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Effect on Ambient Air Quality in Nagpur due to lockdown to contain the spread of COVID-19 pandemic in the year 2020: a case study

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Abstract. The present paper deals with the studies on the change in concentration of three standard pollutants namely, respiratory suspended particulate matter (RSPM or PM_{10}), Sulphur dioxide (SO_2) and Nitrogen dioxide (NO_2) because of lockdown in India to prevent the spread of COVID-19 pandemic in 2020. The monthly average concentrations of the above pollutants observed at four monitoring stations in and around Nagpur city during January to December 2020 were analyzed and compared. Due to COVID-19 pandemic, there was a complete lockdown from 25th March to 31st May 2020 and phased reopening of areas outside containment zones from June 1st onwards. It is found that the average concentration of all the three pollutants at all four stations was reduced by about 50 % to 75 % due to lockdown. During lockdown, the minimum concentration of PM_{10}, SO_2 and NO_2 amongst all stations were found to be 40, 5 and 11 $\mu g/m^{3,}$ respectively, whereas the maximum concentrations were found to be 159, 20, and 50 $\mu g/m^{3,}$ respectively. The concentrations during lockdown were below the standards prescribed by CPCB, which were found to increase due to reopening. The Air quality index (AQI) at all four stations during lockdown was less than 50 (i.e. SATISFACTORY), whereas it increased above 100 (i.e. MODERATE) after reopening. As a result, the annual average concentration of pollutants was reduced in 2020 compared to previous years.

Keywords. Air quality index; RSPM; SO_2; NO_2; pandemic; lockdown.

1. Introduction

The main standard pollutants which pollute the ambient air vigorously are carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and smaller particles, including lead and gasoline additive, suspended particulate matter, etc. [1]. These pollutants are generated by various human activities, industries, construction activities, cyclones, etc. [2]. As India is a developing country, various industrialization, construction and development projects are ongoing in each part of the country releasing pollutants into the atmosphere [3].

Many of the cities are under developing conditions having construction, industrial activities due to which people are attracted towards those cities. This resulted increase in population and increase the use of vehicles which causes automobile pollution [4]. Human health mostly affected by respiratory particles (i.e. PM_{10} and $PM_{2.5}$) present in the atmosphere [5]. These particles in the atmosphere also bounded by the polycyclic aromatic compounds and have a hazardous effect on human health [6] and lead to various carcinogenic compounds [7]. These compond not only affect the atmosphere but also the hydrosphre and stratosphere [8–10]. All these particle's main source is exhaust emission from the combustion of fuel in vehicles [11]. Due to air pollution effects at least 5,00,000 premature deaths are reported each year and the percentage of this on global scale is around 4% to 8% [12]. Pollution due to emission of vehicles in Indian megacities like Delhi contribute 70%, Mumbai 52%, and Kolkata 30% [13].

Particulate matter also contains magnetic minerals, which account for 5–15% of urban atmospheric particulate matter, with iron oxides and hydroxides accounting for 10–70% of the bulk iron content. The most common magnetic mineral contained in particulate matter is

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magnetite [14]. Various meteorological parameters temperature, wind speed, humidity solar radiation also affect the air quality [15]. Different seasons throughout the year also affect the quality of ambient air and are found to be maximum in the post-monsoon and winter season [16, 17].

The whole world has been facing the crisis of novel coronavirus pandemic since November 2019. The first patient of COVID-19 was detected in Wuhan (China), [18]. With effect of this virus, WHO declared Public Health Emergency of International Concern on 30th January 2020, and a pandemic on 11th March 2020. On 30th January 2020, the first COVID-19 patient was identified in Kerala, India. On 9th of March 2020, the first case of COVID-19 was identified in Pune, Maharashtra and on 11th March 2020 in Nagpur. In this way, the COVID-19 has spread day by day all over the world.

In order to break the COVID-19 chain, all countries affected by this virus have adopted lockdown. Government of India also declared a Janta curfew on Sunday, 22nd March 2020 as a trial lockdown. The complete Lockdown was started from March 25th, 2020 in all over the country, which was still in effect in the country due to second wave of CIVID-19. Government implemented the lockdown in different phases i.e. Lockdown 1 from March 25th to April 14th, 2020 (21 days), Lockdown 2: April 15th to May 3rd, 2020 (19 days), Lockdown 3: May 4th to May 17th, 2020 (14 days), Lockdown 4: May 18th to May 31st, 2020 (14 days). During these lockdown phases many people have lost their employment, the industries were closed, transportation and other activities were closed. The lockdown started affecting the economy of the country and since the number cases of COVID-19 were started reducing little bit, the government started unlocking gradually. Which was also known as the "Mission begin again" in phased manner. The Lockdown 5/Unlock 1: June 1st to June 30th, 2020 (30 days), Unlock 2: July 1st to July 31st, 2020 (31 days), Unlock 3: August 1st to August 31st, 2020 (31 days), Unlock 4: September 1st to September 30th, 2020 (30 days), Unlock 5: October 1st to October 31st, 2020 (31 days), Unlock 6: November 1st to November 30th, 2020 (30 days), Unlock 7: December 1st to December 31st, 2020 (31 days). There was a complete lockdown in the country from 25th March to 31st May 2020. From 1st June 2020 the government started reopening the essential services, which was known as lockdown with some relaxation or unlocking in a phased manner. Hence there were three conditions in the year 2020. The first was a normal condition from January to 25th March or 31st March. Then the second phase/ condition was a complete lockdown from April to June 2020, where all the activities, industries, vehicles and all construction activities were closed completely except few from 1st June 2020. The third condition was after lockdown from July to December 2020, where many of the activities were allowed with some rules and restrictions.

The present study deals with the effect on ambient air quality in Nagpur due to lockdown to break the chain of COVID-19 pandemic in the year 2020. For the study, three conditions have been considered in the year 2020, as throughout the year, there was a normal condition in a few months and lockdown/re-opening condition in other months. Hence, these conditions are: (1) before lockdown from January to March 2020, (2) during lockdown condition from April to June 2020, and (3) re-opening condition from July to December 2020. The air pollution concentration data from four ambient air monitoring stations in Nagpur for 2020 has been collected and monthly average concentrations of SO_2, NO_2, and RSPM (PM_{10}) have been determined. The comparison of air pollution concentrations within these three conditions has been reported in the present study.

2. Materials and methods

Nagpur is a city situated in the northeastern part of Maharashtra, a state in western India. It is located at 21.15 latitude and 79.08 longitudes with GPS coordinates 21°8′44.881″ N and 79°5′17.357″ E. It is situated at an elevation of 319 meters above mean sea level. As per the census 2011, Nagpur has a population of 2,228,018 with a population density of 11000 people per km^2. Around 779259 are the main workers and 2.5 lakh children living in the city here who may be affected because of the low quality of air. The city falls under the Universal Transverse Mercator (UTM) zone of 44Q with the coordinate of 301470.33, 2339479.09 by Koppen climate classification with tropical savannah climate (Aw) with dry conditions prevailing for most of the year. Low flat-topped hills, flatlands, and dark, fertile soils in the valleys of streams and rivers define the landscape in and around Nagpur. This city is initiated to become one of India's smart cities. It results in a rapid increase in industrialization and numerous infrastructures in the region.

2.1 *Monitoring sites*

The ambient air quality on Nagpur is being monitored by Visvesvaraya National Institute of Technology (VNIT), Nagpur. There are three monitoring stations under the National Ambient Air Quality Monitoring Programme (NAMP) and one station (i.e., Civil Lines) under State Ambient Air Quality Monitoring Programme (SAMP) sponsored by Maharashtra Pollution Control Board (MPCB), Mumbai, Maharashtra, India. One monitoring station is located at the Institute of Engineers (India), North Ambazari Road, Ramdaspeth Nagpur (Station code: 287), indicated as IE(I) in residential area. The second monitoring station is located at the office of the Executive Engineer, MIDC Hingna Road, Nagpur (Station code: 288), indicated as MIDC in the industrial area. Third monitoring station is at Government Polytechnic, Mangalwari Bazar, Sadar Nagpur (Station Code: 314), indicated as GP in the commercial area. Fourth station is located at MPCB Office Premises, Civil Lines (Station Code: 711) indicated as Civil Lines in government offices area. The location of these stations is shown in figure 1. Three standard pollutants SO_2, NO_2, respirable suspended particulate matter less than 10 µm ($RSPM/PM_{10}$) are being monitored twice a week to get at least 104 samples per year. For daily average concentration, particulate matter is sampled at the 8-hr interval and gaseous pollutants (i.e. SO_2 and NO_2) at a 4 h interval at all four locations.

2.2 *Sampling and analysis of pollutants*

RSPM, SO_2 and NO_2 samples were collected by using respirable dust sampler (RDS) APM460 model (Manufactured by Envirotech Instruments, New Delhi (India)). The Glass Fiber Filters are used to collect RSPM, the absorbing solutions, potassium tetrachloromercurate (TCM) and NaOH plus sodium arsenate are used to absorb SO_2 and NO_2 respectively. The sampling is done at the flow rate of 1.0-1.3 m^3/min for RSPM and 1 L/min for SO_2 and NO_2. The gravimetric method was used for the analysis of RSPM concentration [19]. Spectrophotometer methods; West and Gaeke method is used for the analysis of SO_2 [20] and Jacobs-Hochheiser method is used for the analysis of NO_2 [21].

2.3 *Air Quality Index (AQI)*

This index was created to evaluate air quality using a ratio or number. The air quality index is a regular monitoring index that shows the quality of air in the atmosphere of a particular city. It differentiates the effect of pollution level on human health in short period. AQI helps people to know how the local level of pollution affects on their health. AQI has been classified into different pollution levels based on the index number. All different levels of pollution and their health effects on humans are described in table 1. AQI is calculated by the following equation:

$$I_p = \left\{ \frac{(I_{HI} - I_{LO})}{(B_{HI} - B_{LO})} \times (C_p - B_{LO}) \right\} + I_{LO}$$

Where,

B_{HI} = Breakpoint concentration greater or equal to given concentration.

B_{LO} = Breakpoint concentration smaller or equal to given concentration.

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

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

Cp = Pollutant concentration

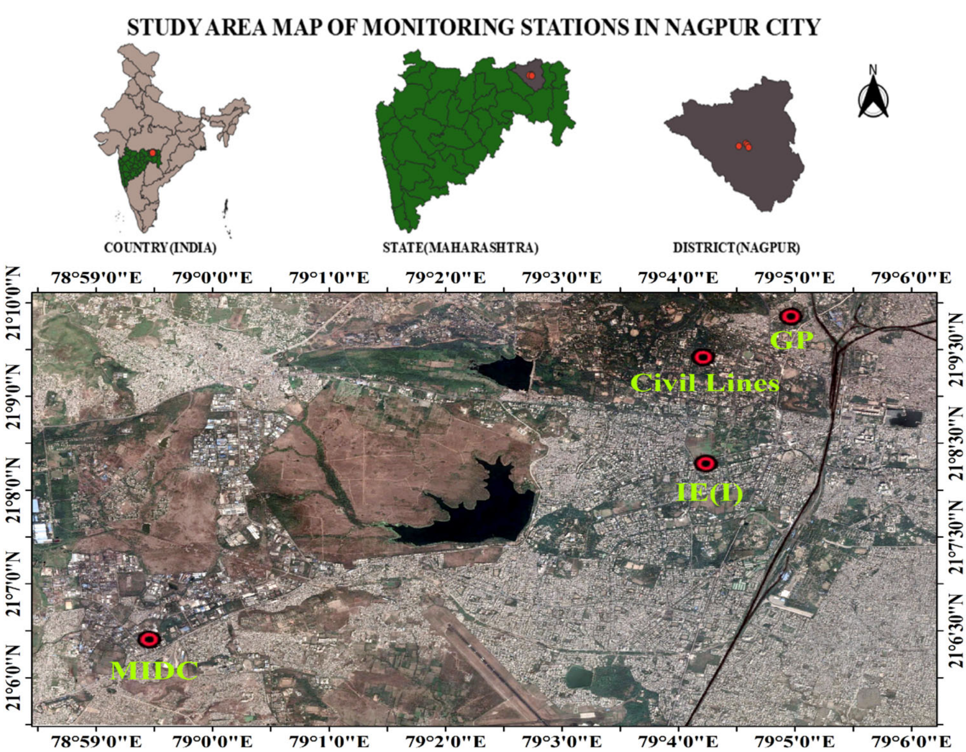


Figure 1. Study Area Map of all Monitoring Stations at Nagpur city, red circles denotes the Location of monitoring stations.

Table 1. Air Quality Index Categories.

AQI	Pollution level	Impact on human health
0-50	GOOD	Minimal Impact
51-100	SATISFACTORY	Minor breathing discomfort to sensitive people
101-200	MODERATE	Breathing discomfort to the people with lung, heart disease, children and older adults
201-300	POOR	Breathing discomfort to people on prolonged exposure
301-400	VERY POOR	Respiratory illness to the people on prolonged exposure
>401	SEVERE	Respiratory effects even on healthy people

3. Results and discussion

3.1 *Concentration of pollutants at IE(I), NAGPUR*

The station is located at the Institution of Engineers (India), on North Ambazari Road, Near Ramdaspeth Nagpur. The sampling is done as described earlier and the monthly average concentrations of pollutants are determined. The average concentrations of all the three pollutants for the year 2020 from January to December are determined and shown in figure 2. From the figure, it can be seen that the concentration of SO_2 before lockdown (from January to March) varies from 14 to 10 μg/m^3, during lockdown (from April to June) varies from 5 and 6 μg/m^3 and in reopening condition (from July to December) varies from 5 to 15 μg/m^3. It may be noted that the average concentration of SO_2 in March is reduced to 10 μg/m^3, as there was a Janta curfew, where there was a complete shutdown in the city on 21st March 2020 and then the complete lockdown started from 25th to 30th June 2020. The average concentration before the lockdown was 12.34 μg/m^3, which is very high compared to the average concentration of SO_2 during lockdown 5.33 μg/m^3. There was a reduction of about 56.76 % in the concentration of SO_2 due to lockdown. The reduction in concentration was due to the shutdown of anthropogenic activities like vehicles, construction, industries, etc. However, the reopening of a few anthropogenic activities with some restrictions started from 1st July 2020, which again started increasing the concentration of pollutants. The average concentration of SO_2 from July to December was 8.83 μg/m^3. A percentage increase in the concentration level of SO_2 due to reopening of the anthropogenic activities was found to increase by about 65.63 % from the concentration during the complete lockdown.

From figure 2, it can be seen that the concentration of NO_2 before lockdown condition varies from 30 to 41 μg/m^3, during lockdown varies from 12 to 14 μg/m^3 and in reopening condition (from July to December) varies from 11 to 42 μg/m^3. It may be noted that the average concentration of NO_2 in March is reduced to 30 μg/m^3, as there was Janta curfew, where there was a complete shutdown in the city on 21st March 2020 and then the complete lockdown started from 25th to 30th June 2020. The average concentration before the lockdown condition was 36.33 μg/m^3, which is very high compared to the average concentration of NO_2 during the lockdown condition, which was 12.67 μg/m^3. Therefore, there was about a 65.14 % reduction in the concentration of NO_2 due to lockdown. All the movement of vehicles, construction activities, industries etc., were closed due to lockdown. However, the reopening of a few anthropogenic activities with some restrictions started from 1st July 2020, which again started increasing the concentration of pollutants. The average concentration of NO_2 from July to December was 23.50 μg/m^3. A percentage increase in the concentration level of NO_2 due to reopening the anthropogenic activities was found to increase by about 85.53 % from the concentration during the complete lockdown.

From figure 2, it can be seen that the concentration of RSPM before lockdown (from January to March) varies from 124 to 148 μg/m^3, during lockdown (from April to June) varies from 66 to 80 μg/m^3 and in reopening condition (from July to December) varies from 76 to 126 μg/m^3. The average concentration before the lockdown condition was 132.67 μg/m^3, which is very high compared to the average concentration of RSPM during lockdown condition was 74 μg/m^3. Therefore, there was about 44.22 % reduction in concentration of RSPM due to lockdown. Due to the lockdown, all the movement of vehicles, construction activities and industries etc., were closed. However, the reopening of a few anthropogenic activities with some restrictions started from 1st July 2020, which again started increasing the concentration of pollutants. The average concentration of RSPM from July to December was 98.67 μg/m^3. A percentage increase in the concentration level of

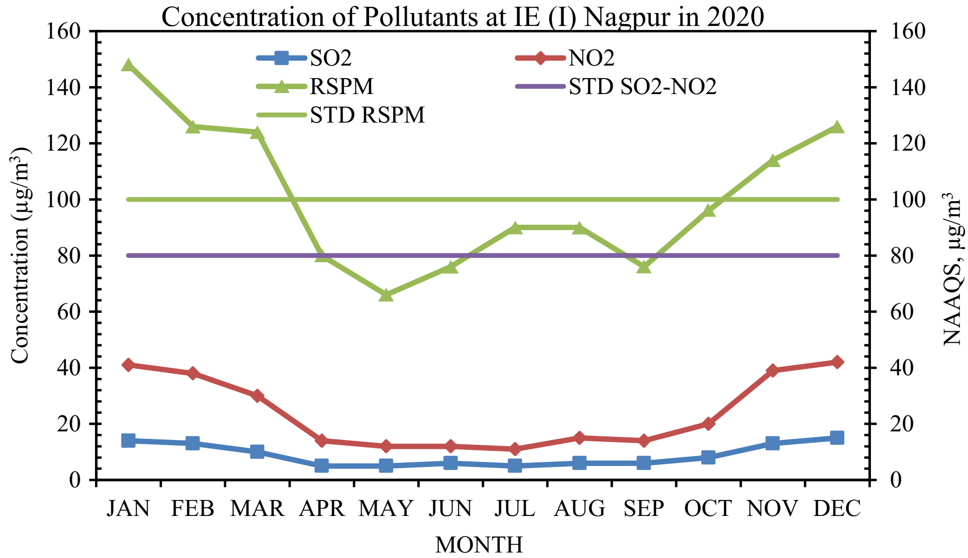


Figure 2. Concentration of pollutants at IEI, Nagpur.

RSPM due to reopening the anthropogenic activities was found to increase by about 33.33 % from the concentration during the complete lockdown.

3.2 *Concentration of pollutants at MIDC, Nagpur*

The station is located at office of Executive Engineer, MIDC, Hingna Raod, Nagpur. The average concentrations of all the three pollutants for the year 2020 from January to December are determined and shown in figure 3. From the figure, it can be seen that the concentration of SO_2 before lockdown (from January to March) varies from 12 to 15 µg/m^3, during lockdown (from April to June) varies from 5 to 6 µg/m^3 and in reopening condition (from July to December) varies from 5 to 20 µg/m^3. It may be noted that the average concentration of SO_2 in March is reduced to 12 µg/m^3, as there was Janta curfew, where there was a complete shutdown in the city on 21st March 2020 and then the complete lockdown started from 25th to 30th June 2020. The average concentration before the lockdown condition was 14 µg/m^3, which is very high compared to the average concentration of SO_2 during the lockdown condition was 6 µg/m^3. Therefore, there was about a 58.54 % reduction in the concentration of SO_2 due to lockdown. From 1st July 2020, this again started increasing the concentration of pollutants. The average concentration of SO_2

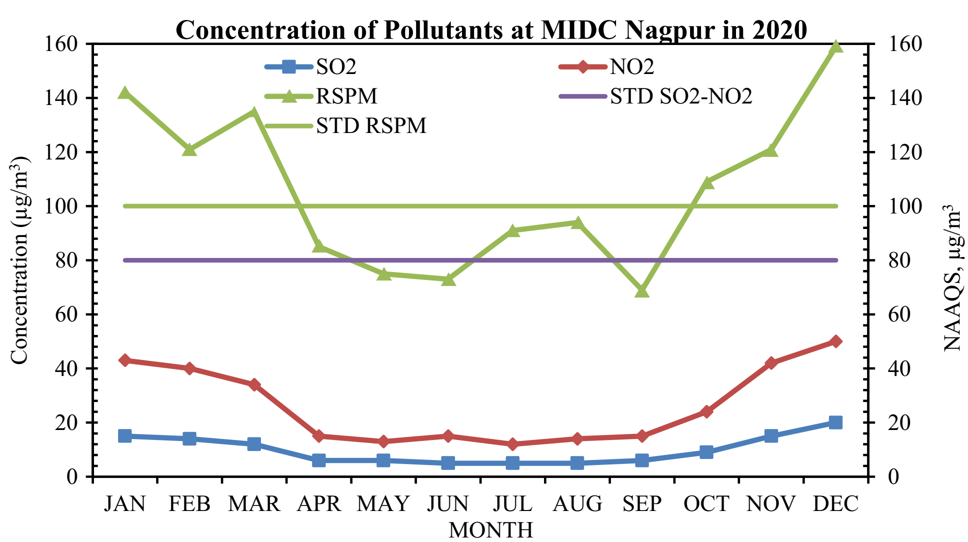


Figure 3. Concentration of pollutants at MIDC, Nagpur.

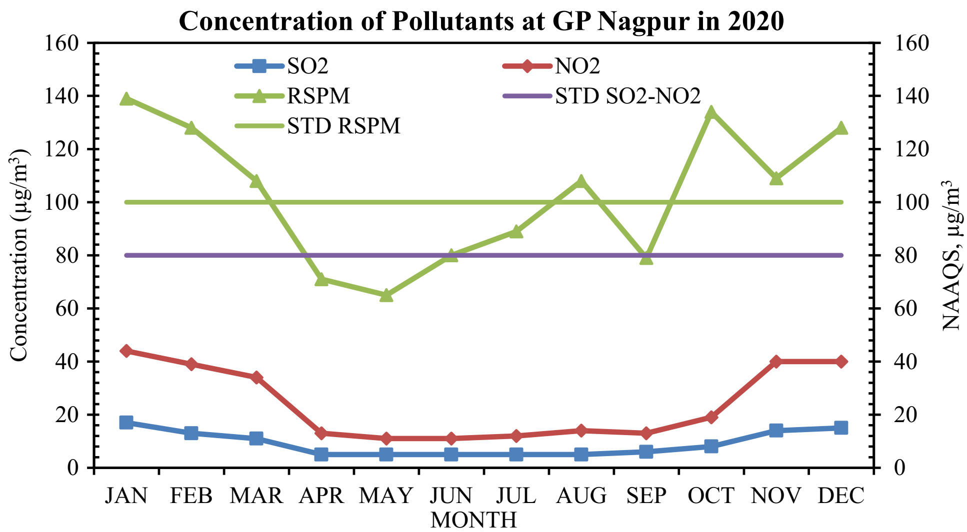


Figure 4. Concentration of pollutants at GP, Sadar, Nagpur.

from July to December was 10 μg/m^3. Therefore, a percentage increase in the concentration level of SO_2 due to reopening the anthropogenic activities was found to increase by about 76.47% from the concentration during the complete lockdown.

From figure 3, it can be seen that the concentration of NO_2 in before lockdown condition varies from 30 to 41 μg/m^3, during lockdown varies from 34 to 40 μg/m^3 and in reopening condition (from July to December) varies from 13 to 15 μg/m^3. It may be noted that the average concentration of NO_2 in March is reduced to 34 μg/m^3, as there was Janta curfew. The average concentration before the lockdown condition was 39 μg/m^3, which is very high compared to the average concentration of NO_2 during the lockdown condition (14 μg/m^3). There was about a 63.25% reduction in the concentration of NO_2 due to lockdown. From 1st July 2020, this again started increasing the concentration of pollutants. The average concentration of NO_2 from July to December was 26 μg/m^3. A percentage increase in the concentration level of NO_2 due to reopening of the anthropogenic activities was found to increase by about 82.56% from the concentration during the complete lockdown.

From figure 3, it can be seen that the concentration of RSPM before lockdown (from January to March) varies from 121 to 142 μg/m^3, during lockdown (from April to June) varies from 73 to 85 μg/m^3 and in reopening condition (from July to December) varies from 69 to 159 μg/m^3. The average concentration before the lockdown condition was 133 μg/m^3, which is very high compared to the average concentration of RSPM during the lockdown condition was 78 μg/m^3. Therefore, there was about a 41.46% reduction in the concentration of RSPM due to lockdown. The average concentration of RSPM from July to December was 107 μg/m^3. A percentage increase in the concentration level of RSPM due to the reopening of the anthropogenic activities was found to increase by about 37.98% from the concentration during the complete lockdown.

3.3 *Concentration of pollutants at GP, Nagpur*

The station is located at Government Polytechnic, Mangalwari Bazar, Sadar, and Nagpur. The average concentrations of all the three pollutants for the year 2020 from January to December are determined and shown in figure 4. From the figure, it can be seen that the concentration of SO_2 before lockdown (from January to March) varies from 11 to 17 μg/m^3, during lockdown (from April to June) varies 5 μg/m^3 and in reopening condition (from July to December) varies from 5 to 15 μg/m^3. It may be noted that the average concentration of SO_2 in March is reduced to 11 μg/m^3. The average concentration before the lockdown condition was 14 μg/m^3, which is very high compared to the average concentration of SO_2 during the lockdown condition was 5 μg/m^3. There was about a 63.41% reduction in the concentration of SO_2 due to lockdown. Some restrictions started from 1st July 2020, and this again started increasing concentration of pollutants. The average concentration of SO_2 from July to December was 9 μg/m^3. A percentage increase in the concentration level of SO_2 due to reopening of the anthropogenic activities was found to increase by about 76.67% from the concentration during the complete lockdown.

From figure 4, it can be seen that the concentration of NO_2 in before lockdown condition varies from 34 to 44 μg/m^3, during lockdown varies from 11 to 13 μg/m^3 and in reopening condition (from July to December) varies from 12 to 40 μg/m^3. It may be noted that the average concentration of NO_2 in March is reduced to 34 μg/m^3. The average concentration before lockdown condition was 39 μg/m^3, which is very high compared to the average concentration of NO_2 during the lockdown condition was 12 μg/m^3. Therefore, there was about a 70.09 % reduction in concentration of NO_2 due to lockdown. The average concentration of NO_2 from July to December was 23 μg/m^3. A percentage increase in the concentration level of NO_2 due to reopening of the anthropogenic activities was found to increase by about 97.14% from the concentration during the complete lockdown.

From figure 4, it can be seen that the concentration of RSPM before the lockdown (from January to March) varies from 108 to 139 μg/m^3, during lockdown (from April to June) varies from 65 to 80 μg/m^3 and in the reopening condition (from July to December) varies from 79 to 134 μg/m^3. The average concentration in before the lockdown condition was 125 μg/m^3, which is very high compared to the average concentration of RSPM during the lockdown condition was 72 μg/m^3. Therefore, there was about 42.40 % reduction in concentration of RSPM due to the lockdown. The average concentration of RSPM from July to December was 108 μg/m^3. A percentage increase in the concentration level of RSPM due to reopening of the anthropogenic activities was found to increase by about 49.77 % from the concentration during complete lockdown.

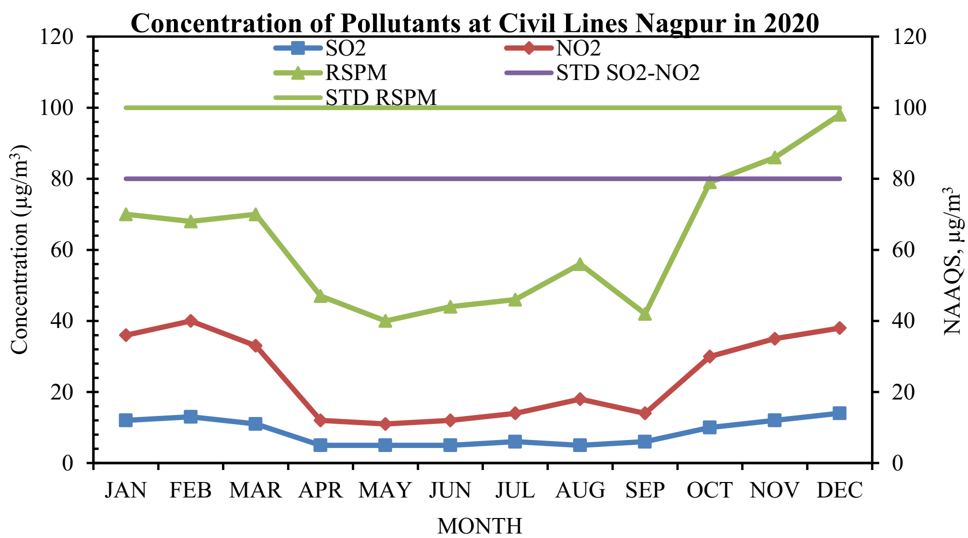


Figure 5. Concentration of pollutants at Civil Lines, Nagpur.

Table 2. Monthly average concentrations (in μg/m^3) of pollutants (i.e. SO_2, NO_2 and RSPM) at monitoring stations i.e. Civil Lines, IEI, MIDC and GP.

Concentration of Pollutants at all Monitoring Stations (μg/m^3)												
	Civil Lines			IE (I)			MIDC			GP		
MONTHS	SO_2	NO_2	RSPM	SO_2	NO_2	RSPM	SO_2	NO_2	RSPM	SO_2	NO_2	RSPM
JAN	12	36	70	14	41	148	15	43	142	17	44	139
FEB	13	40	68	13	38	126	14	40	121	13	39	128
MAR	11	33	70	10	30	124	12	34	135	11	34	108
APR	5	12	47	5	14	80	6	15	85	5	13	71
MAY	5	11	40	5	12	66	6	13	75	5	11	65
JUN	5	12	44	6	12	76	5	15	73	5	11	80
JUL	6	14	46	5	11	90	5	12	91	5	12	89
AUG	5	18	56	6	15	90	5	14	94	5	14	108
SEP	6	14	42	6	14	76	6	15	69	6	13	79
OCT	10	30	79	8	20	96	9	24	109	8	19	134
NOV	12	35	86	13	39	114	15	42	121	14	40	109
DEC	14	38	98	15	42	126	20	50	159	15	40	128

Table 3. Air Quality Indices values for the year 2020 at all four monitoring stations.

Air Quality Index (AQI)				
MONTHS	Civil Lines	IE (I)	MIDC	GP
JAN	70	132	128	126
FEB	68	117	114	119
MAR	70	116	123	105
APR	47	80	85	71
MAY	40	66	75	65
JUN	44	76	73	80
JUL	46	91	89	89
AUG	56	90	94	105
SEP	42	96	106	123
OCT	79	109	114	106
NOV	86	117	139	119
DEC	98	97	101	99

3.4 *Continuous monitoring station at Civil Lines*

The station is located at MPCB office Premises, Udyog Bhawan, Civil Lines, Nagpur. The average concentrations of all the three pollutants for the year 2020 from January to December are determined and shown in figure 5. From the figure, it can be seen that the concentration of SO_2 before lockdown (from January to March) varies from 11 to 13 µg/m^3, during lockdown (from April to June) varies 5 µg/m^3 and in reopening condition (from July to December) varies from 5 to 14 µg/m^3. It may be noted that the average concentration of SO_2 in March is reduced to 11 µg/m^3. The average concentration before lockdown condition was 12 µg/m^3, which is very high as compared to the average concentration of SO_2 during lockdown condition was 5 µg/m^3. Therefore, there was about 58.33 % reduction in concentration of SO_2 due to lockdown. The average concentration of SO_2 from July to December was 9 µg/m^3. A percentage increase in the concentration level of SO_2 due to reopening of the anthropogenic activities was found to increase by about 76.67% from the concentration during the complete lockdown.

From figure 5, it can be seen that the concentration of NO_2 in before the lockdown condition varies from 33 to 40 µg/m^3, during lockdown varies from 11 to 12 µg/m^3 and in the reopening condition (from July to December) varies from 14 to 38 µg/m^3. It may be noted that the average concentration of NO_2 in March is reduced to 33 µg/m^3. The average concentration before the lockdown condition was 36 µg/m^3, which is very high as compared to the average concentration of NO_2 during lockdown condition was 12 µg/m^3. There was about 67.89 % reduction in concentration of NO_2 due to lockdown. The average concentration of NO_2 from July to December was 25 µg/m^3. A percentage increase in the concentration level of NO_2 due to reopening of the anthropogenic activities was found to increase by about 112.86 % from the concentration during the complete lockdown.

From figure 5, it can be seen that the concentration of RSPM before lockdown (from January to March) varies from 68 to 70 µg/m^3, during lockdown (from April to June) varies from 40 to 47 µg/m^3 and in reopening condition (from July to December) varies from 42 to 98 µg/m^3. The average concentration in before lockdown condition was 69 µg/m^3, which is high compared to the average

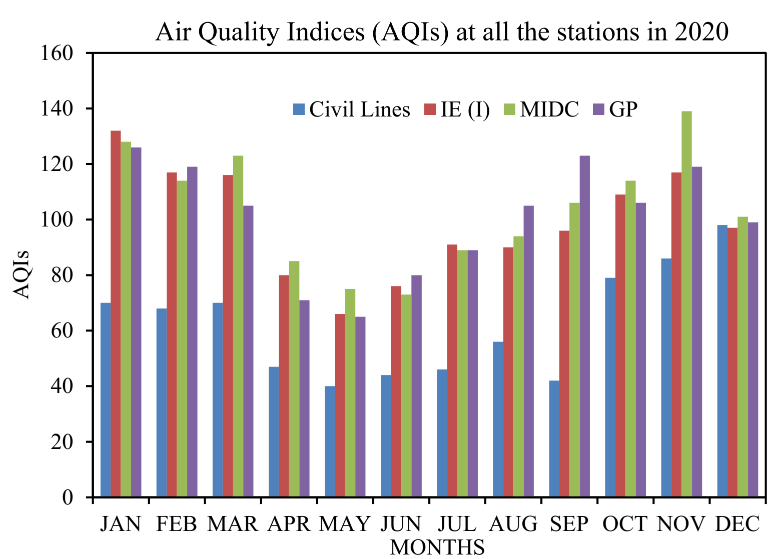
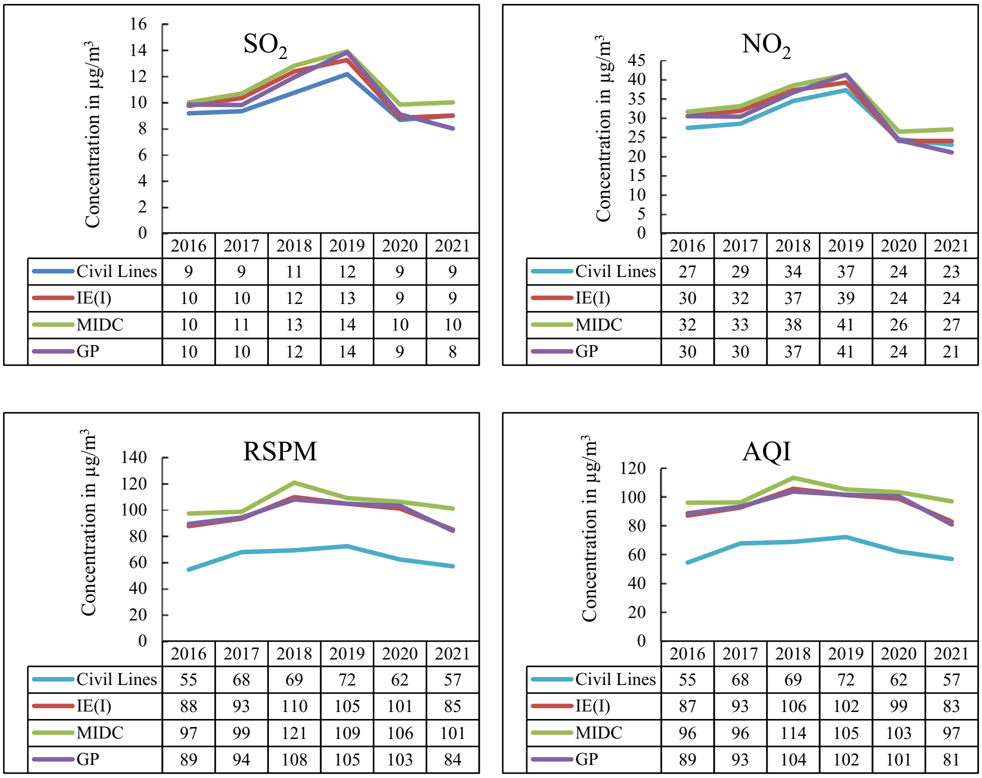


Figure 6. Air Quality Index (AQI) at all four stations for the year 2020.



SO2	2016	2017	2018	2019	2020	2021
Civil Lines	9	9	11	12	9	9
IE(I)	10	10	12	13	9	9
MIDC	10	11	13	14	10	10
GP	10	10	12	14	9	8

NO2	2016	2017	2018	2019	2020	2021
Civil Lines	27	29	34	37	24	23
IE(I)	30	32	37	39	24	24
MIDC	32	33	38	41	26	27
GP	30	30	37	41	24	21

RSPM	2016	2017	2018	2019	2020	2021
Civil Lines	55	68	69	72	62	57
IE(I)	88	93	110	105	101	85
MIDC	97	99	121	109	106	101
GP	89	94	108	105	103	84

AQI	2016	2017	2018	2019	2020	2021
Civil Lines	55	68	69	72	62	57
IE(I)	87	93	106	102	99	83
MIDC	96	96	114	105	103	97
GP	89	93	104	102	101	81

Figure 7. Comparison of all pollutants (a) SO_2, (b) NO_2, (c) RSPM and (d) AQI with previous years from 2016-2021.

concentration of RSPM during lockdown condition was 44 µg/m^3. There was about 37.02 % reduction in concentration of RSPM due to lockdown. The average concentration of RSPM from July to December was 68 µg/m^3. A percentage increase in the concentration level of RSPM due to reopening of the anthropogenic activities was found to increase by about 55.34 % from the concentration during complete lockdown. Table 2 shows the average concentrations of SO_2, NO_2 and RSPM with their standard deviations at all three locations.

3.5 *Air Quality index (AQI)*

Air quality index at all four stations has been determined and shown in table 3 and it is graphically represented in figure 6**.** From table 1 and table 3, it can be seen that the AQI at three monitoring station varies from 101-200. This indicates that the quality of air at three stations was MODERATE. For continuous monitoring (i.e. Civil Lines) station varies from 51-100 which indicate SATISFACTORY quality of air, in before lockdown condition. During lockdown condition, AQI varies from 51 to 100 at three monitoring stations which indicates the SATISFACTORY level of pollution and 0-50 at continuous monitoring (i.e. Civil Lines) station comprises GOOD quality of air. Finally, during reopening conditions, the AQI varies and goes in the range of 101-200 which again shows the MODERATE level of air quality at three stations and SATISFACTORY at continuous monitoring (i.e. Civil Lines) station as it was in the before lockdown condition.

3.6 *Comparison of all the pollutants for 2020 (with the previous four years and a next year) at all the four monitoring stations*

Comparison of all the three pollutants at all the four monitoring stations with the previous four years and the year 2021 has been done. It is found that the difference in annual average concentration in the year 2020 and 2021 is very less as that of the year 2016 to 2019. This could be because of the lockdown due to first wave of coronavirus in the year 2020 and second wave of Coronavirus in the year 2021. In the year 2021 even though there was no complete lockdown, people were much aware of the COVID situation during second wave, and had restricted movement in the city. The concentration went on increasing all the years from 2016 to 2019. Due to the lockdown and reopening in a phased manner gives less pollutant to the environment in the year 2020. From figure 7(a), (b) and (c) it is found that concentration of SO_2, NO_2 and RSPM, respectively are less in the year 2020 at all monitoring stations. AQI shown in figure 7(d) are also decreased in the year 2020 and 2021 due to lockdown effect and improvement in the quality of air.

4. Conclusion

The present study concluded that the main pollutant which affected the quality of air in the city, is respirable suspended particulate matter (which is above the prescribed standard given by central pollution control board i.e., 100 $\mu g/m^3$), SO_2 and NO_2 due to various industries, construction activities, vehicle emission, etc. To contain the spread of novel Corona Virus, Government of India imposed lockdown since 25th march 2020, which was in force till December 2020 in a phased manner, and reopening of lockdown from June 1st 2020 also known as the unlocking phase. Due to the lockdown, the average concentration of pollutants during lockdown decreased drastically (5, 11 and 65 $\mu g/m^3$ for SO_2, NO_2 and RSPM respectively) as compared to the before lockdown condition (13, 37.5 and 115 $\mu g/m^3$ for SO_2, NO_2 and RSPM respectively). In the reopening condition, the concentration of all pollutants again increased (9.25, 24.5 and 95.5 $\mu g/m^3$ for SO_2, NO_2 and RSPM respectively) due to various vehicular activities, construction works, etc. Percentage reduction in the concentration of pollutants during lockdown condition were 59.26%, 66.59% and 41.27% for SO_2, NO_2 and RSPM respectively when compared to before lockdown condition. Percentage increment in reopening condition were 73.86%, 94.52% and 44.11% for SO_2, NO_2 and RSPM respectively, compared to during lockdown condition. Air quality indices change from 101-200 to 51-100 in lockdown and again 101-200 in reopening phase, which shows the quality of air change from MODERATE to SATISFACTIRY in lockdown and SATISFACTIRY to MODERATE in reopening condition again. Comparison of annual average concentration of all pollutants with previous years shows that there was a less pollution in the year 2020 and 2021, due to the lockdown. Due to lockdown, all the anthropogenic activities and industries were closed most of the time in the year, because of first and second wave of Corona Virus. Hence, it can be concluded that the, the main reason for the increase in environmental or air pollution is anthropogenic activities, traffic and industrial activities. If the lockdown is imposed in the pollution affected area the environmental pollution to some extent can be reduced to get the CLEAN environment.

Nomenclature

RSPM	Respirable Suspended Particulate Matter
PM_{10}	Particulate matter particle size less than 10 µm
$PM_{2.5}$	Particulate matter particle size less than 2.5 µm
SO_2	Sulfur dioxide
NO_2	Nitrogen dioxide
CPCB	Central Pollution Control Board
AQI	Air Quality Index
WHO	World Health Organization
NAMP	National Ambient Monitoring Programme
SAMP	State Ambient Monitoring Programme
IE(I)	Institute of Engineers
MIDC	Maharashtra Industrial Development Corporation
GP	Government Polytechnic
MPCB	Maharashtra Pollution Control Board
I_p	Air Quality Index Value
B_{HI}	Breakpoint Concentration greater or equal to given Concentration
B_{LO}	Breakpoint Concentration smaller or equal to given Concentration
I_{HI}	AQI value corresponds to B_{HI}
I_{LO}	AQI value corresponds to B_{LO}
C_P	Pollutants Concentration
STD SO_2-NO_2	Standard concentration values of Sulfur Dioxide and Nitrogen Dioxide prescribed by Central Pollution Control Board
STD RSPM	Standard concentration values of Respirable Suspended Particulate Matter prescribed by Central Pollution Control Board
NAAQs	National Ambient Air Quality Standards

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