Analysing Pollution Levels in Delhi NCR During the COVID-19 Lockdown

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1 INTRODUCTION

Pollution levels in the cities of the Delhi NCR region are known to be some of the world's worst[1] . However, with the imposed lockdowns[2] to tackle the COVID-19 outbreak, a significant reduction in pollution levels was observed in multiple cities across India, including New Delhi. Delhi and the regions around it have high population density, many industries, and very high traffic and movement. With heavy regulation in terms of permitting various economic activities in the different phases of the lockdowns, it would be interesting to note how these activities impact air quality. Besides, these insights can be used to critique or propose actionable steps to take in the post-COVID world to keep a check on the pollution levels.

In this paper, we aim to understand the impact of the lockdown (implying a change in the economic activities) on the air pollution levels in Delhi NCR. The question we answer in this study is "how do various sources of pollution in Delhi NCR contribute to the air quality in the region?"

This study has been commissioned for the use of proactive air pollution activists: Namita Gupta, founder of AirVeda and Manas Fuloria, co-founder of Nagarro.

2 INVESTIGATION METHODOLOGY

This section outlines the methodology, assumptions and standards that were used to conduct this study. The described procedure remained consistent throughout the investigation unless mentioned otherwise.

2.1 Data Collection

Before collecting data from a reliable resource, the metric to measure air quality had to be established. In this study, we chose to analyse five different pollutants (mentioned in Table 1) with respect to their recommended levels.

[1] Bloomberg LP (2020) “Two-Thirds of the World’s Most Polluted Cities Are in India.” Retrieved from Bloomberg database.

[2] Wikipedia (n.d.) “COVID-19 Pandemic Lockdown in India”. Retrieved from https://en.wikipedia.org/wiki/COVID-19_pandemic_lockdown_in_India.

Table 1—List of pollutants analyzed in this study

Pollutant	Sources
Particulate Matter 2.5 (PM 2.5)	Fires, Car Engines, Coal
Particulate Matter 10 (PM 10)	Construction, Road Dust
Nitrogen Oxides (NO_x)	Vehicles, Industries with Combustion Processes
Ozone (O_3)	Power Stations, Lightnings
Carbon Monoxide (CO)	Partial Combustion: Vehicle Engines, Industries

After deciding the choice of pollutants under investigation, for reliability of the data-source, all data was taken from the website of the Central Pollution Control Board (CPCB)[3]. Following the goal of the study, data was obtained for each of the pollution-monitoring stations spread across Delhi NCR (Figure 1).

Figure 1—CPCB air pollution monitoring stations from the Delhi NCR region investigated in this report.

[3] The Central Pollution Control Board of India is a statutory organisation under the Ministry of Environment, Forest and Climate Change. It was established in 1974 under the Water Act, 1974. The CPCB is also entrusted with the powers and functions under the Air Act, 1981.

Further, for simplification and improving the interpretability of the analysis, these stations were clustered into different groups based on their direction and distance from the centre of Delhi (Mandir Marg Station). Stations in the proximity of each other were placed in the same bin.

Table 2—Clusters of Pollution Monitoring Stations based on direction

Cluster	Station(s)	Cluster	Station(s)
C	Mandir Marg	**SE, NOIDA**	Sector-116, Sector-125, Knowledge Park 5, Knowledge Park 3
E, NOIDA	Indirapuram, Sector-62, Noida, Vasundhara, Sanjay Nagar	**SE**	CRRI Mathura Road, IMD, Okhla Phase-II, DTU
E	ITO, Nehru Nagar, Patparganj, Anand Vihar, Vivek Vihar, Sector-16A, Faridabad	**SW, GGN**	Vikas Sadan, Sector-2, IMT Manesar
NE	Ahok Vihar, IHBAS, Dilshad Garden, Sonia Vihar, Loni	**SW**	Dwarka Sector-8, IGI Airport, NSIT Dwarka
NW	Dr. Karni Singh Shooting Range, Rohini, Burari Crossing - IMD, Jahangirpuri, Wazirpur, Alipur, Najafgarh, Pooth Khurd, Bawana	**W**	Pusa, Shadipur, Punjabi Bagh, Mundka, North Campus, DU
S	Jawaharlal Nehru Station, Lodhi Road IMD, BK Puram, Siri Fort, Aya Nagar IMD, Sri Aurobindho Marg, NISE Gwal Pahari		

2.2 Standards & Factual Information

CPCB has divided air quality level into six broad categories based on the pollutant levels: 'Good,' 'Satisfactory,' 'Moderate,' 'Poor,' 'Very Poor,' and 'Severe' (Table 3). The air quality levels in this paper are described with respect to these categories. The units used are as follows: PM 2.5 - $\mu g/m^3$, PM 10 - $\mu g/m^3$, NO_x - ppb, O_3 - ppm, CO - ppm.

Table 3—Air Quality Category based on Pollutant Levels[4]

AQI Category (Range)	PM10	PM 2.5	NO_x	O_3	CO
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0
Moderate (101-200)	101-250	61-90	81-180	101-168	2.1-10
Poor (201-300)	251-350	91-120	181-280	169-208	10-17
Very Poor (301-400)	351-430	121-250	281-400	209-748	17-34
Severe (401-500)	430+	250+	400+	748+	34+

Each phase in the lockdown was associated with a certain level of economic activity (Table 4). In this study, these activities are referenced to draw causal or correlation inferences about the trends in pollution levels over the different phases.

Table 4—Overview of the Lockdown Phases in Delhi NCR

Lockdown Phase	Date	Description	Remarks - Pollution Sources
Before-Covid	01 Feb - 24 Mar	-	Certain behavioral changes started early-March due to fear of the pandemic, however, most are undocumented.
Phase-1	25 Mar - 14 Apr	All services and factories except essential services were closed, such as: • Offices • Educational Institutions • Private Vehicles • Buses, Taxis, Delhi Metro • Alcohol Sale	Near-complete shutdown of all polluting sources ranging from traffic, industrial emission and road dust.
Phase-2	15 Apr - 3 May	The following were allowed to reopen in the non-containment zones 20th April onwards[5]: • Agricultural businesses • Cargo transportation vehicles • Banks and government centres distributing benefits	The following sources started (minimal): • Vehicular: cargo vehicles, trains, planes, and transport of health care staff were allowed

[4] CPCB (2014) "National Air Quality Index." Retrieved and recreated from http://www.indiaenvironmentportal.org.in/files/file/Air%20Quality%20Index.pdf

[5] Hindustan Times (2020) "Lockdown 2.0: What Will Remain Shut, What May Open after Apr 20th?" Retrieved from https://www.hindustantimes.com/

		• Small retail shops (50% staff) • Intra and inter-state movement of stranded persons • Services by the self-employed • Construction within the municipal corporation limits • IT services (50% staff)	• Construction: public works projects were allowed to resume
Phase-3	4 May - 17 May	The following were allowed to open[6]: • Public Transport: Buses • Call Centres and IT Services • E-commerce (essential goods) • Delhi govt offices engaged in essential services • Private offices (33% strength) • Private 4 & 2-wheelers with 50% occupancy • Alcohol Sale	The following sources must have increased more than Phase-2 levels: • Vehicular: buses, deliveries for e-commerce were allowed, offices resumed, and alcohol sale were allowed
Phase-4	18 May - 31 May	The following were allowed to open[7]: • Local Markets • Government & Private Offices • Taxis with two passengers, auto rickshaw with single passenger, and buses with 20 passengers • Construction Activities • Weekly Markets, Street Vendors • Industrial units (with staggered business hours) • Marriages (upto 50 people) • Funerals (upto 20 people)	The following sources increased compared to Phase-3 with continued relaxations (and lesser regulations): • Vehicular: government and private offices increasingly started to open up, markets were opened with staggered timings, taxis were allowed • Construction: construction activities were allowed to resume • Industrial Pollution: industrial units reopened

2.4 Data Analysis for Delhi NCR Region

This section is divided into three parts that detail the impact of lockdown on air pollution levels.

[6] The Economic Times (2020) "Lockdown 3.0: Here's What is Allowed in Delhi?" Retrieved from https://economictimes.indiatimes.com/

[7] Indian Express (2020) "Delhi Lockdown 4.0: Here's a List of What's Open and What's Closed." Retrieved from https://indianexpress.com/

2.4.1 Average Pollution-Levels in Each Phase of the Lockdown

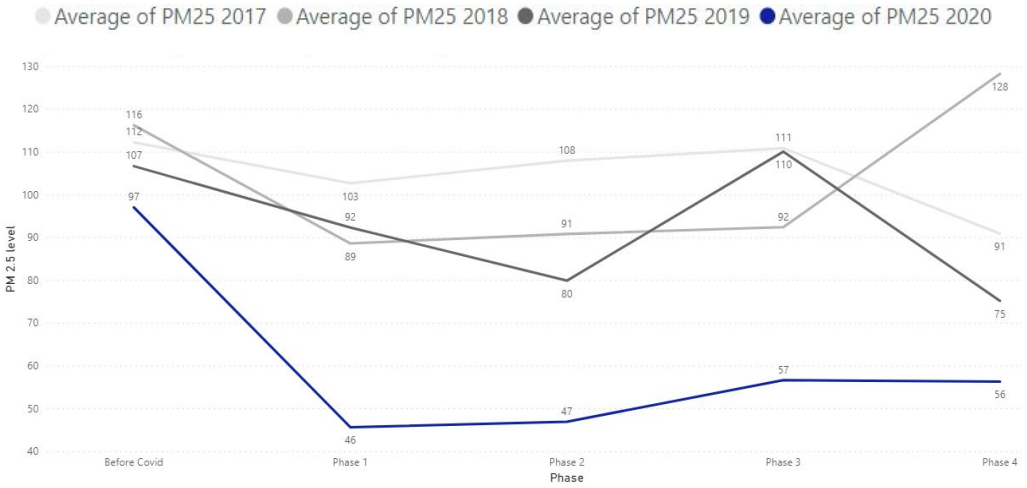

Figure 2—Average PM 2.5 value for each phase of the lockdown compared to PM 2.5 averages for same periods in 2017, 2018 & 2019

From Figure 2, it can be deduced that the phase-wise average PM 2.5 levels for 2020 improved from Moderate to Satisfactory approaching the first phase of the lockdown (sharp drop of 52% from Feb 1st to March 24th), and continued to stay within the Satisfactory levels throughout the lockdown. However, it shows a major increase of 20% from Phase-2 to Phase-3 of the lockdown.

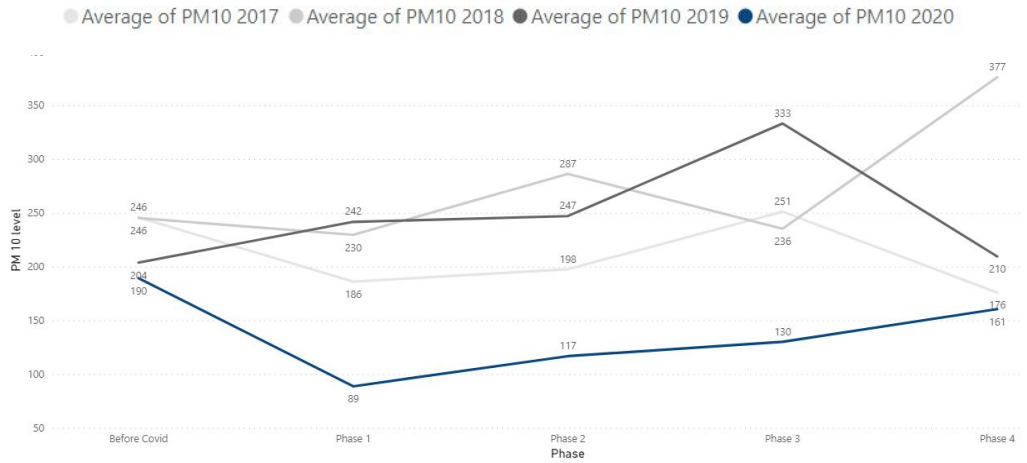

Figure 3—Average PM 10 value for each phase of the lockdown in Delhi NCR compared to PM 10 averages for same periods in 2017, 2018 & 2019

Figure 3 shows the average value of PM 10 in 2017, 2018, 2019 and 2020 with respect to the months corresponding to the various phases of the lockdown. The average PM 10 level for 2020 improved from Moderate to Satisfactory levels approaching the first phase of the lockdown (sharp drop of 53% from Feb 1st to March 24th). PM 10 levels increased consistently through the lockdown phases, showing sharp increases of 31% from Phase-1 to Phase 2, and 23% from Phase-3 to Phase-4.

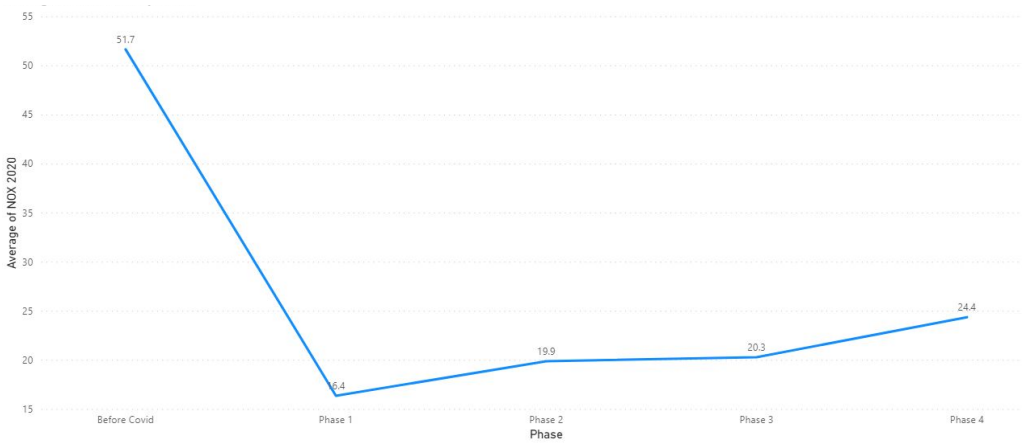

Figure 4—Average NOx levels at each phase of lockdown in Delhi NCR

In 2020, average NO_x values decreased by 68% from Feb 01 to March 24 which was the start of the first phase of the lockdown. It then increased with every phase, notably by 19% from Phase-1 to Phase-2, and by 20% from Phase-3 to Phase-4.

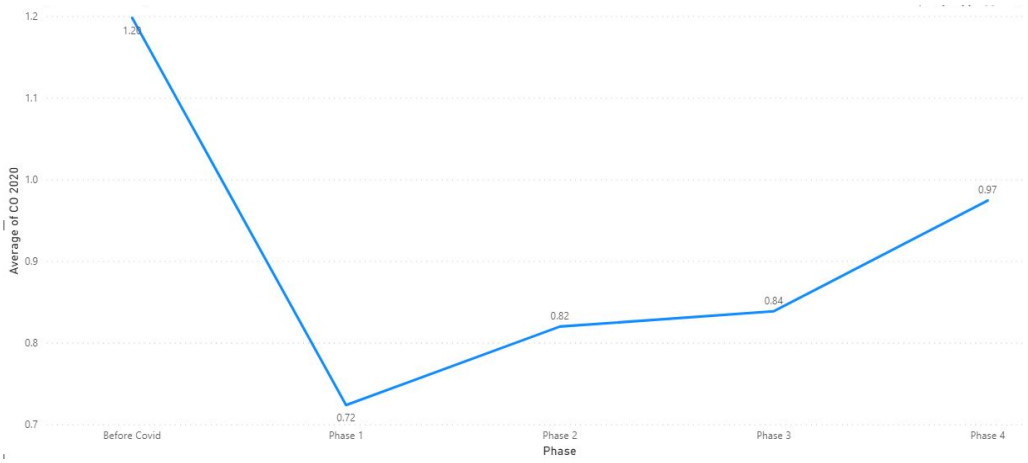

Figure 5—Average CO levels at each phase of lockdown in Delhi NCR

In 2020, the CO values followed a similar pattern as that of NO_x. CO decreased by 40% from 1.2 ppm to 0.72 ppm approaching the first lockdown, and then showed an increasing trend throughout the phases of the lockdown. However, throughout these 4 phases, the values remained below 1.0 ppm which was still in the Good range.

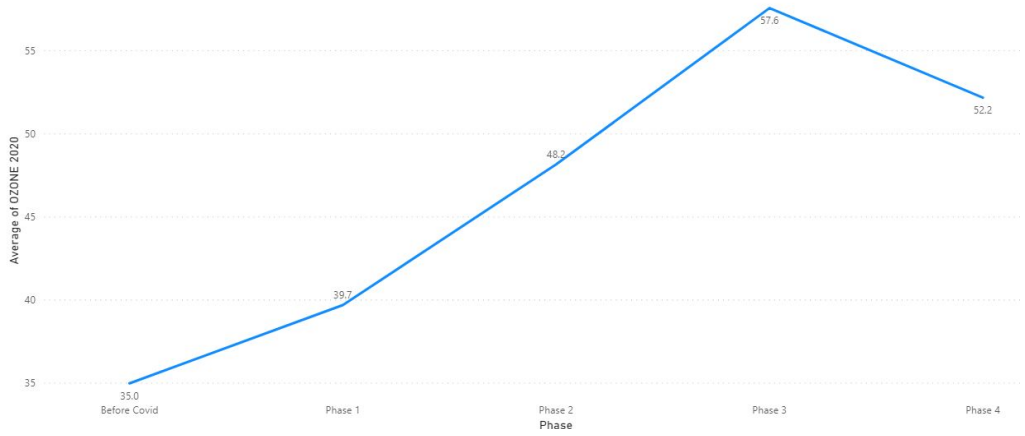

Figure 6—Average Ozone levels at each phase of lockdown in Delhi NCR

Ozone levels exhibited a different pattern compared to NO_x and CO. Starting the Phase-1 with an increasing trend, it steadily increased and peaked in Phase-3, and dipped in Phase-4. The increase in surface ozone level can be attributed to increasing temperature during the lockdown. Being a photochemical oxidant, ozone's production becomes more efficient during the summer[8]. However, the reduction in levels after Phase-3 might be because of higher particulate matter concentration in Phase-4 of the lockdown as with higher particulate matter levels in air, the sunlight gets scattered which then reduces the chances of producing ozone.

Table 5—Change in Pollutant Levels from Pre-Covid to Each Phase of the Lockdown

Pollutant	→ Phase 1	Pre-Covid → Phase 2	Pre-Covid → Phase 3	Pre-Covid → Phase 4
PM 10	-53.15%	-38.4%	-31.5%	-15.2%
PM 2.5	-52.58%	-51.5%	-41.2%	-42.2%
NOx	-68%	-61.5%	-60.7%	-52.8%
CO	-40%	-31.6%	-30%	-19.1%

[8] Sicard, P., De Marco, A., Agathokleous, E., Feng, Z., Xu, X., Paoletti, E., ...(2020). Amplified ozone pollution in cities during the COVID-19 lockdown. Science of The Total Environment, 139542.

Ozone	+13.4%	+37.7%	+64.5%	+49.1%

Table 6—Change in Pollutant Levels Across Lockdown-Phases (2020)

Pollutant	→ Phase 1	Phase 1 → Phase 2	Phase 2 → Phase 3	Phase 3 → Phase 4
PM 10	-53.15%	+31.46%	+11.11%	+23.85%
PM 2.5	-52.58%	+2.17	+21.28	-1.75
NOx	-68%	+19%	+2%	+20%
CO	-40%	+14%	+2.4%	+15.5%
Ozone	+13.4%	+21.4%	+19.5%	-9.4%

From Table 5 & Table 6, the general trend that can be observed is that the average pollution levels of PM 2.5, PM 10, NO_x and CO were the least at Phase-1; this can be attributed to the fact that nearly all services and factories were suspended during this phase.

For PM 2.5, PM 10 and CO, the pollutant concentrations decreased till the start of Phase-2, likely to be because of the relaxations provided by the government at phase of the lockdown which resulted in the increase in economic activity.

The steep increase in PM 10 in Phase-2 can be attributed to two important events in the third week of April: crop burning occurring around NCR[9] and a dust storm[10]. The former can indicate the increase in NO_x too.

[9] Hindustan Times (2020) "COVID-19 Lockdown: Stubble Burning Returns to Haunt Punjab Region." Retrieved from https://www.hindustantimes.com/

[10] Times of India (2020) "Wind Brings Dust, Air Quality Dips in Delhi." Retrieved from https://timesofindia.indiatimes.com/city/delhi/

2.4.2 Behavioral Trends: PM 2.5 and PM 10 Levels During the Lockdown

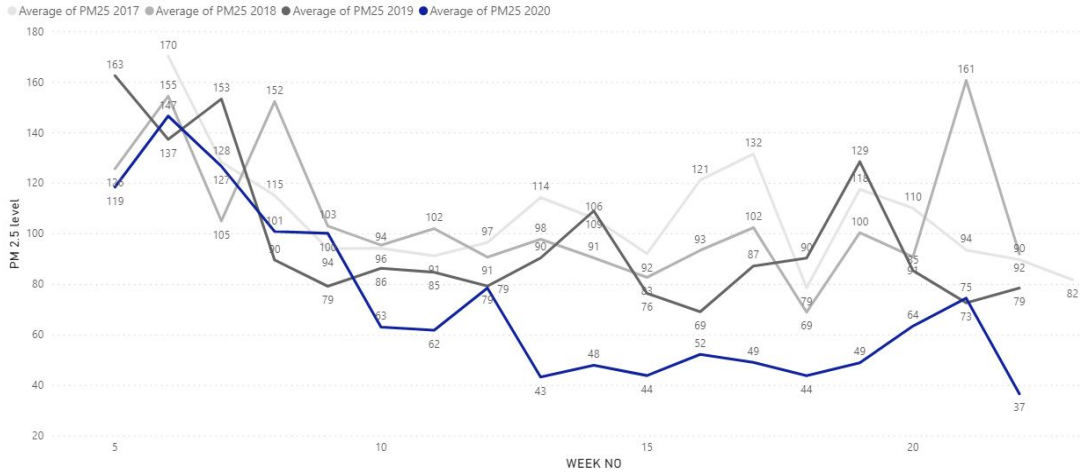

Figure 9—Weekly average of PM 2.5 values from Feb to May 2020, compared with the years 2017, 2018 and 2019

Table 7—Behaviour Trends for PM 2.5 Values from Feb-May, 2020.

Phase	Trend
Phase 1	PM 2.5 levels decreased from 91 (Poor) on 20th March to 23 (Good) on 27th March. Further, PM 2.5 levels increased to Moderate levels on 30th March and remained so ending Phase-1 at 61.
Phase 2	PM 2.5 levels remained Moderate at the start of the phase before dropping to 28 (Good) on 15th April. It rose back to 72 on 22nd April and back to 30 (Satisfactory) on 27th April.
Phase 3	Pollutant levels remained at Satisfactory levels for the majority of the phase. However, it rose to Moderate levels around 15th May. With gradual increase, the phase ended at 91 (Poor).
Phase 4	PM 2.5 values showed a decreasing trend for the majority of Phase-4.

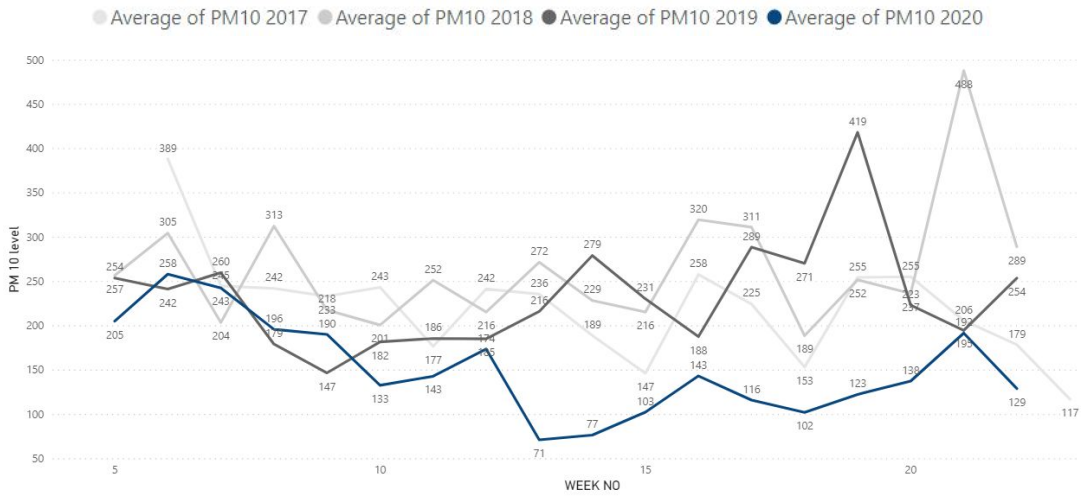

Figure 10—Weekly average of PM 10 values from Feb to May 2020, compared with values from the years 2017, 2018 and 2019

Table 8—Behaviour Trends for PM 10 Values from Feb-May, 2020

Phase	Trend
Phase 1	PM 10 levels changed from Moderate to Satisfactory within 20th March to 22nd March (50% drop in the levels). The levels gradually decreased to reach a minimum on 27th March. However, from 27th March to 5th April the values increased from 34.48 to 113 (Good to Moderate). By 14th April, PM 10 concentrations reached 170.38.
Phase 2	Peak value (213) on 15th April. Within two days, on 17th April, the values dropped to 83, jumping from Moderate to Satisfactory. The values fluctuated between Satisfactory and Moderate levels, and ended the phase at 74.
Phase 3	PM 10 increased from 95 on 4th May to 150 on 6th May, changing from Satisfactory to Moderate within two days. Remained at Moderate throughout the phase, ending at 189.
Phase 4	PM 10 values remained at Moderate levels till 28th May and dropped to 64 on 29th May, ending at 40 at the end of the phase.

It is important to note, for this investigation, that the Delhi government ruled primary schools to be closed from 6th March[11], and restaurants to be closed from 20th March.[12] Moreover, a gathering of more than 20 people was also forbidden. Hence, it is highly likely that for these

[11] Economic Times (2020) "Delhi Schools Closed: All Primary Schools Closed as Coronavirus Spreads." Retrieved from https://economictimes.indiatimes.com/

[12] The Hindu (2020) "Delhi Orders Restaurants to Remain Closed." Retrieved from https://www.thehindu.com/news/national/

reasons coupled with precautionary quarantines, the Delhi pollution levels started to drop before the nationwide lockdown started. Since this report does not cover information for the month of June, it would be interesting to see if and how Delhi's air pollution levels returned to higher values with more relaxations.

2.4.3 How did pollution levels in 2020 fare compared to previous years?

On comparing the PM levels for 2020 with previous years for the same months as the lockdown, it is found that 2020 had much better quality throughout the 4 lockdown phases.

Table 9—Phase-wise PM 2.5 values in 2020 compared to 2017, 2018 and 2019

PM 2.5	Pre-Covid	Phase-1	Phase-2	Phase-3	Phase-4
2017 → 2020	-22.8%	-52.2%	-40.9%	-48.4%	-8.5%
2018 → 2020	-22.8%	-61.3%	-59.2%	-44.9%	-57.3%
2019 → 2020	-6.8%	-63%	-52.6%	-60.9%	-23.3%

Table 10—Phase-wise PM 10 values in 2020 compared to 2017, 2018 and 2019

PM 10	Pre-Covid	Phase-1	Phase-2	Phase-3	Phase-4
2017 → 2020	-13.4%	-55.3%	-56.5%	-48.6%	-38.5%
2018 → 2020	-16.4%	-48.3%	-48.4%	-38.0%	-56.2%
2019 → 2020	-9%	-50%	-41.2%	-48.2%	-25%

In addition to reduced pollution levels in 2020 during the pre-COVID period, Phases 1-3 during 2020 saw huge decreases of at least 48% (half) compared to previous years owing to the reduced economic activity. 2020 has had only 5.6% days during lockdown where PM 2.5 was in the Poor/Very Poor/Severe categories (compared to previous years with 20-40% days falling in those same categories).

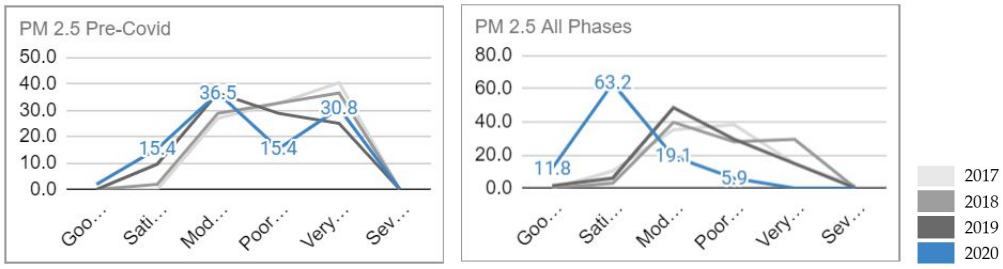

Figure 11—%days for each air quality category for PM 2.5 levels in the pre-Covid time and overall in all phases of the lockdown

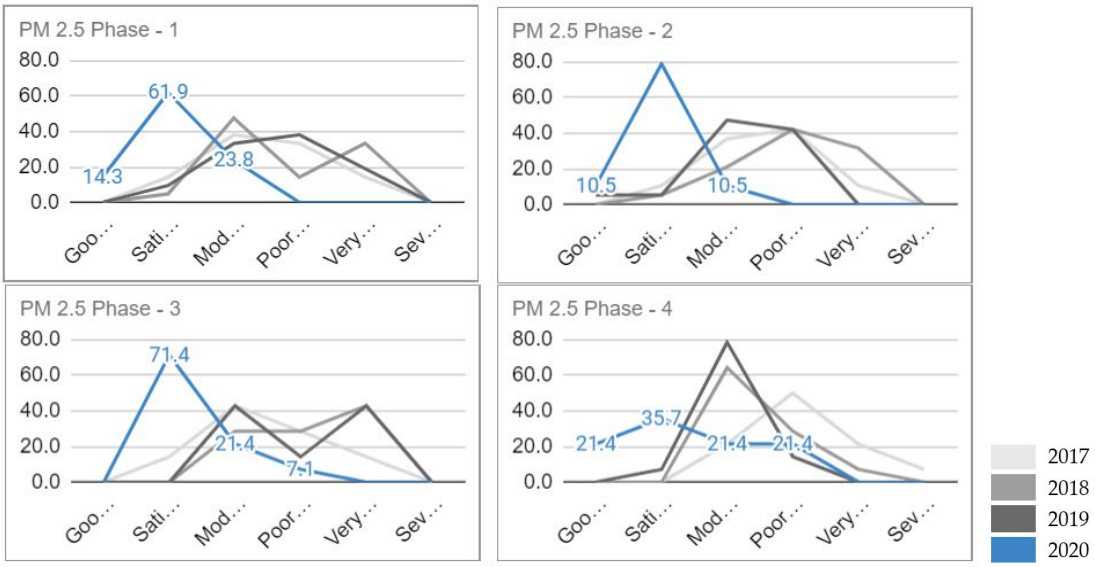

Figure 12—%days for each air quality category for PM 2.5 levels across the first 4 phases of the lockdown

Within the lockdown, Phase-1 and Phase-2 in 2020 fared the best compared to other phases in terms of PM 2.5. 14.5% of the days in Phase-1 had Good air quality, and 61% of the days had Satisfactory air quality. In Phase-2, the percentage of Good air quality days decreased to 10% and that in the Satisfactory range increased to 80%. There were 0% days of Poor quality in these two phases. This number increased to 7% in Phase-3 and 21% in Phase-4. This deterioration in air quality as the lockdown progressed can be attributed to the resumption of economic activities (Table 4).

Even in Phase-1, Delhi did not see Good/Satisfactory PM 2.5 levels on all days. One possible reason for this can be Delhi's geography/location close to agricultural and desert regions. Additionally, there are miscellaneous factors including but not limited too, power plants, waste burning, cooking using wood stoves. A more extensive analysis is required on a geographic and temporal basis to conclusively determine factors that deteriorate the quality of Delhi's air.

Further, it is interesting to note that even without the lockdown, there was improvement in air quality from before to after 2018. 2017 and 2018 have more instances of Poor/Severe levels of pollutant (both PM 2.5 and PM 10) concentrations as compared to 2019 and 2020 (Figure 11, Figure 13). The decreases in these levels for 2020 can also be associated with initiatives such as shifting from BS-IV fuel to BS-VI fuel, closing the Badarpur power plant, banning coal and

kerosene in Delhi and strictness in industrial pollution regulation, taken by the Delhi government[13].

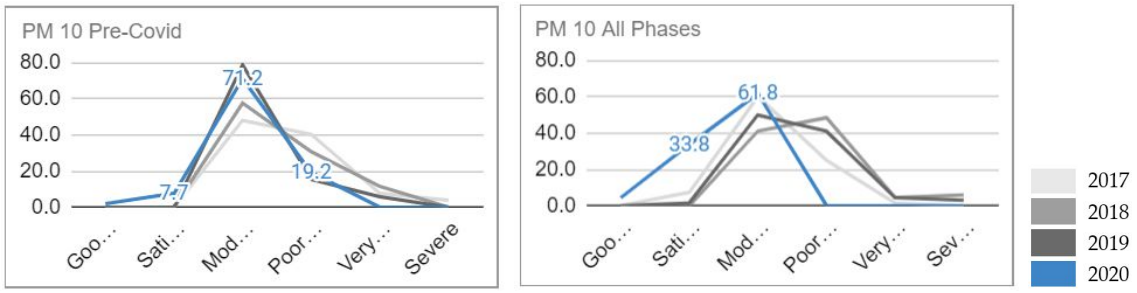

Figure 13—%days for each air quality category for PM 10 levels in the pre-Covid time and overall in all phases of the lockdown

One can see that during pre-covid months, 2020 performed nearly the same as 2019 in PM 10 levels. In the 4 phases of lockdown overall, in 2020, there were 0 days in the Poor/ Very Poor/ Severe range, with more than 35% days being in the Good/ Satisfactory range. In contrast, in 2019, nearly 40% days lied in the Poor range, with less than 10% in the Good/ Satisfactory range.

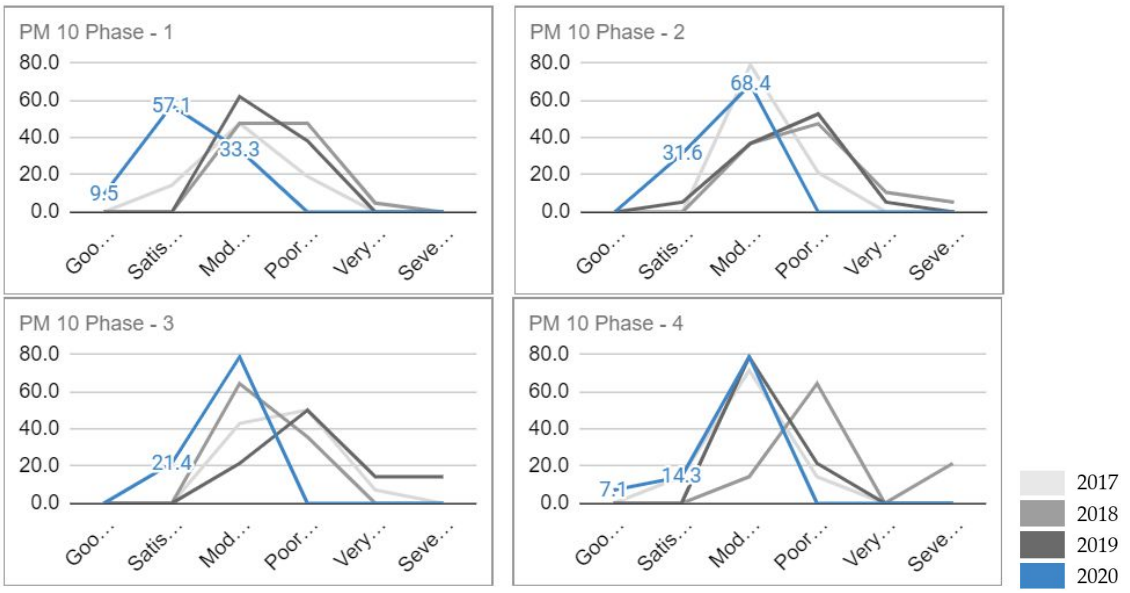

Figure 14—%days for each air quality category for PM 10 levels across the first 4 phases of the lockdown

[13] Hindustan Times (2019) "Delhi's Air Quality Bad this Year but Better Compared to 2016 and 2017." Retrieved from https://www.hindustantimes.com/delhi-news/

Expectedly, PM 10 was the best during Phase-1 where nearly 66% of the days fell in the Good/Satisfactory limits. This number however subsequently dropped to only 31.6% days being in the Good/Satisfactory limits in Phase-2. These increases in PM 10 levels may be attributed to progressively increasing construction or vehicular movement with every phase.

However, even in Phase-1, with no construction activity and limited vehicular activity, PM 10 levels were in the Moderate category for nearly 33% of the days. There are possibly due to Delhi's geographical position, with smoke and dust coming in from regional agricultural/desert lands. 80% of the days in Phase-3 had moderate PM 10 levels. A likely factor for this is the resumption of construction vehicular movement.

Even for PM 10, in every phase, 2020 fared better than the previous years. In 2020, in Phase-1, there were 33.3% of the days in the moderate or worse ranges (with 0 days in the worse ranges). This is a stark improvement from the previous years where more than 80% of the days were in the Moderate or Worse range. These trends are very similar to the trends of PM 2.5 values.

Phase-4 saw improvements compared to 2019, but they were not as significant as in the case of PM 2.5. In this phase, 2020 had nearly 80% of the days in the moderate range, with 0 days in a worse range. More than 20% of the days were in the good or satisfactory range. In contrast, the equivalent in 2019 had around 75% of the days in the Moderate range, 20% of the days in the Poor range, and 0 days in the Good/Satisfactory ranges. Surprisingly, 2017 is more similar than 2019 is to 2020 in terms of its distribution. The cause for this was not researched here.

Note: Refer to Appendix 5.3 for answers to the same question by analyzing the overall AQI values instead of just the PM 2.5 or PM 10 values. The same section also compares the performance of 2020 compared to the average of 2017, 2018, and 2019. This was done at a later stage, covering an extended timeline, and hence not included in the main body of this whitepaper.

2.5 Hyper-local Findings

So far, the paper outlines pollution values at the city level. This section explores the pollution within Delhi in each cluster as grouped for this study (Table 2). This analysis has been performed using box plots to inspect the distribution of pollutant values for each cluster, and then investigate stations that show exceptional behaviour. The observations have been noted for specific clusters as available below.

Although generally outliers are treated in the analysis if they add noise, in this case of pollution meter readings, outliers may not necessarily be incorrect readings by the meter. A sudden event of a fire or a dust storm can spike the value on a particular day, way beyond the pollutant levels in that place typically.

These box plots denote the range of values with the solid filled boxes indicating the 25th percentile, 50th percentile (denoted by the middle line) and the 75th percentile values respectively. The dots outside the box or line are termed as outliers, as they don't follow the general distribution of the values.

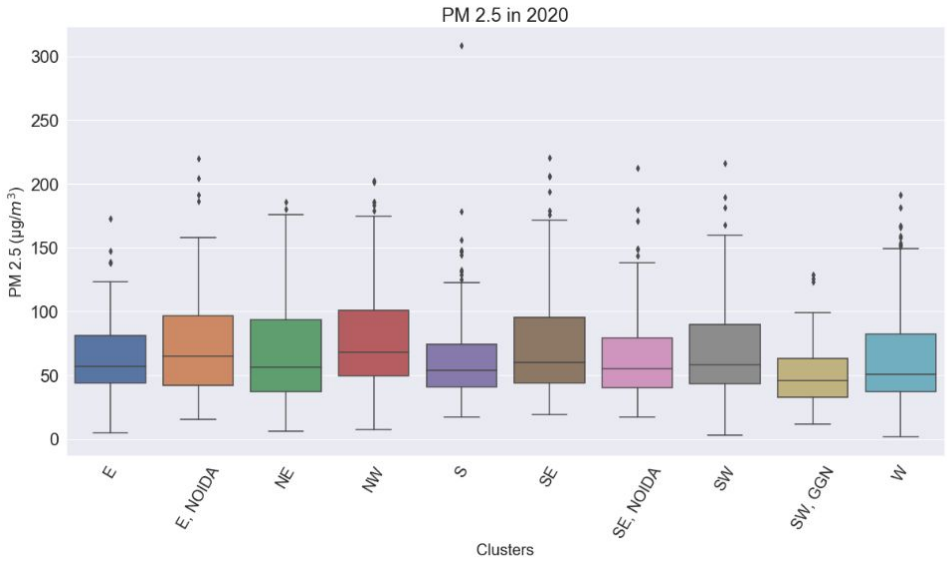

Figure 15—PM 2.5 levels during lockdown per geographical cluster

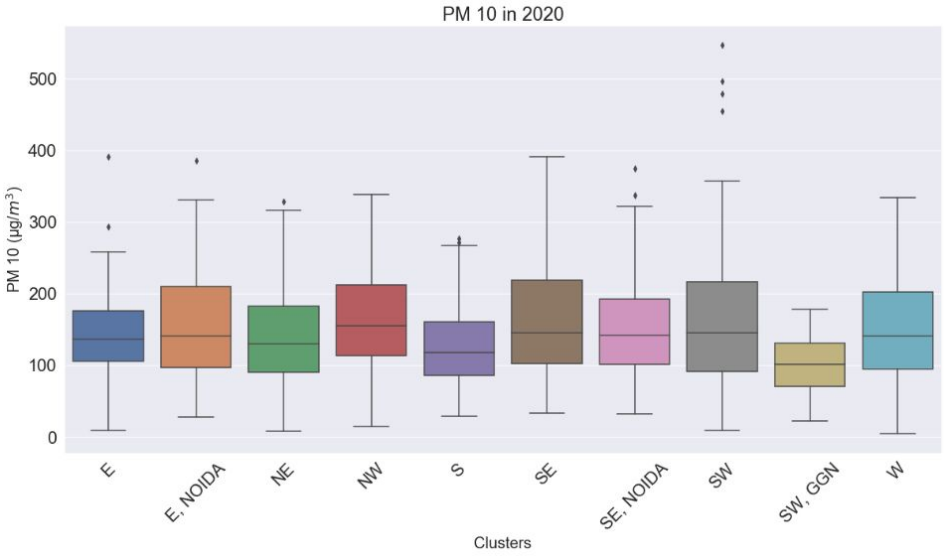

Figure 16—PM 10 levels during lockdown per geographical cluster

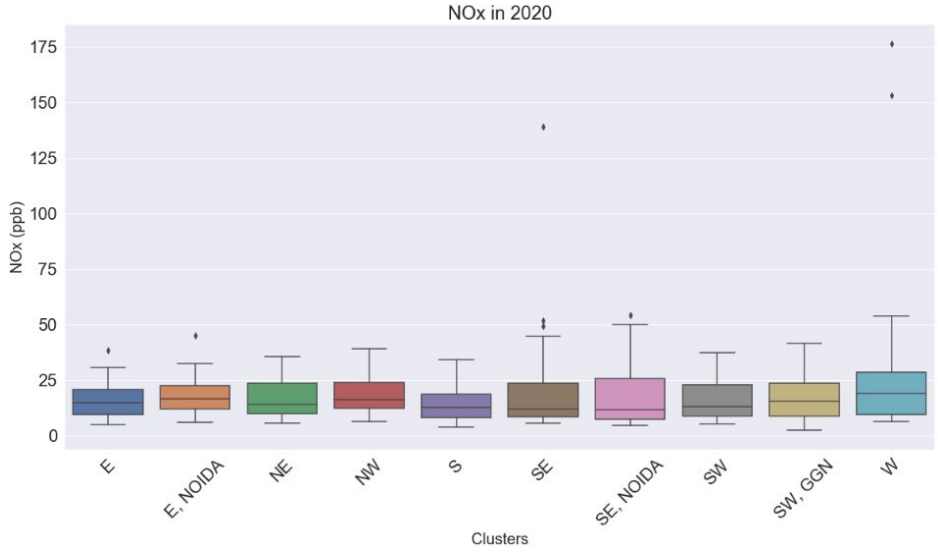

Figure 17—NOx levels during lockdown per geographical cluster

It can be seen that the North-Western cluster performed among the worst in all the categories of pollutants: PM 2.5, PM 10 and NO_x. This is followed typically by the area in far Eastern Delhi-Noida, and the South-Eastern parts of Delhi. The two clusters which had the lowest 75th percentile values were the Southern Delhi and the South-Western Gurgaon clusters. Surprisingly, the south western part of Gurgaon (which includes Manesar) did fairly well in terms of PM values, with median values falling in the satisfactory range.

It was not as easy to delineate one or two key sources to explain the bad/good behaviour for most of the clusters, except a few for which the impact of the type of activity there could be more clearly linked to the pollution levels. They are given below.

2.5.1 ITO (Traffic)

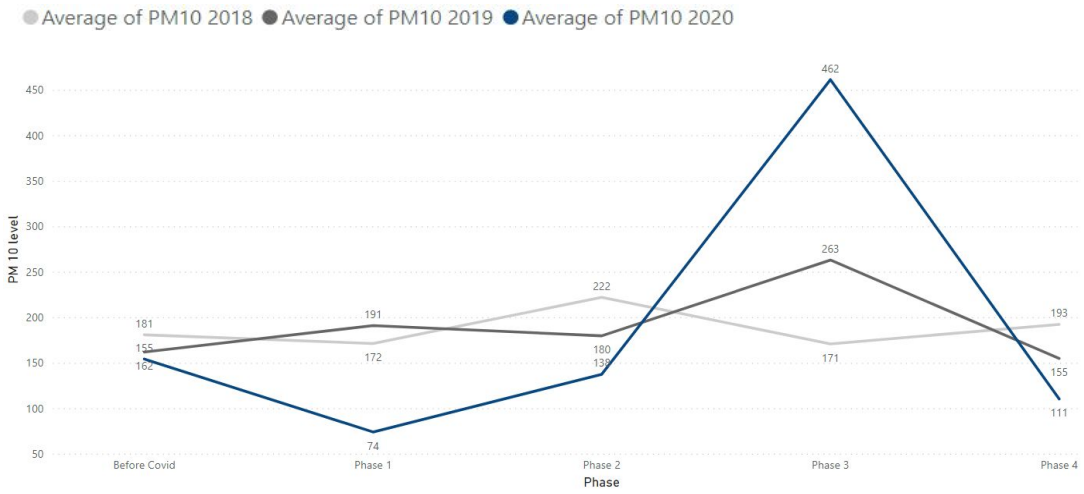

Figure 18—Phase-wise PM 10 averages for ITO (2020 vs 2019 vs 2018)

ITO shows high pollution levels even during the lockdown. On 27th March and 28th March , when the PM 10 levels across Delhi improved to Satisfactory/Good levels, ITO's pollution remained at Very Poor. This is can be attributed to a large number of migrants rushing[14] to ITO to find a ride back to their home-towns. Another increase is observed during Phase-3 which could have been a result of government offices reopening and increase in migration.

[14] Live Mint (2020) "Amid Lockdown, UP Govt Arranges Special Buses for Scores of Migrants." Retrieved from https://www.livemint.com/news/india/

2.5.2 Jahangirpuri (Industrial)

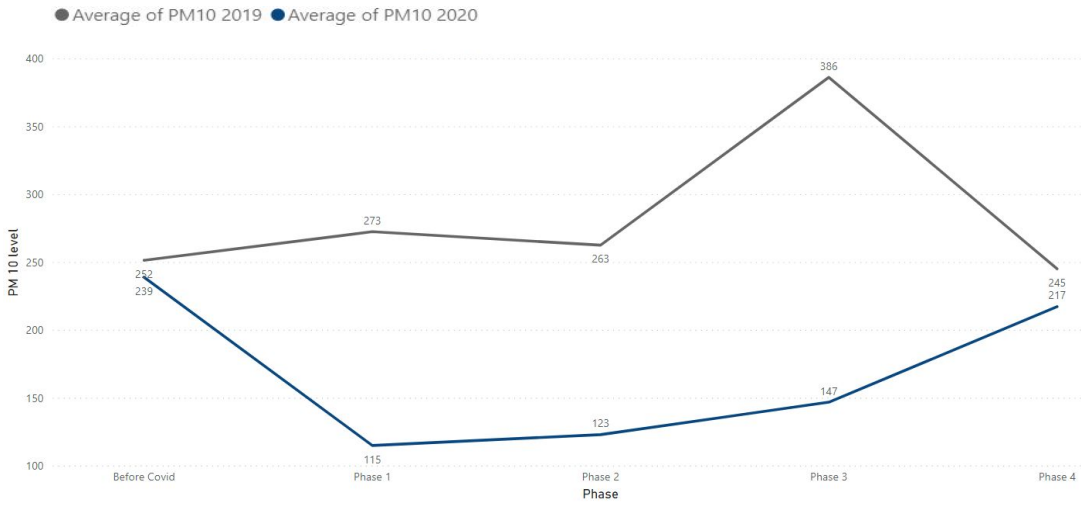

Figure 19—Phase-wise PM 10 averages for Jahangirpuri (2019 vs 2020)

PM 2.5, PM 10 and NO_x concentrations were high for the North western cluster. Jahangirpuri is one station that is part of this cluster, for which the behaviour can be explained. The likely reason is that the region is in the vicinity of a major national highway (several interstate goods carriers) and many industries.

2.5.3 Manesar (Industrial)

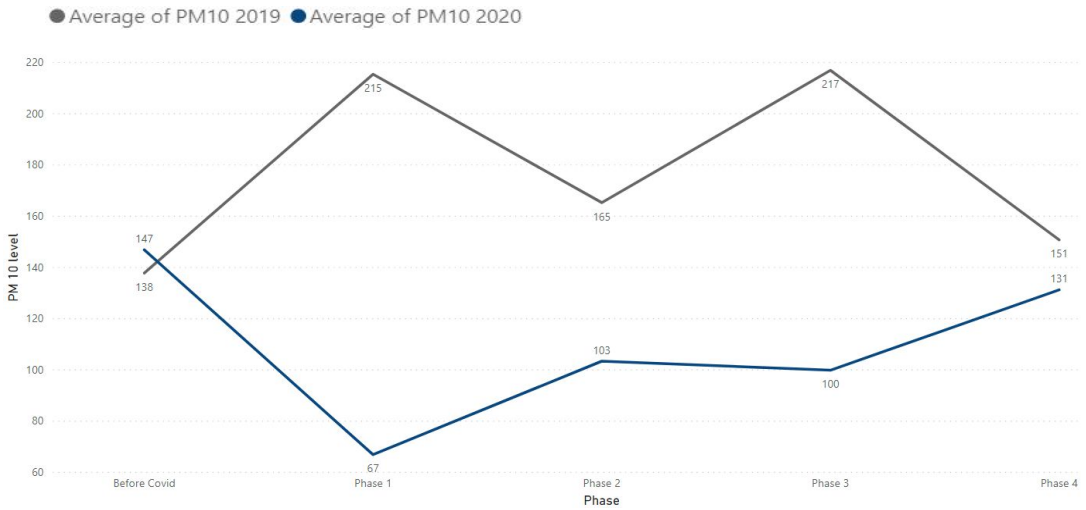

Figure 20—Phase-wise PM 10 averages for Manesar (2020 vs 2019)

Manesar contains many automobile industries which stopped working after the imposition of the lockdown. As a result, the NO_x values dropped to nearly single digits (compared to Delhi's

average of 19-24.4 ppb), and the pollutant concentrations remained low throughout Phase-2, Phase-3 and Phase-4. However, the PM 10 and PM25 levels were comparable to the rest of Delhi. Therefore, this region shows the impact of industrial plants on air pollution, as there was a notable increase in pollution in Phase-4 when industries restarted their operations.

From the box plot however, it can be seen that 75% of the PM values seemed to be in the Good/ Satisfactory range and among the lowest compared to other clusters. On the other hand, NO_x seemed to not follow this rank, with NO_x being comparable to other stations, with some spiked values too. Whether or not these were because of values in pre-covid or Phase-4 when industry operations restarted, is not part of this study.

2.5.4 Aya Nagar (Road Pollution)

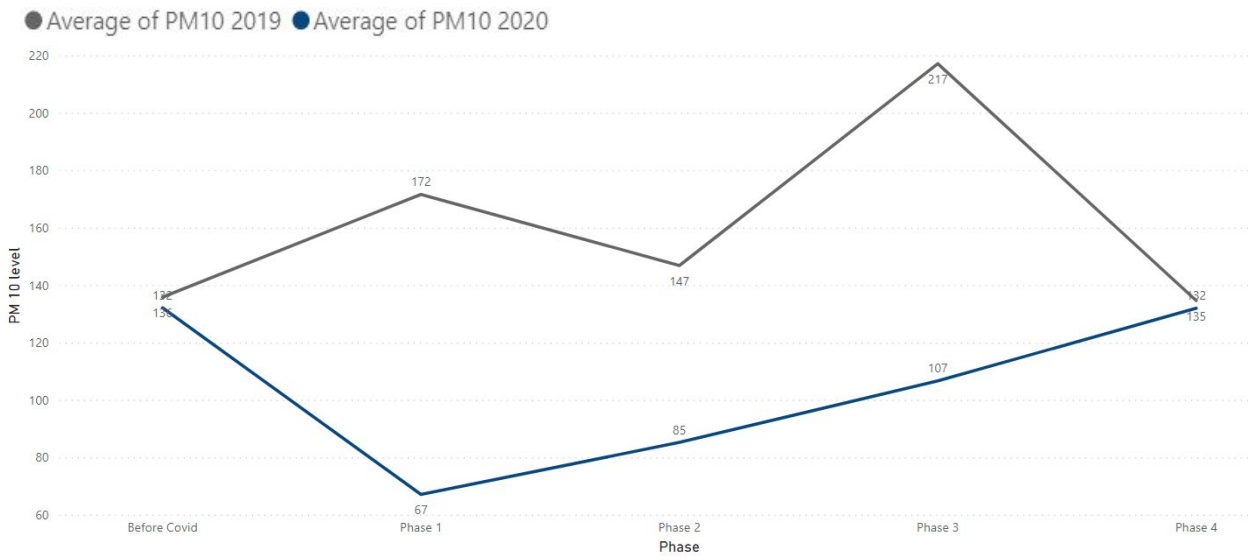

Figure 21—Phase-wise PM 10 averages for Aya Nagar (2020 vs 2019)

Aya Nagar is a residential colony which is very close to NH 148A, which is one of the two major roads that connect Gurgaon to Delhi. With the imposition of the lockdown, the majority of the cross-border traffic movement was restricted, which could have led to the dip in Phase-1. Further, with ease of lockdown restrictions with each passing phase, the traffic increased and by Phase-4 there were traffic jams at this border[15], which could be a major factor leading to the increase in pollution by Phase-4, nearly reaching the average value observed in 2019.

[15] Business League (2020) "Delhi-Gurugram border: Traffic Pressure on Delhi-Haryana Border Increased from 8 AM, Jammed." Retrieved from https://www.businessleague.in/

3 CHALLENGES FACED

3.1 Data Accessibility

Obtaining consistent data through automated means was a hindrance, overcome by access to AirVeda's API. However, there was still some data that could not be extracted via the API: CO, Ozone, NO_x data for years before 2020. In the case of directly using CPCB, the portal poses a challenge in terms of manual effort and unidentified glitches in downloading data with higher frequency for a longer time span. Moreover, credible and updated spatial data for locations of highly probable sources of air pollution such as industries, coal power plants was not readily available.

3.2 Missing/Incorrect Data

Not atypical in a data analysis study, the data obtained contained many missing values and incorrect values that are likely a result of a hardware malfunction or a general maintenance issue.

3.3 Multiple Factors at Play

Air pollution is affected by a multitude of factors at play: source, weather conditions (temperature, wind, precipitation). Pinpointing pollution to a particular sector is impossible as we did not collect pollution emissions at their source. There is also a shortage of government pollution monitoring centres in Delhi NCR. Further, data reliability for air pollution data depends on the factors related to population density and hardware reliability of the meter such as location of the meters, calibration where these are not maintained very well.

4 CONCLUSION

The COVID-19 lockdown provided a controlled setting for understanding air pollution in the region of Delhi NCR. While it was tricky to assort singular sources of pollution even in a reasonably moderated environment, this study establishes that the air pollution levels dropped in Delhi NCR during the lockdown due to decreased economic activity.

By studying the trends across the phases, we can see that the drop in pollution has been more 50% for Phase-1 of the lockdown, as compared to the previous years, for the same time period. Across the phases, the average drop in pollution is 30%, this shows that under strict controls and measures, air quality can be improved.

On shutdown, it was noted that sources such as traffic, industrial emissions and road dust had a significant effect on the pollution levels (PM 2.5, PM 10 and NO_x), with a drop of ~40% for all pollutants from the Pre-covid time to Phase-1 (except Ozone). Moreover, it was noted that it takes at least two days for particulate matter (PM 2.5 and PM 10) to drop to Satisfactory levels, let alone maintaining those levels. Therefore, these observations call for stricter regulations for the prevention or control of pollution such as or beyond what was implemented in 2018, and casts doubt on the effectiveness of one-off events themed around air pollution in Delhi NCR.

On locally inspecting pollution trends (Section 2.5), Aya Nagar and ITO, regions with noted high road traffic, exhibit a high correlation with air pollution levels. Further, in industrial areas like Jahangirpuri and Manesar, we observe that resumption of industrial activities resulted in a sudden increase in air pollution levels of these areas. On average, with no economic activity, the pollution levels took six to seven days to drop to the minimum value (typically in the Good ranges) from the pre-covid phase (from the point of maximum pollution). However, it took two days for the pollution levels to drop to Satisfactory levels when there was controlled economic activity. Hence, we can conclude that pollution in Delhi NCR is caused by unchecked economic activities. Therefore, corrective measures and environmental policies need to account for regulation of economic activities and their contribution towards the air pollution levels in the region of Delhi NCR.

In conclusion, there are 3 main takeaways from this study, to be considered and acted upon in order to tackle the air quality issue:

1. Air pollution is not a seasonal problem faced only during the winters. Throughout summer, we barely saw any Good days even though the air quality was almost 50% better than previous years.

2. While we have to tackle seasonal issues like crop burning, fire crackers etc. - and BS6 will help with vehicular pollution, even when we take all these out almost completely we are still not meeting the required levels set by WHO (at 10 $\mu g/m^3$) or even India at (30 $\mu g/m^3$) in summer when other effects like inversion don't make the matter worse.

3. Unmonitored issues like waster burning, power generation, biomass burning for cooking, vehicular traffic for essential logistics which were still happening during lockdown clearly need to be tackled to really get air quality to healthy levels.

Clearly there needs to be greater awareness and attention towards air pollution not just in the winters but all year round and concerted efforts need to be made to tackle each source if we want to get India to breathe clean air.

5 APPENDICES

5.1 Acknowledgements

Namita Gupta, founder AirVeda for guiding us throughout the project by providing domain expertise and context. Without her, this project would have never been possible.

Manas Fuloria, CEO Nagarro, Co-founder Plaksha University for connecting us to Namita to work on this project and for inspiring us with his social activism especially when it comes to air pollution.

5.2 Tables and Data

Table A—% of Days in Each Phase in Each Air Quality Category for PM 2.5

PM 2.5 (4 Lockdown Phases)	2017	2018	2019	2020
Good (0-30)	0.0	0.0	1.5	11.8
Satisfactory (31-60)	10.3	2.9	5.9	63.2
Moderate (61-90)	35.3	39.7	48.5	19.1
Poor (90-120)	38.2	27.9	29.4	5.9
Very Poor (120-250)	14.7	29.4	14.7	0.0
Severe (250+)	1.5	0.0	0.0	0.0

PM 2.5 Pre-COVID	2017	2018	2019	2020
Good (0-30)	0.0	0.0	0.0	1.9
Satisfactory (31-60)	0.0	1.9	9.6	15.4
Moderate (61-90)	26.9	28.8	36.5	36.5
Poor (90-120)	32.7	32.7	28.8	15.4
Very Poor (120-250)	40.4	36.5	25.0	30.8
Severe (250+)	0.0	0.0	0.0	0.0

PM 2.5 Phase-1	2017	2018	2019	2020
Good (0-30)	0.0	0.0	0.0	14.3
Satisfactory (31-60)	14.3	4.8	9.5	61.9

Moderate (61-90)	38.1	47.6	33.3	23.8
Poor (90-120)	33.3	14.3	38.1	0.0
Very Poor (120-250)	14.3	33.3	19.0	0.0
Severe (250+)	0.0	0.0	0.0	0.0

PM 2.5 Phase-2	**2017**	**2018**	**2019**	**2020**
Good (0-30)	0.0	0.0	5.3	10.5
Satisfactory (31-60)	10.5	5.3	5.3	78.9
Moderate (61-90)	36.8	21.1	47.4	10.5
Poor (90-120)	42.1	42.1	42.1	0.0
Very Poor (120-250)	10.5	31.6	0.0	0.0
Severe (250+)	0.0	0.0	0.0	0.0

PM 2.5 Phase-3	**2017**	**2018**	**2019**	**2020**
Good (0-30)	0.0	0.0	0.0	0.0
Satisfactory (31-60)	14.3	0.0	0.0	71.4
Moderate (61-90)	42.9	28.6	42.9	21.4
Poor (90-120)	28.6	28.6	14.3	7.1
Very Poor (120-250)	14.3	42.9	42.9	0.0
Severe (250+)	0.0	0.0	0.0	0.0

PM 2.5 Phase-4	**2017**	**2018**	**2019**	**2020**
Good (0-30)	0.0	0.0	0.0	21.4
Satisfactory (31-60)	0.0	0.0	7.1	35.7
Moderate (61-90)	21.4	64.3	78.6	21.4
Poor (90-120)	50.0	28.6	14.3	21.4
Very Poor (120-250)	21.4	7.1	0.0	0.0
Severe (250+)	7.1	0.0	0.0	0.0

Table B—Phase-wise % of Days for All Air Quality Categories for PM 10

PM 10 (4 Lockdown Phases)	**2017**	**2018**	**2019**	**2020**

Good (< 50)	0	0	0	4.4
Satisfactory (51-100)	7.4	00	1.4	33.8
Moderate (101-250)	60.5	41.1	50	61.8
Poor (251-350)	25	48.5	41.2	0
Very Poor (350-430)	1.4	4.4	4.4	
Severe	0	5.9	2.9	0

PM 10 Pre-COVID	**2017**	**2018**	**2019**	**2020**
Good (< 50)	0	0	0	1.9
Satisfactory (51-100)	0	0	0	7.7
Moderate (101-250)	48	57.7	78.8	71.2
Poor (251-350)	40.4	30.8	15.4	19.2
Very Poor (350-430)	7.7	11.5	5.7	0
Severe	3.8	0	0	0

PM 10 Phase-1	**2017**	**2018**	**2019**	**2020**
Good (< 50)	0	0	0	9.5
Satisfactory (51-100)	14.3	0	0	57.1
Moderate (101-250)	47.6	47.6	61.9	33.3
Poor (251-350)	19	47.6	38	0
Very Poor (350-430)	0	4.7	0	0
Severe	0	0	0	0

PM 10 Phase-2	**2017**	**2018**	**2019**	**2020**
Good (< 50)	0	0	0	0
Satisfactory (51-100)	0	0	5.3	31.6
Moderate (101-250)	78.9	36.8	36.8	68.4
Poor (251-350)	21	47.4	52.6	0
Very Poor (350-430)	0	10.5	5.3	0
Severe	0	5.3	0	0

PM 10 Phase-3	**2017**	**2018**	**2019**	**2020**
Good (< 50)	0	0	0	0
Satisfactory (51-100)	0	0	0	21.4

Moderate (101-250)	42.9	64.3	21.4	78.6
Poor (251-350)	50	35.7	50	0
Very Poor (350-430)	7.1	0	14.3	0
Severe	0	0	14.3	0

PM 10 Phase-4	**2017**	**2018**	**2019**	**2020**
Good (< 50)	0	0	0	7.1
Satisfactory (51-100)	14.3	0	0	14.3
Moderate (101-250)	71.4	14.4	78.6	78.6
Poor (251-350)	14.3	64.3	21.4	0
Very Poor (350-430)	0	0	0	0
Severe	0	21.4	0	0

Box-Plots

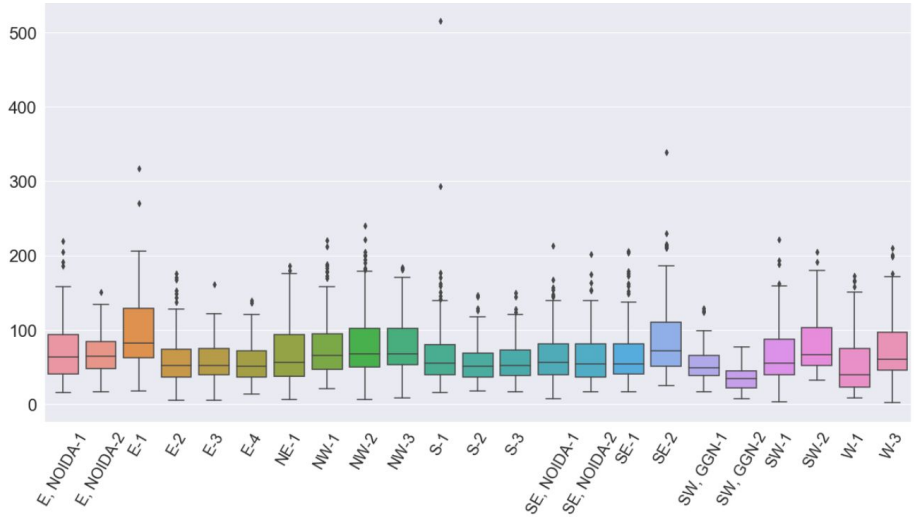

Figure A—PM 2.5 levels during lockdown per (tighter) geographical cluster

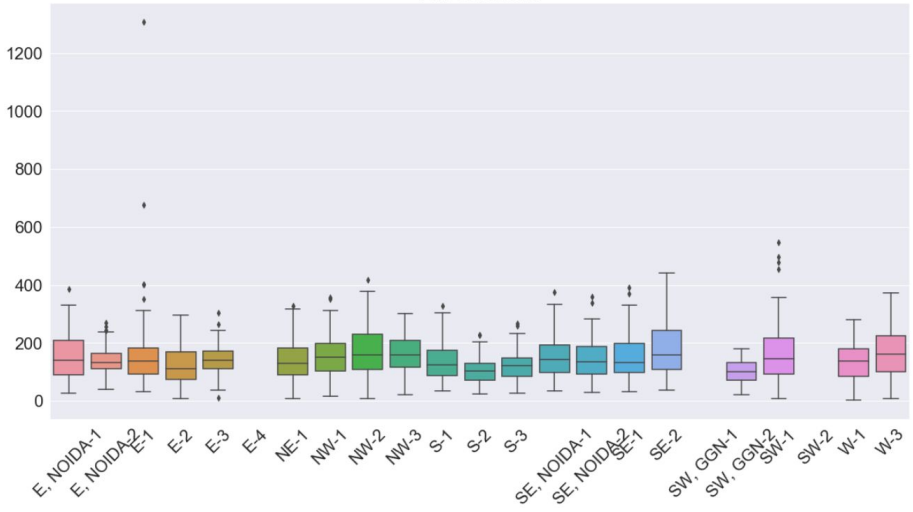

Figure B—PM 10 levels during lockdown per (tighter) geographical cluster

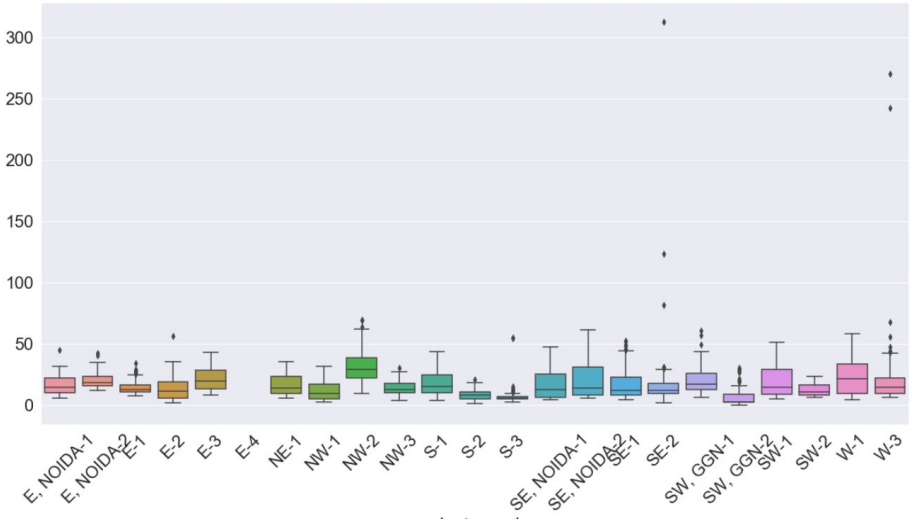

Figure C—NO_x levels during lockdown per (tighter) geographical cluster

Table C—Clusters of Pollution Monitoring Stations

Cluster	Station(s)	Cluster	Station(s)
C	Mandir Marg	**S-2**	Aya Nagar IMD, Sri Aurobindho Marg
E, NOIDA-1	Indirapuram, Sector-62, Noida, Vasundhara	**S-3**	NISE Gwal Pahari
E, NOIDA-2	Sanjay Nagar	**SE, NOIDA-1**	Sector-116, Sector-125
E-1	ITO	**SE, NOIDA-2**	Knowledge Park 5, Knowledge Park 3
E-2	Nehru Nagar, Patparganj	**SE-1**	CRRI Mathura Road, IMD, Okhla Phase-II
E-3	Anand Vihar, Vivek Vihar	**SE-2**	DTU
E-4	Sector-16A, Faridabad	**SW, GGN-1**	Vikas Sadan, Sector-2, IMT Manesar
NE-1	Ahok Vihar, IHBAS, Dilshad Garden, Sonia Vihar	**SW-1**	Dwarka Sector-8, IGI Airport
NE-2	Loni	**SW-2**	NSIT Dwarka
NW-1	Dr. Karni Singh Shooting Range, Rohini	**W-1**	Pusa, Shadipur
NW-2	Burari Crossing - IMD, Jahangirpuri, Wazirpur	**W-2**	Punjabi Bagh
NW-3	Alipur, Najafgarh, Pooth Khurd, Bawana	**W-3**	Mundka, North Campus, DU
S-1	Jawaharlal Nehru Station, Lodhi Road IMD, BK Puram, Siri Fort		

5.3 A further study on "*How did pollution levels in 2020 fare compared to previous years?*", using AQI

This analysis was done to evaluate AQI instead of particulate matter. Additionally, the time period analyzed was extended to include Unlock 1.0. The key observations are mentioned below.

Figure D—Distribution of air quality in each phase of Covid-19 lockdown - 2020 compared to the average of the past 3 years

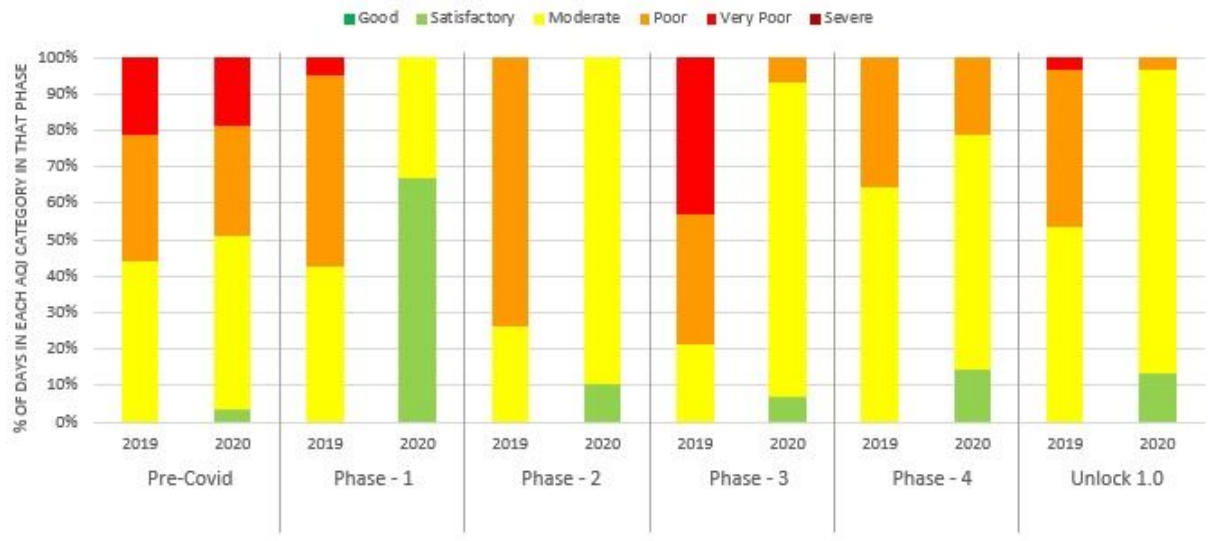

Figure E—Distribution of air quality in each phase of Covid-19 lockdown - 2020 compared to 2019

Lockdown period | Average of 2017, 2018, and 2019 compared to 2020

- Days with satisfactory air quality grew from 0.5% to 27.9% in 2020
- Days with moderate air quality grew from 22.6% to 66.2% in 2020
- Days with poor/ very poor / severe air quality dropped from 76.96% to just 5.88% poor days and no very poor or severe days in 2020

Lockdown period | 2019 compared to 2020

- In 2019 there were no days with good or satisfactory air quality, only 38.2% days saw even moderate air quality.
- In 2020 there no good, 27.9% satisfactory, 66.2% moderate, and 5.9% poor days
- 61.8% days saw poor or worse air quality in 2019 compared to just 5.9% poor days in 2020.
- As expected, Phase 1 saw the maximum improvement with 66.7% satisfactory days and no poor or worse days, compared to 2019 which had 57.1% of poor or worse days during the equivalent time period.
- As expected with the opening of the economy, the percentage of good / satisfactory days reduced. Where Phase 1 and Phase 2 only had days with either satisfactory or moderate air quality, Phase 3 saw 7.1% days with poor air quality and Phase 4 saw 21.4% days
- During the same period in 2019 Phase 2 had 73.7% days with poor air quality and Phase 3 had 78.6% of days with poor or worse air quality.

Unlock (1.0) period |Average of 2017, 2018, and 2019 compared to 2020

- There were no good days in 2020. Surprisingly, the average of 2017-19 did indicate 1.15% days with good air quality.
- Despite reduced economic activity, the days with satisfactory air quality did not see any improvement, with a marginal drop from 13.7% to 13.3% in 2020.
- However, the days with very poor / severe air quality did reduce to 0 in 2020
- Days with moderate air quality, grew from more than 52.7% to 83.3% in 2020.

Unlock 1.0 period | 2019 compared to 2020

- The days with satisfactory air quality grew from 0 to 13.3% whereas the days with moderate air quality also grew from 53.3% to 83.3% in 2020.
- The number of poor days decreased from 43.3% to 3.3%.
- Air quality improved in Unlock 1.0. This could be due to hotter temperatures which typically is associated with better air quality. However, 2020 still had fewer than 15% of days with satisfactory (not even good) air quality. The rest, majority, were moderate, with 3.3% days in the poor category as well, which is not to be aspired to. This also indicates the Delhi NCR's air pollution problem is not just a seasonal issue. Moreover, economic activity would only increase after Unlock 1.0, returning closer to regular levels, which would worsen the air quality.