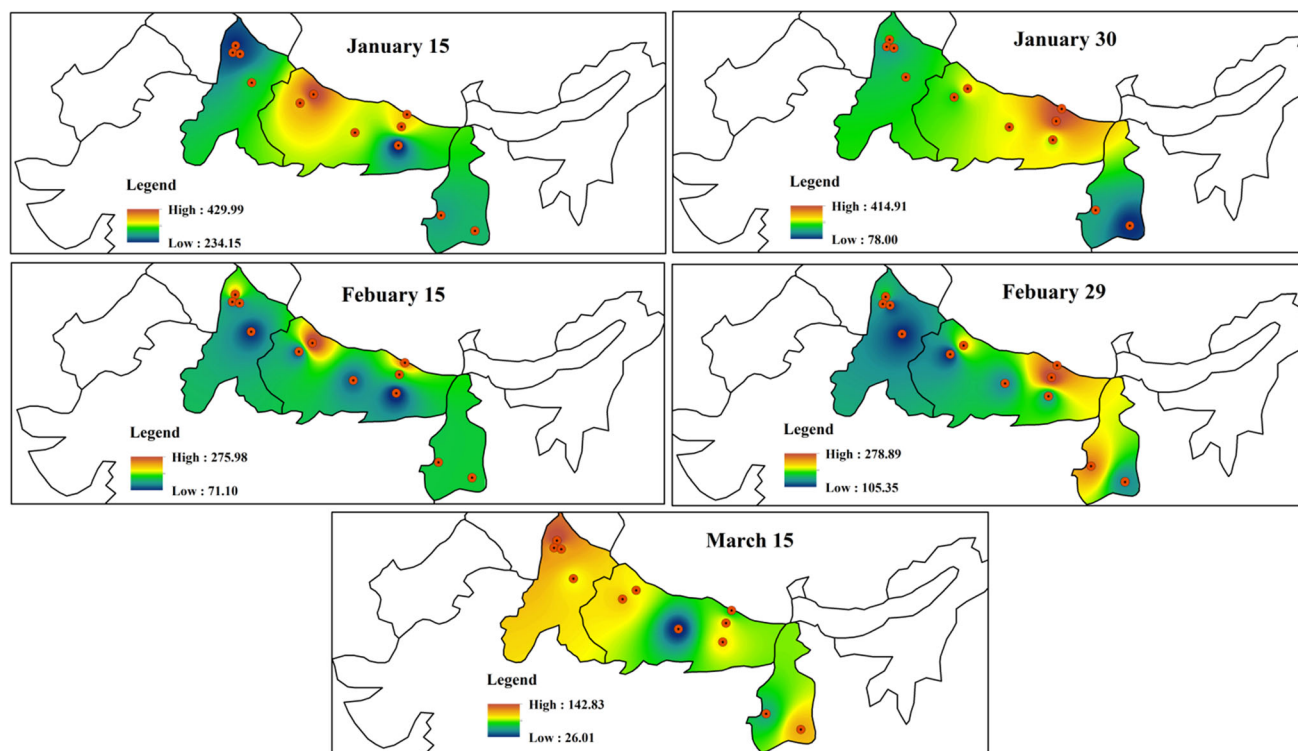


Fig. 12 Concentration of PM_{2.5} before lockdown in IGP

number of cities of IGP on the basis of average PM_{2.5} ($\mu\text{g}/\text{m}^3$) concentration in different phases of lockdown and 30 days before lockdown. It clearly denotes that there were all 12 cities with average concentration of PM_{2.5} above 50. But after implementation of lockdown, the number of cities with average concentration of PM_{2.5} above 50 declined. It clearly indicates that average concentration of PM_{2.5} across the cities of IGP declined during lockdown periods. During 4th phase of lockdown, number of cities with average concentration of PM_{2.5} above 50 increased. This was most probably due to relaxations of guidelines during this phase of lockdown.

3.3 Monthly variation of PM_{2.5} ($\mu\text{g}/\text{m}^3$) in IGP before lockdown

In this section of the study, monthly variation of PM_{2.5} concentrations has been examined before lockdown (from January to 24th March, 2020). During January, average concentration of PM_{2.5} was (252) with highest concentration of 316 in Delhi (UGP) followed by Lucknow (310.68), Kanpur (283.71) respectively (MGP).

The average concentration of PM_{2.5} over the cities of IGP was 206 during the month of February. The highest average concentration of PM_{2.5} during month was recorded Delhi (297.41) (UGP) again followed by Lucknow (248), Kanpur (202.59), Varanasi (199.69) respectively (MGP).

During the month of March, average concentration of PM_{2.5} was 123 with highest average concentration of 164 (Lucknow) followed by Muzaffarpur (163.03) (MGP), Delhi (161.58) (UGP), Patna (151) (MGP) respectively (Fig. 12).

3.4 Monthly variation of PM_{2.5} ($\mu\text{g}/\text{m}^3$) in IGP during lockdown

In India, lockdown was imposed on 24th March for 21 days (24th March to 14th April) for the first phase and it was further extended from 15th April to 3rd May (19 days); from 4th May to 17th May (14 days) and from 18th May to 31st May (13 days), 2020. After the implementation of lockdown there was a substantial decrease of PM_{2.5} concentrations over the cities stretched in IGP.

In earlier section of the study it has been stated that during March average monthly PM_{2.5} concentrations across the cities of IGP was 123 that reached to 83.30 during the month of April (decreased by more than 30%).

In April, average PM_{2.5} concentration was 83.80 with highest concentration of 132 in Lucknow (MGP) followed by Delhi (110.83), Agra (88) (UGP) and Kanpur (82.27) (MGP).

During the month of May, average concentration of PM_{2.5} 88.79 with highest average concentration of 154 in Lucknow (MGP) followed by Gurugram (107.50), Agra

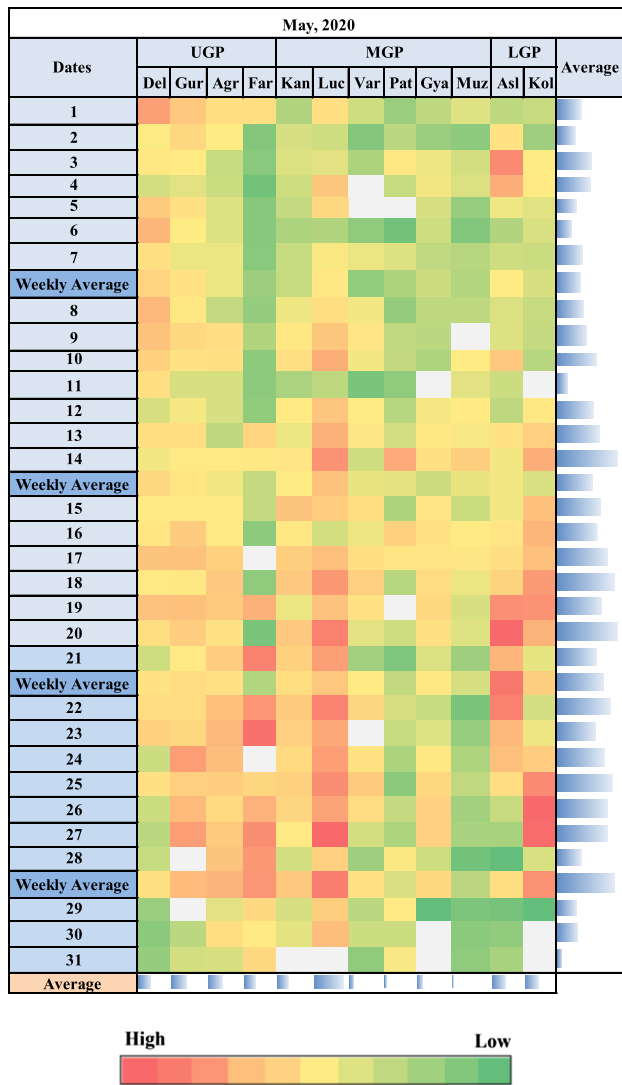


Fig. 13 Daily concentration of PM_{2.5} across cities during May, 2020

(96.58), Delhi (95.80). Thus, from the overall analysis it is obvious fact that relatively higher concentration of PM_{2.5} was recorded in Delhi, Lucknow, Gurugram, Agra, Kanpur and Muzaffarpur respectively. All these cities are located in UGP and MGP. The concentration of PM_{2.5} was relatively low across LGP cities (Kolkata and Asansol) (Fig. 13).

Table 4 represents the variation of PM_{2.5} (µg/m³) over IGP in pre-lockdown and during lockdown phases. Regional variation of PM_{2.5} can be well understood by coefficient of variation (CV). The result showed that before 30 days of lockdown, CV was 10.49% that gradually decreased in successive phases (except Phase III) and reached to 6.18% during fourth phase of lockdown in UGP. It clearly denotes that spatial variation concentration of PM_{2.5} over the cities of UGP declined since before lockdown. On the other hand, CV increased in case of cities

located in MGP and LGP since before lockdown to during lockdown phases. For example, in MGP before 30 days of lockdown CV was 14.70% that reached to 36.74% during fourth phase of lockdown. Similar fact can be found for LGP. It clearly indicates the fact that spatial variation of PM_{2.5} concentration increased across cities located in MGP and LGP. As per as one way ANOVA analysis, it was observed that there were no significant difference of PM_{2.5} concentrations across cities in different phases of lockdown in IGP (*p* value was 0.437 which was not significant at *p* < 0.05).

3.5 Comparison PM_{2.5} concentrations during lockdown and without lockdown

In this section, the concentrations of PM_{2.5} were compared between lockdown period due to COVID-19 of 2020 (April and May) and same period of 2018 and 2019. Here it was seen the substantial decline of PM_{2.5} concentrations across the region during full lockdown of 2020 to that of 2018–2019 (without lockdown) (Table 5). The average concentration of PM_{2.5} was 177.35 (2018) and 164.49 (2019) across UGP cities that reached to 109.35 in 2020 (decreased by 38% and 33%) during same periods (April–May). Similarly, in MGP concentration of PM_{2.5} declined by 30% from 2018–2019 with highest decrease in Varanasi (49%) followed by Gaya (48%), Patna (36%), Kanpur (20%) respectively. In LGP cities, concentration of PM_{2.5} decreased by more than 30% since 2018–2020 (April–May).

Thus, from the overall result among all three regions (UGP, MGP and LGP), highest decrease of PM_{2.5} concentrations was recorded over LGP cities (36.75%) followed by UGP (33.52%) and MGP (26.37%).

Weekly concentration of PM_{2.5} across the cities located in IGP has been examined since first week of January to 2nd week of May, 2020 (Fig. 14). The upper part (upper whisker) and lower part (lower whisker) of box plots indicates the maximum and minimum average concentrations of PM_{2.5}. A line within box (middle quartile) represents the median value of PM_{2.5} concentrations. The results showed that there was sharp decline of PM_{2.5} concentrations after 3rd week of February, 2020. In addition to this, there were also variations of PM_{2.5} concentrations across cities of IGP. In India, first COVID-19 confirm case was reported from Kerala on 30th January 2020 and second as well as third cases was also reported from the same state on 2nd and 3rd February, 2020. Since the outbreak of COVID-19, government imposed a number of restrictions on travel advisory, transportations etc. Thus implementation of restrictions resulted in the reduction of PM_{2.5} concentrations from the early stage of COVID-19 outbreak (from February, 2020) (Figs. 15, 16).

Table 4 Basic statistics on concentration of PM_{2.5} (µg/m³) in IGP

Cities		30 days before	Phase I	Phase II	Phase III	Phase IV	Average (during lockdown period)
UGP	Delhi UA	75.00	42.20	46.50	55.60	60.30	51.15
	Gurugram	63.40	36.50	44.90	48.50	53.40	45.83
	Agra	59.00	43.60	49.60	45.50	61.50	50.05
	Faridabad	69.50	36.20	40.80	55.00	59.70	47.93
	Mean	66.73	39.63	45.45	51.15	58.73	48.74
	SD	7.00	3.83	3.66	4.95	3.63	2.36
	CV	10.49	9.66	8.06	9.68	6.18	4.84
MGP	Kanpur	61.40	44.80	48.50	43.80	51.30	47.10
	Lucknow	69.20	56.50	54.20	52.00	67.10	57.45
	Varanasi	62.60	55.80	33.10	36.80	41.30	41.75
	Patna	67.30	51.00	25.60	46.50	30.90	38.50
	Gaya	54.60	41.70	36.60	41.60	42.40	40.58
	Muzaffarpur	83.40	67.00	28.80	40.10	22.40	39.58
	Mean	66.42	52.80	37.80	43.47	42.57	44.16
LGP	Asansol	63.30	35.80	26.50	35.00	26.20	30.88
	Kolkata	60.50	34.30	17.20	18.50	17.60	21.90
	Mean	61.90	35.05	21.85	26.75	21.90	26.39
	SD	1.98	1.06	6.58	11.67	6.08	6.35
	CV	3.20	3.03	30.10	43.62	27.77	24.05

Table 5 Concentration of PM_{2.5} with lockdown and without lockdown periods

Cities		2018	2019	2020	Change (2018–2020)	2019–2020
UGP	Delhi UA	157.84	186.45	143.15	– 9.31	– 23.22
	Gurugram	236.53	187.55	99.71	– 57.84	– 46.83
	Agra	146.46	136.70	97.31	– 33.56	– 28.81
	Faridabad	168.57	147.25	97.21	– 42.33	– 33.99
MGP	Mean	177.35	164.49	109.35	– 38.34	– 33.52
	Kanpur	118.79	110.81	94.87	– 20.13	– 14.38
	Lucknow	190.45	213.83	163.90	– 13.94	– 23.35
	Varanasi	153.68	177.14	77.75	– 49.41	– 56.11
	Patna	164.98	125.34	106.25	– 35.60	– 15.23
	Gaya	158.48	118.45	82.22	– 48.12	– 30.59
	Muzaffarpur	114.38	112.59	106.86	– 6.58	– 5.09
LGP	Mean	150.13	143.03	105.31	– 29.85	– 26.37
	Asansol	161.23	170.21	112.51	– 30.22	– 33.90
	Kolkata	149.32	163.58	98.62	– 33.95	– 39.71
	Mean	155.28	166.90	105.57	– 32.01	– 36.75

3.6 Metrological conditions over the region in last five years (2015–2020)

In this section of the study, the basic weather conditions (air temperature, wind speed, rainfall and relative humidity) during the same periods has been assessed across

different spatial segments of IGP in last five years (2015–2020). The result showed that there was no extreme variation of weather conditions (except rainfall) since last five years (2015–2020). Average rainfall over the region of LGP, MGP and UGP (except 2019) was relatively high in 2020 in comparison to previous last five years (Table 6).

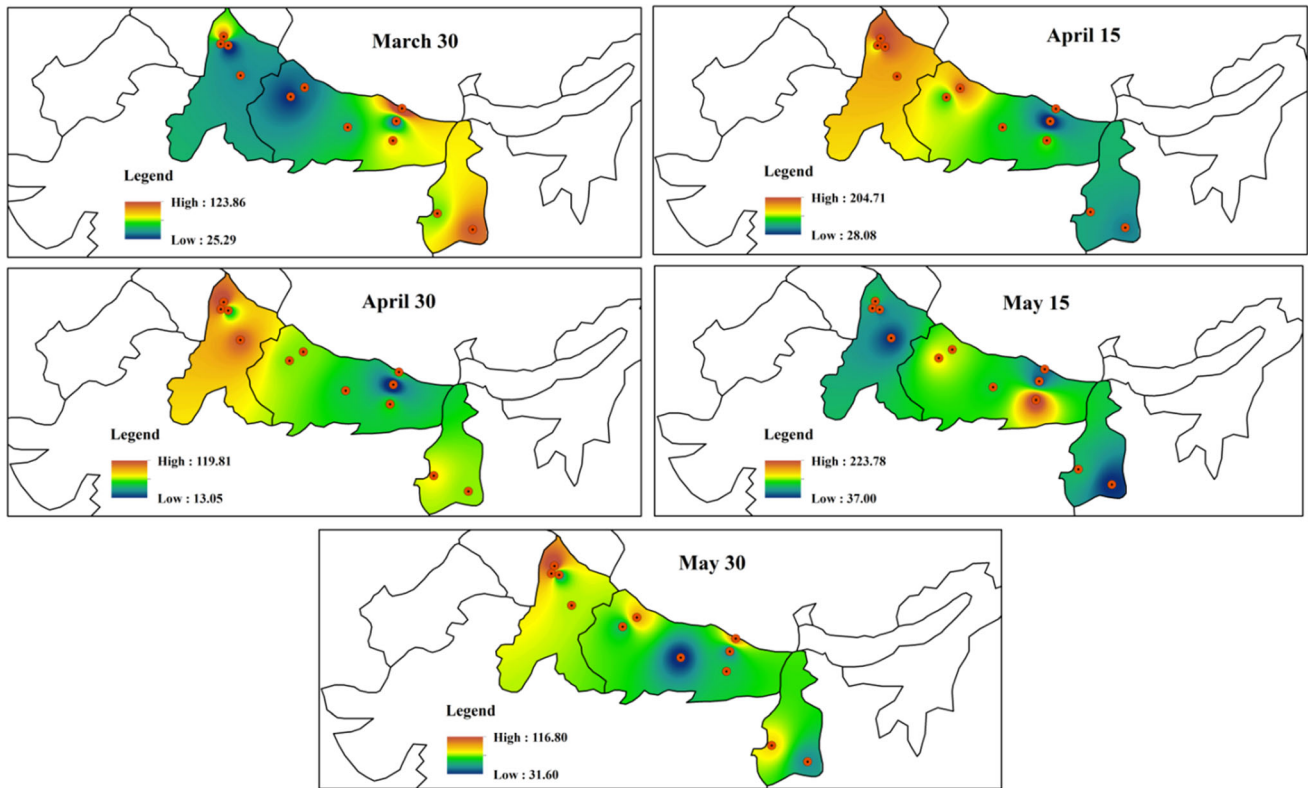


Fig. 14 Concentration of PM_{2.5} during lockdown in IGP

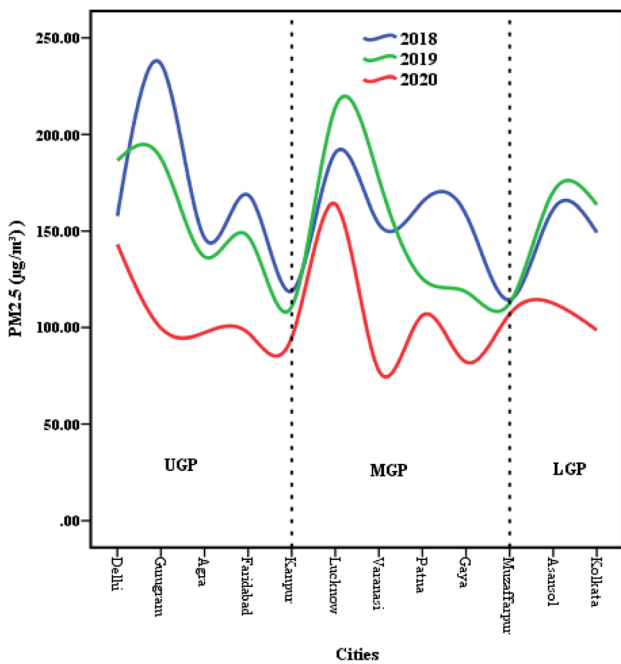


Fig. 15 Concentration of PM_{2.5} in different spatial segments of IGP (across cities) in last two year

Except rainfall, there were no extreme variations of air temperature, rainfall and wind speed in last five years during same periods.

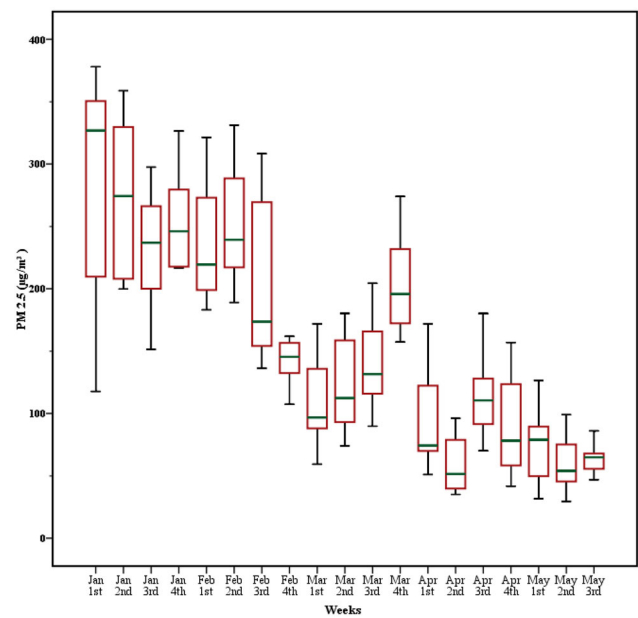


Fig. 16 Weekly concentration of PM_{2.5} in IGP across the cities

3.7 Seasonal variations of PM_{2.5} concentrations (µg/m³) across regions

In this section, the seasonal variation (winter-January to March and pre-monsoon-April and May) of PM_{2.5} for 2020

Table 6 Meteorological conditions during same periods (lockdown) in last five years (2015–2020)

Parameters	Statistics					LGP					MGP					UGP									
	2015	2016	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020	
Temperature (°C)	Mean	32.7	32.2	32.7	32.5	35.8	33.5	35.3	35.3	35.2	34.5	38.4	35.6	34.7	35.3	35.3	23.8	38.1	37.0	34.7	35.3	35.3	23.8	38.1	37.0
	SD	1.3	1.6	1.0	1.0	1.0	0.5	2.7	0.6	1.5	2.0	1.9	2.1	3.6	2.5	1.4	2.0	3.1	2.4	3.6	2.5	1.4	2.0	3.1	2.4
	CV	3.9	5.0	3.2	3.1	2.9	1.5	7.8	1.7	4.3	5.8	5.0	5.9	10.5	7.1	4.0	8.3	8.2	6.4	10.5	7.1	4.0	8.3	8.2	6.4
Rainfall (mm)	Mean	23.2	9.5	12.7	24.2	80.8	106.4	19.8	16.2	8.6	11.2	21.9	80.8	18.7	11.1	7.9	13.1	36.7	19.5	18.7	11.1	7.9	13.1	36.7	19.5
	SD	20.1	9.7	14.7	23.4	84.4	100.9	22.6	17.9	5.8	8.0	24.1	111.7	20.2	11.2	9.6	18.3	44.2	5.7	20.2	11.2	9.6	18.3	44.2	5.7
	CV	86.7	102.1	115.6	96.6	104.5	94.9	114.3	110.1	68.0	71.2	110.5	138.3	108.0	100.9	121.5	139.8	120.5	29.0	108.0	100.9	121.5	139.8	120.5	29.0
Relative Humidity (%)	Mean	54.2	50.3	56.0	53.5	49.8	53.8	30.4	30.9	31.3	32.4	28.8	33.8	23.4	23.7	22.0	23.2	19.0	23.6	23.4	23.7	22.0	23.2	19.0	23.6
	SD	5.7	7.8	2.6	4.6	4.5	8.0	7.0	12.1	5.6	6.9	8.9	16.3	7.8	8.9	8.0	7.8	2.9	4.8	7.8	8.9	8.0	7.8	2.9	4.8
	CV	10.5	15.5	4.6	8.6	9.1	14.9	23.0	39.1	17.9	21.3	31.0	48.3	33.2	37.8	36.5	33.5	15.2	20.5	33.2	37.8	36.5	33.5	15.2	20.5
Wind speed (kmph)	Mean	18.4	12.8	13.1	12.7	15.8	16.0	13.8	12.4	12.1	12.8	13.9	13.1	11.7	10.5	10.5	10.5	12.0	19.9	11.7	10.5	10.5	10.5	12.0	19.9
	SD	6.0	0.2	0.7	1.3	1.6	1.1	1.0	1.2	0.5	1.0	1.4	0.8	0.9	0.4	0.7	1.3	1.4	14.0	0.9	0.4	0.7	1.3	1.4	14.0
	CV	32.3	1.3	5.0	10.2	9.8	6.8	6.9	9.4	4.0	8.2	9.9	5.8	8.0	3.7	7.1	12.2	11.7	8.5	8.0	3.7	7.1	12.2	11.7	8.5

Table 7 Seasonal variations of PM_{2.5} concentrations across the region

Regions	Cities	2018		2019		2020	
		winter	Pre-monsoon	winter	Pre-monsoon	winter	Pre-monsoon
UGP	Delhi	336 ± 112	380 ± 42	270 ± 114	242 ± 41	272 ± 50	249 ± 68
	Gurugram	352 ± 113	492 ± 69	268 ± 68	359 ± 48	193 ± 35	138 ± 44
	Agra	298 ± 98	180 ± 53	230 ± 86	259 ± 45	184 ± 53	138 ± 45
	Faridabad	268 ± 101	345 ± 78	241 ± 60	246 ± 41	208 ± 15	190 ± 42
MGP	Kanpur	229 ± 73	168 ± 44	230 ± 69	140 ± 33	202 ± 42	151 ± 34
	Lucknow	210 ± 86	348 ± 26	344 ± 122	334 ± 86	295 ± 68	183 ± 49
	Varanasi	321 ± 146	235 ± 56	299 ± 136	188 ± 52	216 ± 38	66 ± 16
	Patna	338 ± 153	228 ± 61	268 ± 69	143 ± 48	255 ± 75	133 ± 11
	Gaya	386 ± 20	245 ± 66	258 ± 88	264 ± 50	209 ± 59	98 ± 28
LGP	Muzaffarpur	314 ± 123	124 ± 24	283 ± 100	145 ± 34	252 ± 54	98 ± 15
	Asansol	214 ± 101	186 ± 58	225 ± 61	182 ± 39	201 ± 44	86 ± 29
	Kolkata	186 ± 123	159 ± 89	198 ± 82	156 ± 46	168 ± 51	79 ± 23

has been discussed and compared with last two years (2018–2019). From the result, it was well documented that there was substantial decrease of PM_{2.5} concentrations during pre-monsoon (April–May, 2020), which was the lockdown period due to COVID-19. In 2018, during pre-monsoon season, the average PM_{2.5} concentrations over the region was 248 ± 59 that declined to 215 ± 44 in 2019 and 128 ± 34 in 2020. In 2020, during pre-monsoon season, the average concentrations of PM_{2.5} was observed in UGP (179 ± 49 in Delhi) followed by MGP (121 ± 26 in Lucknow) and LGP (82 ± 26 in Asansol). In 2018, during winter season, average PM_{2.5} concentrations over the region was 288 ± 106 that declined to 248 ± 84 in 2019 and 212 ± 48 in 2020. In 2020, during winter, average concentrations of PM_{2.5} was observed in UGP (241 ± 38 in Delhi) followed by MGP (238 ± 56 in Lucknow) and LGP (221 ± 47 in Asansol) (Table 7).

4 Discussion

This present mainly focuses on the assessment the impact of lockdown on the PM_{2.5} concentrations across the most polluted cities of Indo-Gangetic Plain (IGP) of India. Result of the study clearly denoted that there was substantial reduction of PM_{2.5} concentrations across the cities of IGP after the implementation of lockdown. The maximum reduction of PM_{2.5} concentration since 2019–2020 during same periods has been recorded from cities located in Lower Gangetic Plain (36.75%) followed by the cities located in Upper Gangetic Plain (33.52%) and Lower Gangetic Plain (26.38%) respectively. This result of the study is similar with other recent studies (He et al. 2020;

Liu et al. 2020; Watts and Kommenda 2020; Cadotte 2020; Ogen 2020; Coccia 2020). The outbreak of COVID-19 of course has brought serious threats to the entire human world. Apart from this it has also helped to realize how human activities made the environment polluted. COVID-19 outbreak has also helped environment to restore its capacity. In many recent studies it was well recognized that air quality in many of the cities significantly improved due to lockdown. Most recently, a study was conducted by Mahato et al. (2020) over Delhi megacity and the result of the study documented that there was substantial decrease of PM_{2.5} concentrations of during lockdown. Wang et al. (2020) performed a study on major cities of China and the study result showed that the concentration of PM_{2.5} across the cities declined by more than 20%. In addition to this, other cities of the world also experienced rapid improvement of air quality during lockdown such as Milan in Italy (Collivignarelli et al. 2020), Sao Paulo state in Brazil (Nakada and Urban, 2020), Northern China (Wang et al. 2020), 22 cities in India (Sharma et al. 2020), Barcelona in Spain (Tobías et al. 2020), Rio de Janeiro in Brazil (Dantas et al. 2020), 120 cities in China (Zhu et al. 2020) respectively.

Many countries of the world adopted a number of measures to combat with COVID-19 such as travel restrictions, social distancing, closing of most public spaces etc. Along with measures, lockdown has emerged as an effective measure to the severely affected countries of the world to slow down the speed of COVID-19 transmissions such USA, Spain, France as well as India (Nigam 2020). In India nationwide lockdown has been imposed from 24th March to 31st May, 2020 (in four phases). During these lockdown, all social spaces (such as

restaurants, shopping malls, and educational institutions) were closed. All type of transportations services (except essential services), manufacturing as well as industrial activities were strictly prohibited and shutdown. Thus complete nationwide lockdown has brought immense negative impact on socio-economic lives of the people. But outbreak of COVID-19 has also given us an opportunity to understand the dramatic improvement of air pollution level due to restricted emissions from transportations and limited economic activities (Gautam 2020) in manufacturing and industrial sectors. Although Central government of India imposed nationwide lockdown to combat with COVID-19 pandemic but later on states government adopted their own additional measures related to lockdown to control COVID-19 transmissions. A number of measures have been also imposed by the state governments in severely affected cities such as Delhi, Kolkata, Kanpur, Varanasi, Patna, Gurugram etc. For example, in case of UGP cities like Delhi and Gurugram, there were no permission on metro services, opening of shopping malls and strict restrictions on construction activities, transportations (such as 2 and 20 passengers in taxis and buses). The cities located in MGP (such as Patna, Varanasi, Kanpur, Lucknow etc.) and LGP (such as Kolkata, Asansol) also adopted a number of measures to control COVID-19 transmission on restricted use of public spaces, transpirations and other economic activities within the city. The adoptions of effective measures by both central and state governments have shown immense impact on the restricted emissions from various sources (such as transportations, industrial activities). Thus measures related to lockdown ultimately results reduction of air pollution across the cities of IGP.

5 Conclusion

From the overall analysis it was well recognized that the concentration of $PM_{2.5}$ was substantially declined. The outbreak of COVID-19 of course has brought threats to the human lives but apart from this it has also brought an immense impact on the improvement of air quality. The lockdown due to outbreak of COVID-19 has given a scope to realize the restoration capacity of environment. The air pollution across the polluted cities can be checked if emissions from different sources can control through effective measures such as short term lockdown. The long term lockdown may lead extreme burden on socio-economic condition of the people particularly in developing countries like India. Sustainable development and environmental sustainability is not possible through the implementation of long term lockdown. In this context short term lockdown may be an effective measure to build

environmental restoration. The result of the study showed that the concentration of $PM_{2.5}$ was substantially decreased just after one week of lockdown. Therefore, the short term lockdown (3 to 7 days) may be an alternative measure for environmental restoration.

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