CLEAN AIR BLUE SKIES

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AIR POLLUTION DURING A SUMMER OF LOCKDOWNS

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EXECUTIVE SUMMARY

These are extraordinary times. The public health emergency and humanitarian crisis of unbelievable scale, triggered by the COVID-19 pandemic, have caused unprecedented disruption to business-as-usual. But it has also given us a new prism through which we can view the air pollution crisis. An economic slowdown and implementation of lockdown measures to stop the spread of the virus have bent the pollution curve dramatically. Blue skies have reappeared over cities where smog used to rule the roost – and this has caught public imagination. We have understood how clean the air can get. The summer of 2020 has undoubtedly been different.

There has been a fundamental change in activity patterns during this period. The crisis has led to significant social and workplace reengineering for social distancing, and this has unlocked the potential of digital and virtual interconnectedness – leading to a complete change in the idea of the workplace. Vehicle miles travelled have reduced, and travel at human scale – walk and cycle – has increased. Manufacturing and construction have stopped. Some pollution has, however, continued as power plants, some traffic, use of solid fuels for cooking and intermittent waste burning have remained.

The reduction in pollution levels during the first three lockdown phases (beginning March 25, 2020) has been dramatic. Satellite sensors of the US National Aeronautics and Space Administration (NASA) have observed aerosol levels at a 20-year low for this time of the year in parts of northern India. Aerosols are tiny solid and liquid particles suspended in the air that reduce visibility and can cause damage to human lungs and hearts.[1]

This also mirrors the global trend – satellite images from NASA show very low pollution concentration during the lockdown phases in different regions of the world. Images from the European Space Agency have indicated a striking reduction in northern Italy and Spain after confinement orders came into force.[2]

But as the peak crisis wanes, emissions are increasing once again. During a more relaxed fourth phase of the lockdown in India, when the economy started to reopen, pollution levels have shown a quick upturn and substantial increase from the lowest average level observed during the initial lockdown phases. This has raised a pertinent question: What should be done to sustain the air quality gains once the economy reopens?

This crisis shows that when people are confronted with something which is an immediate and powerful health risk, it leads to building up of a strong collective community support for difficult measures to contain that risk. But this is not the case with the risk perception of air pollution-related diseases. As many as 1.2 million people die prematurely in India every year due to diseases triggered by air pollution[3] – public perception of this latent risk remains very weak and not clearly understood.

During winters, when Delhi and the National Capital region (NCR) experience severe smog episodes, the Graded Response Action Plan (GRAP) is implemented

Note: This study uses NO_2 concentration as a proxy for NO_x in the air, which is an established practice among the scientific community.

as an emergency response. It leads to temporary closure of industry, conventional brick kilns, construction work and stone crushers, stopping of trucks, introduction of license plate-based odd and even schemes for vehicles etc for a few days. This invariably leads to strong public reaction against harsh measures and is perceived as draconian and inconvenient, and often, resented.

The lockdown might have served to open people's eyes. They have now experienced air that is clean and breathable. They have now witnessed and understood the scale of change that is needed for drastic reduction in pollution and the systemic measures that are needed to sustain such an improvement.

Scientists have established a significant connection between the pandemic and air pollution – they have warned that the pandemic can get worse in areas with high pollution levels. As the lungs and the overall health of people are already compromised with long-term exposure to air pollution, vulnerability and risk

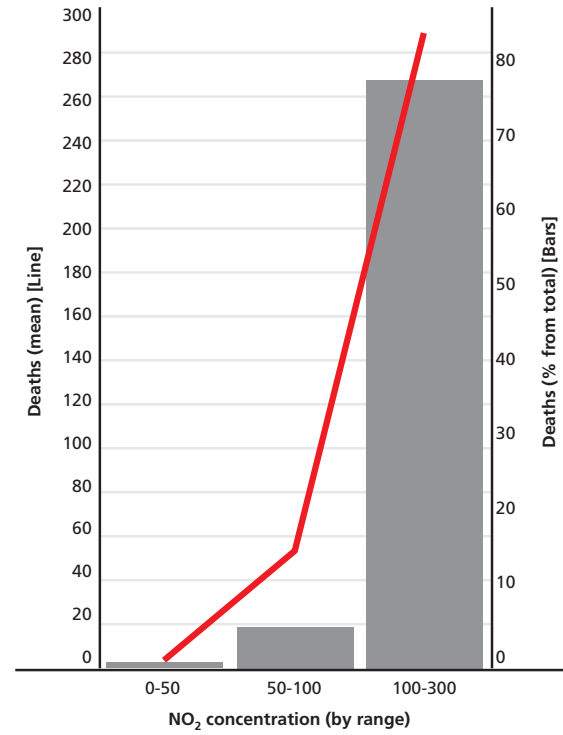
The pandemic and air pollution

The COVID-19 pandemic has stirred the scientific community into urgent action – new studies have been initiated and past evidences have been reviewed to understand its linkages to air pollution. Scientists have informed that the impact of the pandemic is expected to be higher in polluted regions where people's lungs have been weakened by the long-term exposure to air pollution.

United States: A Harvard analysis[6] led by Francesca Dominici is the first nation-wide study to show a statistical link between COVID-19 deaths and other diseases associated with long-term exposure to fine particulate matter ($PM_{2.5}$). This review of 3,080 counties in the US has found that higher levels of PM2.5 are associated with higher death rates from the disease. An increase of only 1 microgramme per cubic metre (µg/m^3) in PM2.5 concentration is associated with an 8 per cent increase in the COVID-19 death rate.

The results are statistically significant. A slight increase in long-term pollution exposure can have serious coronavirus-related impacts (accounting for smoking rates and population density etc). It estimates that if a city or a borough like Manhattan had reduced its average particulate matter by just 1 µg/m^3 over the past 20 years, it would most likely have seen 248 fewer COVID-19 deaths during the outbreak.

Graph: Correlation between NO_2 levels and deaths associated with coronavirus in Italy



Source: *Yaron Ogen, April 2020, 'The link between air pollution and COVID-19 deaths', Science of the Total Environment, https://www.sciencedirect.com/science/article/pii/S0048969720321215https://www.weforum.org/agenda/2020/04/link-between-air-pollution-covid-19-deaths-coronaviruspandemic/, as accessed on May 19, 2020*

from the virus is higher. Dirty air may intensify COVID-19 cases in polluted areas. The European Public Health Alliance, a Belgium-based alliance of European non-profits, had warned in mid-June that patients with chronic lung and heart conditions caused or worsened by long-term exposure to air pollution are less likely to be able to fight lung infections.[4] In India, the Collective of Doctors for Clean Air, a network of medical professionals from across the country, has warned that people living in highly polluted areas whose lungs have already been adversely affected, can be more vulnerable to the deadly coronavirus.[5] The World Health Organization (WHO), however, has not reported airborne spread of the virus but has cautioned health workers to guard against airborne droplets in close proximity of patients (*see Box: The pandemic and air pollution*).

It is being hoped that a greater awareness about the role of air pollution in enhancing vulnerability of populations to such pandemics and to the overall

Europe: Another study published in the journal *Science of the Total Environment*[7] has found that exposure to air pollution is one of the most important contributors to fatalities caused by coronavirus in four countries – Germany, France, Italy and Spain: 78 per cent of the deaths had occurred in just five regions in northern Italy and Spain. These regions are known to have very high concentrations of nitrogen dioxide (NO_2). High NO_2 concentration affects the human respiratory systems, while their geography means these areas also suffer from downward air pressure, which can prevent the dispersal of airborne pollutants (*see Graph*).

Italy: A study by the University of Siena, titled 'Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?[8] investigates the correlation between high level of Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2) lethality and the atmospheric pollution in northern Italy. Correlation implies an evidence of the role of chronic exposure to atmospheric contamination in the spread and virulence of the SARS-CoV-2 within a population subjected to a higher incidence of respiratory and cardiac affections. The study concludes that the high level of pollution in northern Italy should be considered an additional co-factor in the high level of lethality[9], and deemed responsible for indirect systemic effects associated with pro-inflammation and oxidation mechanisms in the lungs and extra pulmonary organs, as well as with immune system alteration processes. Other factors such as the age of the exposed people and gender also exercise an impact, says the study, but the detrimental effects of air pollution are clear and plausible.[10]

Now, a search is on to understand the role of particulate pollution in the spread of the virus. Reportedly, scientists in some Italian universities (Societa Italiana Medicina Ambientale, Universita di Bologna and the University di Bari) are investigating the link between particulate pollution and corona outbreak in Po Valley in northern Italy during February this year.[11]

China: A study titled 'Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China'[12] has observed significant positive linkages of $PM_{2.5}$, PM_{10}, NO_2 and O_3 (ozone) with recently confirmed COVID-19 cases. A 10 $\mu g/m^3$ increase in $PM_{2.5}$, PM10, NO_2 and O_3 has been associated with a 2.24 per cent, 1.76 per cent, 6.94 per cent, and 4.76 per cent rise in the daily counts of confirmed cases, respectively. It is clear that there is a significant relationship between air pollution and COVID-19 infection, which could partially explain the effect of national lockdowns and provide implications for the control and prevention of this novel disease.

The SARS pandemic of 2003 had caused higher number of deaths in more polluted regions, and the death rates had increased with pollution levels – from about 4 per cent in low pollution zones to 7.5 to 9 per cent in moderate or high air pollution areas.[13]

disease burden will strengthen collective and political action in future. This public health emergency inevitably needs drastic short-term as well as longer term measures and strong community and political support.

Within this broader context of pandemic and air quality, Centre for Science and Environment (CSE) has put the available air quality data under scanner to understand different dimensions of the change in air quality during the lockdown period. A more granular view of pollutant-wise local trends across cities can give a deeper insight into the challenges and how the new normal needs to be shaped.

This pandemic-led change in air quality has happened during the summer of 2020. This is, thus, an opportunity to understand summer pollution, which is also different from winter pollution. Normally, every year the popular focus remains on winter pollution – the nature and characteristics of summer pollution do not get adequate attention.

The summer season is normally characterised by high winds and intermittent rains and thunderstorms, along with high temperatures and heat waves. This is in contrast to winter with inversion and lower mixing height, and cold and calm conditions that can trap the air and pollutants. Seasonal impacts, therefore, are different.

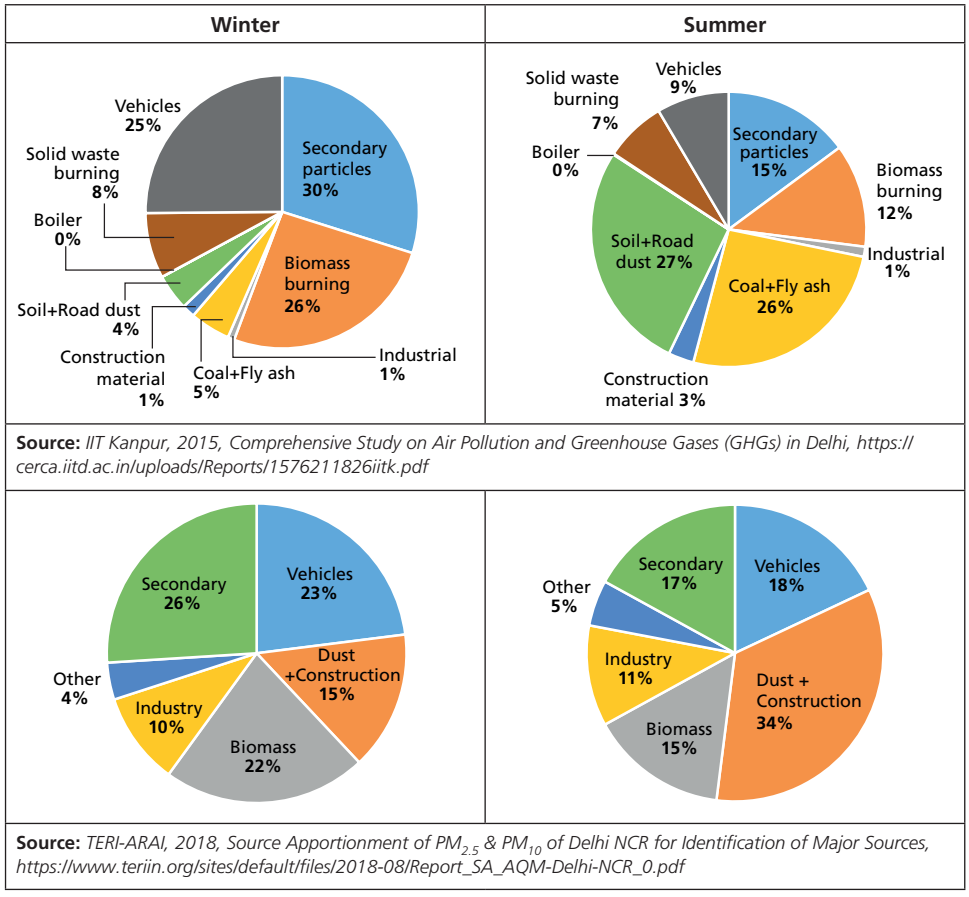
There are not many source apportionment studies in Indian cities on the seasonal difference. Studies by the Indian Institute of Technology, Kanpur (IIT-Kanpur) in 2015[14], and a joint study by The Energy and Resources Institute (TERI) and the Automotive Research Association of India (ARAI) in Delhi in 2018[15] show that the summer season experiences relatively higher contribution of dust compared to the winter season; also, the concentration of secondary particulates that form from the gases in the atmosphere is comparatively lower during summer (*see Graph 1: Changing seasons – source apportionment studies in Delhi*). Summer conditions prevailed during the entire lockdown period.

This analysis has, therefore, examined the trends in behavior of key pollutants during the lockdown within the context of summer. In fact, all through the national lockdown that started on March 25, 2020, the dramatic reduction in particulate and nitrogen dioxide has hogged national and global attention. This certainly remains the focus of attention even for this study to understand how low the pollution can get in our cities and regions and the likely background level at a regional scale.

But there is an additional concern during summer that has not received adequate attention yet – it is tropospheric ozone pollution (henceforth ozone). Every year, the limited data that exists on ozone in different cities has continued to warn that ozone is a sunny weather problem in India. While it remains highly variable during the year, it is around spring and summer – when the skies are clear – that its levels accelerate and peak across most of India. In coastal cities, it is found to be high even during the winter months. This analysis has, therefore, while tracking the changes in $PM_{2.5}$ and NO_2 levels, also put a special spotlight on the way ozone has behaved.

While the analysis has provided important insights into the emerging trends that require policy attention, it does not include modeling to isolate the impact of the lockdown (or any other impacts).

Graph 1: Changing season – source apportionment studies in Delhi



Source: *IIT Kanpur, 2015, Comprehensive Study on Air Pollution and Greenhouse Gases (GHGs) in Delhi, https://cerca.iitd.ac.in/uploads/Reports/157621826iitk.pdf*

Source: *TERI-ARAI, 2018, Source Apportionment of $PM_{2.5}$ & PM_{10} of Delhi NCR for Identification of Major Sources, https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf*

THE DATASET FOR TREND ANALYSIS

Before the findings of this analysis are laid down, it is important to understand the dataset that has been used to analyse the trend. CSE has studied the trends in $PM_{2.5}$, PM_{10}, NO_2 and ozone in 22 cities spread across 15 states, besides the National Capital Territory of Delhi. This also includes spatial trend analysis of ozone in selected cities. This analysis has been carried out for the period January 1, 2019 to May 31, 2020 – the pre-lockdown period has been considered to be from March 1- 21 (unless specified otherwise). Lockdown phases include Lockdown 1.0 (March 25-April 14), Lockdown 2.0 (April 15-May 3), Lockdown 3.0 (May 4-17), and Lockdown 4.0 (May 18-31). Overall, lockdown refers to the March 25-May 31 period. For some part of the analyses, the dates March 22-24 have been ignored, as these were transitory days with wild variations in policies among states and in enforcement in cities.

The most granular data (15-minute averages) has been sourced from the Central Pollution Control Board's (CPCB) official online portal, the Central Control Room for Air Quality Management – All India (https://app.cpcbccr.com/). This has analysed over 23 million data points recorded by 116 air quality monitoring stations or about 50 per cent of the existing network under the Continuous Ambient Air Quality Monitoring System (CAAQMS) of the CPCB. All cities with three or more CAAQMS stations are included in this analysis; more have been chosen to ensure geographical and demographical representation.

Cities have been clubbed into three pools for trend analysis, based on their population and the region they are located in. These are broadly termed as mega cities, tier 1 cities in the Indo-Gangetic plains and tier 1 cities outside the Indo-Gangetic plains. Except central India, all the regions covered by the CAAQMS are represented in the analysis.

THE KEY HIGHLIGHTS: WHAT DID WE FIND?

Ozone

Concentrations exceeded the standard during lockdown: All mega cities except Hyderabad exceeded the eight-hour ozone standard at least on one day at one of its stations. The city-wide average exceeded the standard on four days in Delhi and on eight days in Kolkata – but Delhi and Kolkata had 67 days (every day of the lockdown) and 17 days respectively when at least one station in the city exceeded the standard. Not acknowledging this can undercount the problem. Almost all stations in Delhi exceeded the standard for two continuous days. In Chennai, the Manali Village station registered 35 contiguous days of exceedance while in Kolkata, the Victoria station registered 17 contiguous days.

All cities in the Indo Gangetic Plain (IGP), except Amritsar and Lucknow, exceeded the ozone standard at least on one day at one of their stations during the lockdown. At the city-wide level, Gurugram exceeded standards on 26 days, Faridabad on four days, Noida 12 days, Ghaziabad 15 days, and Howrah on three days. But at least one station in these cities has exceeded the standard on a higher number of days – 57 days in Gurugram, 46 in Faridabad, 42 in Noida, and 56 days in Ghaziabad.

Among the tier-1 cities outside IGP, Ahmedabad recorded 43 days of exceedance during the lockdown. Ahmedabad also recorded an increase in the number of days exceeding the standard compared to the same period in 2019. Ujjain, with 38 days exceeding the standard, was the second most ozone-polluted city in this group.

How daily ozone trends changed: As ozone levels have not dropped sharply and predictably like other criteria pollutants, it is interesting to see how its daily levels changed during the lockdown. In Chennai, Delhi, and Hyderabad the daily average level of ozone rose for the first three phases of the lockdown at a varying pace. Bengaluru and Mumbai both had their daily maximum hovering around the standard mark during pre-lockdown, and started experiencing a dip in this level as lockdown progressed. Kolkata had a similar declining trend with a slight bump during lockdown 3.0 when it registered average 6 per cent higher than its lockdown 2.0.

In NCR cities, daily average level of ozone rose for first three phases of lockdown. Faridabad and Gurugram noted 55 per cent and 17 per cent lower levels during lockdown 4.0 compared to their lockdown 3.0 levels. Gurugram had the daily maximum levels constantly above standard, while other three NCR towns had their average levels above the standard in 3 out of 4 lockdown phases. Lucknow and Howrah had multiple instances of exceedances during the pre-lockdown period but they mostly remained within the standard for all of lockdown. Patna stayed within the standard during the first two phase of lockdown but its average levels were above the standard during lockdown 3.0 and lockdown 4.0. Pre-lockdown phase like others was high and fluctuating.

Outside IGP, Ahmedabad and Jodhpur's daily average level of ozone rose for first three phases of lockdown. They marginally dropped by 5 per cent and 6 per cent during lockdown 4.0 compared to their lockdown 3.0 levels. Jaipur recorded a 22 per cent drop in its ozone level during lockdown 1.0 compared to pre-lockdown but its levels rose for next three phases of the lockdown. Rest of the cities did not have a pronounced difference among the different phases of lockdown and pre-lockdown. Levels in Ujjain remained above the standard for first three phases of lockdown and only settled marginally south of the standard in lockdown 4.0.

With all pollutants down, ozone led: Another curious trend noticed during the lockdown phases is the daily air quality index (AQI) in different cities being led by ozone. As most of the criteria pollutants plummeted during the lockdown phases the daily AQI that is reported by CPCB for cities showed that with change in the relative positioning of all criteria pollutants, AQI was being led by ozone. While AQI is estimated for all individual pollutant the combined AQI is led by the highest pollutant of the day. Normally, particulate matter leads the AQI most of the time. But during this summer lockdown (April-May) with dramatic collapse of concentration levels of particulate matter and other pollutants ozone started to show up as the lead pollutant of the day in the daily AQI bulletin of the CPCB.

This is evident in several cities. During April and May of 2020, ozone was the lead pollutant in the AQI bulletin in Chennai for 59 days, Delhi for 48 days and Kolkata 57 days. These number of days had increased by 10, 20 and three days respectively in these cities from the same period in 2019.

But this does not mean that the days when AQI was led by ozone, its levels always exceeded the standard. This happened largely because other pollutants had dropped more sharply vis-à-vis their respective standards than ozone. AQI could be led by ozone even if its level was in the satisfactory category; but overall ozone levels were comparatively higher. This is about relative positioning.

How the ozone build-up relates to NO_x concentration in cities: The lockdown phase was an opportunity to spatially map out the ozone and NO_2 build-up in selected cities. Overall, NO_2 levels were low across monitoring stations during the lockdown phase. But wherever its levels were comparatively higher, ozone concentration was lower. It is visually evident that ozone builds up in areas with very low NO_2. This is evident across Chennai, Delhi, Hyderabad, Kolkata, Bengaluru and Mumbai.

Night-time ozone: All inland mega cities show a drop in the ratio at city-wide level, which implies that the ozone built up during day-time was dissipating at a rate 25-43 per cent lesser compared to 2019. Station-level analysis shows that the maximum drop is noted at stations located close to arterial roads. For instance, in Delhi, the stations at Jawaharlal Nehru Stadium, National Stadium, and Sri Aurobindo Marg had a ratio of 35, 33, and 29 respectively in April-May of 2019 – but during the lockdown, it shrunk to 5.30, 3.07, and 7.78 respectively. Absence of evening rush hour traffic which provided the NO_x needed to neutralise ozone can be attributed as a reason for this change. Similarly, in Bengaluru, the station at BWSSB had a 7.86 ratio in 2019; the ratio reduced to 2.99 during lockdown.

All IGP cities show a drop in the ratio which implies that the ozone built up during day-time was dissipating at a 2-80 per cent lesser rate. Faridabad had

the highest reduction in the ratio – 80 per cent – while Howrah had the least of 2 per cent.

Non-IGP cities were a mixed bag. The ratio dropped in Jaipur, Guwahati and Visakhapatnam, but it increased in the rest. Ahmedabad showed the maximum increase with the lockdown ratio being 159 per cent higher than in 2019; Jodhpur with a 105 per cent increase stood second.

Particulate matter

The cleanest days: The dramatic drop in particulate pollution created surreal images of blue skies in Indian cities. In the towns of the NCR, the lowest range observed was 15-24 µg/m^3. In the arid western plains (Rajasthan and Gujarat), the lowest range was 9-20 µg/m^3. In the central parts and the Deccan Plateau, it ranged at 12-18 µg/m^3; it was 8 µg/m^3 on the west coast; 7-8 µg/m^3 on the east coast; and 8 µg/m^3 in the north-east.

Among the mega cities, the cleanest day of the season was noted during lockdown 2.0 in Bengaluru (16 µg/m^3 on April 29), Chennai (7 µg/m3 on April 28), Hyderabad (18 µg/m^3 on April 29) and Kolkata (8 µg/m^3 on April 28). Kolkata registered a marginally cleaner (less than 1 µg/m^3) $PM_{2.5}$ average on May 21, a day after the city was hit by cyclone Amphan. Mumbai registered its cleanest day during lockdown 4.0 on May 29 with a 24-hourly average of 8 µg/m^3. The cleanest day in Delhi was also recorded in lockdown 4.0 on May 30 when heavy rains washed down the city to a 24 µg/m^3 24-hourly average. Otherwise, the cleanest day without a major rain event was at 26 µg/m^3 on March 28.

Among the IGP cities, the cleanest day of the season was noted during lockdown 1.0 in Gurugram (18 µg/m^3 on March 28), Lucknow (31 µg/m^3 on March 27), and Patna (14 µg/m^3 on March 26). During lockdown 2.0, Amritsar (9 µg/m^3 on April 18) and Faridabad (15 µg/m^3 on May 4) registered their cleanest days. The cleanest day in Noida and Ghaziabad was on May 30 when heavy rains washed down the city to a 20 µg/m^3 24-hourly average, same as Delhi. Otherwise, the cleanest day without a major rain event was at 21 µg/m^3 on March 28.

Among the non-IGP cities, the cleanest day of the season was noted during lockdown 1.0 for Jodhpur (20 µg/m^3 on March 27) and Jaipur (9 µg/m^3 on March 27). Visakhapatnam (8 µg/m^3 on April 29) registered its cleanest day during lockdown 2.0. Pune (12 µg/m^3 on May 6), Ujjain (15 µg/m^3 on May 11), and Ahmedabad (19 µg/m^3 on May 15) recorded their cleanest days during lockdown 3.0. Kochi (8 µg/m^3 on May 28) and Guwahati (8 µg/m^3 on May 26) noted their cleanest days during lockdown 4.0.

Change in number of days exceeding the daily standard: What has been the change in daily exceedences of $PM_{2.5}$ – or, in other words, the number of days that the levels have exceeded the national ambient air quality standard for a 24-hour average? To understand the impact of the lockdown on short-term exposure, an assessment of daily $PM_{2.5}$ levels *vis-à-vis* the 24-hour standard was carried out for each city. This assessment compares the March 25-to-May 31 period for both 2019 and 2020. It has only looked at the number of days exceeding the standard and not the severity of pollution that is captured in AQI. In mega cities, the year 2020 so far has been cleaner than 2019.

Except Delhi, no other mega city exceeded the $PM_{2.5}$ daily standard during lockdown at a city-wide level. But station-level data shows that all mega cities

except Mumbai observed at least one day of exceedance. Delhi stands out with 50 days where at least one of the city stations exceeded the $PM_{2.5}$ daily standard. But this is 25 per cent lower than in the previous year. Bengaluru, Chennai, Hyderabad and Kolkata have shown 91 per cent, 88 per cent, 91 per cent, and 76 per cent reduction in number of days with at least one city station exceeding the daily standard.

All IGP cities – except Howrah – exceeded the $PM_{2.5}$ daily standard during lockdown at the city-wide level. In Lucknow and Ghaziabad, the levels exceeded the standard in over 20 days. Overall, the number of days not meeting the standards was down by 62-95 per cent compared to 2019. Station-level data shows lesser improvement. NCR cities, interestingly, have noted considerably lower numbers exceeding the standard than Delhi. This could be influenced by the varying number of stations.

Among the non-IGP cities, Ahmedabad and Kochi do not show any day exceeding the daily average standard during the lockdown phase. Guwahati and Ujjain have registered an increase in the number of days exceeding standards compared to 2019.

Jaipur, Jodhpur, Pune and Visakhapatam registered an 88 per cent, 67 per cent, 54 per cent, and 67 per cent reduction in the number of days exceeding standards compared to the same period in 2019. In Ahmedabad, the numbers dropped from 42 days in 2019 to zero this year. Jaipur is the only city with multiple stations in this pool and has recorded an 80 per cent reduction in the number of days when at least one of its three stations registered exceedance.

Dramatic drop in daily $PM_{2.5}$ trends during lockdown: The impact of lockdown was felt immediately across all mega cities. The change was dramatic during lockdowns 1.0 and 2.0; but lockdown 3.0 onwards and progressively into lockdown 4.0 when restrictions were relaxed, there was a sharp increase in pollution levels once again.

During lockdown 1.0, the levels dropped sharply from the pre-lockdown phase (March 1-21). In Bengaluru, it dropped by 35 per cent, Chennai 20 per cent, Delhi 37 per cent, Kolkata 34 per cent, and in Mumbai, by 27 per cent. Levels continued to further drop during lockdown 2.0 except in Delhi – the capital registered a rise of 12 per cent in average $PM_{2.5}$ levels, which can be attributed to a series of dust storms that battered the city in this period. All mega cities, except Delhi, had their average $PM_{2.5}$ levels drop down to 'Good' category of AQI (less than half the 24-hourly standard); and it remained in the 'Good' category in lockdown 3.0.

A similar trend is evident in the cities of IGP. The $PM_{2.5}$ average level during lockdown 1.0 was considerably lower than the pre-lockdown (March 1-21) level. Amritsar noted a 38 per cent decline, Gurugram dipped by 41 per cent, Faridabad 53 per cent, Noida 43 per cent, Ghaziabad 44 per cent, and Howrah had a 44 per cent drop. Levels continued to further drop during lockdown 2.0. As in the mega cities, there was an increase during lockdown 3.0 due to the reopening of the economy: this accelerated during lockdown 4.0.

In tier 1 non-IGP cities, the impact of the lockdown varied. The $PM_{2.5}$ average level dropped considerably during lockdown 1.0 from the pre-lockdown level. It varied between 32 per cent in Ahmedabad to 45 per cent in Kochi. Guwahati and Ujjain registered increases of 12 per cent and 5 per cent, respectively. But

during lockdown 2.0, Guwahati recorded a 72 per cent fall. Other cities also experienced further drops.

Toxicity of particulates: Tinier particulates like $PM_{2.5}$ that also come more from combustion sources are considered more toxic and harmful compared to coarser particles like PM_{10}. Crustal dust has stronger influence on PM_{10}. If the share of $PM_{2.5}$ in the PM_{10} is higher, it makes the dose more toxic. Therefore, it was important to know how this ratio changed during the lockdown.

This ratio changes with season. Summer in the IGP, particularly, has more airborne dust; the overall $PM_{2.5}$ is likely to be comparatively lower than in the winter, with some variation across cities depending on the local situation. During winter, share of $PM_{2.5}$ is higher in the trapped air during inversion. Overall, secondary particulates that are formed from gases like sulphate from suplhur dioxide and nitrate from nitrogen oxides are also higher during winter. This makes winter air more toxic.

It is also evident that in non-IGP areas – particularly the southern cities like Bengaluru and Chennai or western cities like Mumbai where the overall influence of dust is comparatively lower – the share of $PM_{2.5}$ in PM_{10} is normally higher. In fact, this is one of the reasons why these regions, despite the overall lower particulate burden, should not be complacent and need urgent measures to reduce $PM_{2.5}$. State-wide global burden of disease shows that health risk from particulate pollution in terms of premature deaths per 100,000 population is quite uniform in India.

This analysis shows that compared to the same period in 2019, the percentage share of $PM_{2.5}$ has increased as overall PM_{10} levels have come down across all cities under consideration. But as the overall levels are significantly lower it may not be appropriate to label this to claim that the overall toxicity levels have gone up. But it is important to note that the overall share of $PM_{2.5}$ even in the much reduced particulate concentration has been higher.

In mega cities, the percentage share of $PM_{2.5}$ varied between 43 per cent in Delhi to 46 per cent in Kolkata. This range is not very different from the summer of 2019 when it ranged between 36 per cent in Delhi to 48 per cent in Bengaluru. In fact, there is only a slight increase in the share of $PM_{2.5}$ during lockdown because of higher reduction in PM_{10} and overall reduction in both the pollutants. But it is also clear that the winter air is a lot more toxic. During the winter of 2019, the share of $PM_{2.5}$ in mega cities ranged between 65 per cent in Delhi to 47 per cent in Bengaluru.

Similarly, in cities of the IGP the share of $PM_{2.5}$ ranged between 34 per cent in Amritsar to 4 per cent in Howrah. This is nearly the same range in the IGP cities in 2019 summer as well. But the winter share is very high – it varies between 52 per cent in Howrah to 73 per cent in Patna.

It is also evident that overall, the non-IGP cities – especially in the south, east and west – have comparatively higher $PM_{2.5}$ ratio even though the overall levels are lower compared to IGP cities. This shows lower influence of crustal dust.

Was the lockdown phase cleaner than the monsoon season? This study has not controlled for meteorological factors to assess the trend in different pollutants. Therefore, there was an interest to see how the lockdown period compared

with the monsoon months that are supposed to be cleanest months as long and frequent rain spells wash down the air.

For this analysis, average daily $PM_{2.5}$ concentration for 54 days of the first three phases of lockdown – March 25 to May 17 – has been taken as the benchmark. Lockdown 4.0 has not been considered as most cities resumed economic activities during this phase and the $PM_{2.5}$ level rose. To establish the cleanest contiguous 54 days before lockdown during 2019-20, rolling average of 54 days was computed and the lowest average value was used for comparison. The study also noted the dirtiest contiguous 54 days before the lockdown.

This shows that Chennai and Kolkata's average daily $PM_{2.5}$ for the contiguous 54 days during the lockdown was the cleanest contiguous 54 days observed since January 1, 2019. It was cleaner than their monsoon season as well. Bengaluru and Delhi came within 20 per cent of their monsoon levels while Mumbai and Hyderabad were significantly off from their monsoon lows. Lockdown was 54-91 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019. This certainly helps us to know how clean it can get.

Among the tier 1 cities in IGP, Amritsar and Howrah had the cleanest contiguous 54 days during lockdown since January 1, 2019, including the monsoon season. Gurugram and Patna come within 20 per cent of their monsoon levels while other NCR cities were observed to be 25-35 per cent higher than the monsoon level. Lucknow was significantly off from its monsoon lows. Lockdown was 68-88 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

Among the tier 1 cities outside the IGP, Ahmedabad, Jaipur, Jodhpur and Visakhapatnam had average daily $PM_{2.5}$ for the contiguous 54 days during lockdown that was the cleanest contiguous 54 days observed since January 1, 2019, including the monsoon season. Ahmedabad and Visakhapatnam were over 30 per cent cleaner during lockdown compared to their monsoon lows – the highest among all cities in the study. Guwahati, Pune and Ujjain were significantly off from their monsoon lows, with Ujjain's lockdown average being more than double its monsoon low. Lockdown was 58-84 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

Clearly, the IGP is the most polluted region in the country even during summer. Within the IGP, the NCR is the most polluted area, but Lucknow and Patna are not that clean either. In fact, Lucknow had the worst PM 2.5 level during the lockdown among all the cities in this study.

Even though pollution levels are bad in the IGP, the toxicity in cities outside the IGP can be more for the same concentration value – especially in the case of land-locked cities like Bengaluru, Hyderabad, Guwahati and others. The arid west (Rajasthan and Gujarat) is the most polluted region after the IGP. Coastal cities' pollution problem is distinct from that of the IGP and the rest of the inland, but due to really poor monitoring infrastructure it is not understood well. For instance, ozone formation in these cities is at its peak during the sunny winter and spring seasons and not in summer.

Pollution is a big problem in smaller cities like Ujjain and Guwahati, but it is much less understood. None of the cities studied were able to retain the clean air that was accidentally achieved during the lockdown. For many smaller cities, this clean air was not good as per the AQI.

Nitrogen dioxide

How the levels fell: Nitrogen dioxide (NO_2) comes entirely from combustion sources. NO_2 in cities is primarily driven by vehicular traffic and industries. Episodic burning can also have a temporal impact on its trend. The impact of lockdown on NO_2 levels was more pronounced than on $PM_{2.5}$. Therefore, shutting down of industry and traffic is expected to have had a dramatic impact on ambient concentration of NO_2.

In mega cities, the impact of the lockdown was felt immediately all across. The NO_2 average level during lockdown 1.0 was considerably lower than the pre-lockdown period (March 1-24) average levels. Bengaluru saw a 55 per cent reduction, Delhi 49 per cent, Hyderabad 30 per cent, Kolkata 65 per cent, and Mumbai had a 70 per cent dip. Chennai witnessed a reduction of 7 per cent during lockdown 1.0. Levels continued to further drop during lockdown 2.0. With relaxation, the levels started to rise from lockdown 3.0 onwards and accelerated during lockdown 4.0.

In tier 1 cities of the IGP, the NO_2 average level fell sharply during lockdown 1.0. It varied from 48 per cent in Gurugram, 18 per cent in Faridabad, 59 per cent in Noida, 53 per cent in Ghaziabad and Lucknow each, 20 per cent in Patna and 67 per cent in Howrah. In Amritsar, the initial change was minimal, but it increased to 47 per cent during lockdown 2.0.

In the non-IGP cities, the NO_2 average level immediately dropped during lockdown 1.0 – by 22 per cent in Ahmedabad, 40 per cent in Guwahati, 62 per cent in Jaipur, 58 per cent in Jodhpur, 26 per cent in Pune, 44 per cent in Ujjain, and 4 per cent in Visakhapatnam. In almost every city, NO_2 levels started to rise when restrictions were relaxed from lockdown 3.0 onwards and accelerated during lockdown 4.0.

Hourly NO_2 pattern flattened during lockdown: The most dramatic change was noted in the hourly variations during the day, which was essentially an impact of the traffic. NO_2 levels are known to mimic traffic volume curve in urban centers through the day. NO_2 levels during rush hours worsened public exposure.

With the lockdown removing non-essential vehicles, the curve flattened. To understand this impact, the study considered hourly pollution concentration data for the month of April for 2019 and 2020 to create a typical April day. Basically, all the readings for a specific hour of the day for all days of April were averaged to arrive at an average pollution level at that given hour of the day. Only April data was used instead of the whole lockdown data because from May 4, 2020, restrictions on vehicular movement eased in lockdown 3.0.

In mega cities, following the lockdown, the morning peak (7-8 AM) collapsed by 78 per cent in Mumbai and 60 per cent in Delhi. Kolkata and Bengaluru both saw a 53 per cent drop in morning, while Hyderabad and Chennai registered a 29 per cent and 5 per cent drop respectively. Similarly, the evening peak (8-9 PM) dropped in Mumbai by 77 per cent and in Bengaluru by 71 per cent. Delhi, Kolkata and Hyderabad saw drops of 60 per cent, 55 per cent, and 50 per cent respectively.

Among IGP cities, the lockdown made the morning peak (7-8 AM) collapse by 88 per cent in Faridabad and 63 per cent in Lucknow. Noida and Ghaziabad saw a 56 per cent and 53 per cent drop in morning peaks respectively, while

Patna and Amritsar registered a 21 per cent and 22 per cent drop respectively. Evening peak (8-9 PM) dropped in Faridabad by 90 per cent and in Ghaziabad by 64 per cent. Amritsar, Noida, Lucknow, and Patna saw drops of 51 per cent, 57 per cent, 54 per cent and 60 per cent respectively.

In non-IGP cities, the morning peak collapsed by 64 per cent in Ahmedabad and 55 per cent in Jodhpur – it also moved two-three hours earlier in the morning. Visakhapatnam had only a 5 per cent lowering of the morning peak. Evening peak shifted one-two hours later in the evening and collapsed by over 60 per cent in Ahmedabad, Jaipur and Jodhpur. Guwahati, Ujjain and Visakhapatnam registered a 28 per cent, 22 per cent, and 29 per cent drop in their evening peaks, respectively.

Was the lockdown cleaner than the monsoon season? For this analysis, average daily NO_2 concentration for 54 days of the first three phases of lockdown – March 25 to May 17 – has been taken as a benchmark. Lockdown 4.0 has not been included. To establish the cleanest contiguous 54 days before lockdown during 2019-20, rolling average of 54 days was computed and the lowest value was used for comparison. The study also noted the dirtiest contiguous 54 days before the lockdown.

During the lockdown, all mega cities except Hyderabad registered the cleanest contiguous 54 days observed since January 1, 2019 for average daily NO_2. It was 26-50 per cent cleaner than their earlier cleanest periods that were naturally encountered during monsoon season. Hyderabad was the only mega city that had observed cleaner times before the lockdown. The lockdown period was 52-92 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

In IGP, Noida, Ghaziabad, Lucknow and Howrah had average daily NO_2 for the contiguous 54 days during lockdown that were the cleanest contiguous 54 days observed since January 1, 2019, including in the monsoon season. Amritsar, Gurugram and Patna were significantly off from their monsoon lows. Lockdown was 38-88 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

Outside the IGP, Ahmedabad, Jaipur and Visakhapatnam had average daily NO_2 for the contiguous 54 days during lockdown that were the cleanest contiguous 54 days observed since January 1, 2019, including in the monsoon season. Guwahati and Jodhpur's lockdown levels were almost the same as the lowest recorded in 2019 monsoon. Pune and Ujjain were significantly off from their monsoon lows, with their lockdown averages being 74 per cent and 68 per cent higher than their monsoon lows, respectively. The lockdown was 48-87 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

AN AGENDA TO MOVE FORWARD

The message from this analysis of summer air quality during the lockdown period is quite clear. It has helped us understand the scale and speed at which change is needed to clean up the air in our cities and regions. However, the improvement in air quality came about through an enormous disruption and human cost – is this the only way to move forward? We need an agenda for blue skies and clear lungs for the post-pandemic period.

This period (and its analysis) has helped us understand the lowest level of pollution that it is possible to achieve under the current scenario. It has also helped us understand how important it is to address regional influences. A substantial reduction in cities is possible only if the entire region cleans up together. But the change has to happen at scale and speed across all critical sectors including vehicles, industry, power plants, waste, construction, use of solid fuels for cooking, and episodic burning. This has to inform action across all non-attainment cities under the ongoing National Clean Air Programme (NCAP), as also in the regions.

This analysis has also put the spotlight on the seasonal nature of the pollution problem in India. Winter months, when cold and calm weather conditions and inversion trap the pollution leading to severe smog episodes, attract a lot of attention. These episodes are largely driven by the accumulated particles in the air. But the pollution during summers – that gets further complicated by ozone levels – is not yet very well understood. Global experience shows that ozone is the new generation problem and needs equally strong attention and action.

This essentially means that the action plans that are being framed and implemented across the cities of India need to ensure the co-benefit of reducing both particulate and gaseous emissions, with a special focus on ozone. At the same time, we need good science to assess air quality based on the ever expanding monitoring grid for better understanding of the changing trends in different pollutants, as well as their compliance with the national ambient air quality standards. The method and protocol needed to report compliance for different pollutants must be specified urgently.

Today, we are re-opening the country without any plans to hold on to the clean air benefits of the lockdown. But locally and regionally, across 122 cities in India, appropriate action plans are taking shape and getting implemented. This process can be informed better for multi-sectoral interventions. However, at the national level, it is important to link the new overarching but priority reform agenda more specifically with the economic stimulus and reform packages that will work for both economy and environment. This is needed for a nation-wide up-scaled transition.

DECODING THE SUMMER POLLUTION DURING LOCKDOWN

This analysis has put a spotlight on three critical pollutants of concern – the tiny particles of less than 2.5 micron size ($PM_{2.5}$), nitrogen dioxide (NO_2) and tropospheric ozone (henceforth ozone). The analysis has been carried out in 22 cities representing the Indo-Gangetic Plains (IGP), coastal plains, arid western zone, the Deccan plateau, and the north-east. If we take only the population living within the municipal boundaries of these cities – and not the larger urban agglomeration (for which getting a more precise Census data is difficult) – then this study has covered about 40 per cent of the urban population living in class I cities in India.

Data has been sourced from the CPCB's official online portal, the Central Control Room for Air Quality Management - All India (https://app.cpcbccr.com/). The most granular data (15-minute averages) that is available, has been accessed and analysed. This analysis has tracked trends between January 1, 2019 to May 31, 2020 with special focus on the changes between pre-lockdown and lockdown phases (see Box on methodology).

The analysis has tracked the daily and seasonal change from pre-lockdown phase to lockdown phase and as appropriate, compared it with the same period in the previous year. It has helped capture the speed and quality of change for each pollutant, and the regional variations according to the type of cities and geography. This has helped understand the cleanest range during this phase and also, how quickly a lot of the gain was undone once the lockdown was eased in phase 4. While there is a lot of similarity in the pattern of change in $PM_{2.5}$ and NO_2 as these are primary emissions from different sources, ozone (which is a secondary pollutant), behaved differently.

This pollutant-wise insight is, therefore, needed to inform policy action at a time when 122 cities that do not meet the particulate standards are implementing action plans under the National Clean Air Programme (NCAP) of the Union Ministry of Environment, Forest and Climate Change. This is also a time when the ministry is contemplating action at a regional scale.

The methodology

The air quality analysis covers 22 cities spread across 15 states (*see Table*) and the National Capital Territory of Delhi. The analysis uses over 23 million data points recorded by 116 air quality monitoring stations or about 50 per cent of the existing network under the Continuous Ambient Air Quality Monitoring System (CAAQMS) of Central Pollution Control Board (CPCB). All cities with three or more CAAQMS stations have been included in the analysis; more have been chosen to represent wide geography and demography.

Table: Cities and their monitoring stations

Mega cities	Tier-1 cities in the Indo-Gangetic Plains	Tier-1 cities outside the Indo-Gangetic Plains
Delhi: 38 (monitoring stations)	Patna (Bihar): 6	Visakhapatnam (Andhra Pradesh): 1
Bengaluru (Karnataka): 10	Faridabad (Haryana): 4	Guwahati (Assam): 1
Mumbai (Maharashtra): 10	Gurugram (Haryana): 4	Ahmedabad (Gujarat): 1
Chennai (Tamil Nadu): 4	Amritsar (Punjab): 1	Kochi (Kerala): 1
Hyderabad (Telangana): 6	Ghaziabad (Uttar Pradesh): 4	Jaipur (Rajasthan): 3
Kolkata (West Bengal): 7	Lucknow (Uttar Pradesh): 5	Jodhpur (Rajasthan): 1
	Noida (Uttar Pradesh): 4	Ujjain (Madhya Pradesh): 1
	Howrah (West Bengal): 3	Pune (Maharashtra): 1

Note: The values in figures denote the number of CAAQMS stations in the city as of May 20, 2020
Source: Compiled by CSE

Data has been sourced from the CPCB's official online portal, the Central Control Room for Air Quality Management – All India (https://app.cpcbccr.com/). The most granular data (15-minute averages) available has been accessed and analysed to construct 24-hourly values using USEPA protocol for data completeness and formulas, but with equivalent Indian National Ambient Air Quality Standard (NAAQS) for each station individually and for a combined dataset for the city. Tropospheric ozone (henceforth ozone) has hourly and eight-hour standards – therefore, the daily value for ozone is based on the maximum eight-hour average recorded in the day from rolling eight-hour averages. Reference document for ozone daily value computation is the USEPA's *40 CFR Appendix P to Part 50*, while the 24-hourly values for $PM_{2.5}$, PM_{10}, and NO_2 have referenced the method mentioned in the USEPA's *40 CFR Appendix N to Part 50*.

The study period of the analysis is January 1, 2019 to May 31, 2020. The pre-lockdown phase has been considered to be from March 1-21 (unless specified differently). The other time periods used in this analysis are Lockdown 1.0 (March 25-April 14), Lockdown 2.0 (April15-May 3), Lockdown 3.0 (May 4-17), and Lockdown 4.0 (May 18-31). General term lockdown refers to the March 25-May 31 period. For some lockdown analyses, the March 22-24 period has been ignored, as these were transitory days with wild variations in policy among states and in enforcement among cities. The term 'spring season' refers to the February 1-March 24 period, while 'summer season' refers to the March 25-May 31 period.

For cities with more than one monitoring station, the analysis is based on the combined dataset of a city, but the comparative analysis and trends with 2019 pollution conditions have been done only for stations that have adequate data for both 2019 and 2020.

Nevertheless, the numbers of exceedances have been calculated based on the combined dataset agnostic to the number of stations present in the computation of a city's 24-hourly value for a given day. This is in accordance with the AQI reporting policy of the CPCB that spatially averages all available and valid data in computing a city's AQI. Analysis of individual stations has been carried out separately to understand micro-variations and spatial nuances where it was found necessary and feasible.

OZONE

DIFFERENT FROM OTHER POLLUTANTS

Ozone's behaviour

The trends with respect to ozone levels during the lockdown are not as straightforward as other criteria pollutants. While other pollutants have shown a sharp and consistent drop during the lockdown, ozone concentration has been variable; it even shows a rising trend in several locations across cities under consideration.

This is largely because of the nature of the pollutant. Ozone is called a 'secondary pollutant'. It is not directly emitted by any source. Other gases like oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) that are emitted from combustion sources undergo chemical reactions triggered by sunlight and ambient temperature in the air to form ozone. Therefore, to control ozone, primary emissions of other gases will have to be controlled.

The resident time of ozone in the air is highly volatile. It is formed in high pollution areas. But the photochemical reactions that form ozone are also cyclical in nature. Ozone that is formed from the reaction of other gases once again reacts with these gases – primarily NO_x – to get instantly consumed and dissipated. It is quite likely, therefore, that the areas where ozone is formed may not show high concentrations due to this cyclical process.

Only when ozone drifts to relatively cleaner areas that do not have enough NO_x and VOCs, it builds up. This is also the reason why we see drastic variations in its levels within a city. This is different from other criteria pollutants like particulate matter and NO_x that have larger geographical uniformity in their concentrations. This typical phenomenon of ozone can make even an overall low pollution area unsafe.

This, of course, makes the lockdown period very interesting. With overall pollution levels down, how did ozone behave this summer? Overall, the ambient concentrations of key ingredients of ozone such as NO_x were very low during this phase. It is not possible to estimate the level of VOCs – but, it is expected that VOCs from combustion sources would have reduced, although those from natural sources would have persisted.

ASSESSING OZONE TRENDS IN CITIES

The blanket method of spatial averaging of ozone for city-wide averages that is used by the CPCB currently to compute city-wide Air Quality Index (AQI) does not explicitly reflect the magnitude of the danger posed by ozone pollution. Currently, as it is evident, the conventional practice is to consider only an 8 AM-4 PM concentration average of ozone to compare with the eight-hour standard. But this has limitations. There is a divergence in the way ozone averaging is done by the CPCB and by the USEPA.

It may be noted that ozone formation is linked with sunlight hours and analysis of hourly data of Delhi. Its concentration generally peaks in the afternoon in

Delhi during summer; the usual peak hour is either 4-5 PM or 5-6 PM. Therefore, exclusively using 8 AM-4 PM averages leaves out the most polluted hours from the calculations. For instance, on May 20, 2020, the eight-hour average for Delhi (city-wide) for 8 AM-4 PM stood at 98 μg/m^3, just under the standard. But the eight-hour average for 9 AM-5 PM rose to 102 μg/m^3 and remained the same for the 10 AM-6 PM period as well. Even the 11 AM-7 PM average was 99 μg/m^3, higher than the CPCB's reference time period.

Given the volatile nature of ozone pollution build-up, these maximum pollution hours can vary among cities and within a city during different seasons. Having a blanket approach is undermining the public health implications of ozone pollution. This is why the USEPA approach of computing all possible eight-hour averages for a day and then checking for the maximum value among them is a more accurate capture of the ozone pollution problem (*see Box: Estimating ozone trends – the CPCB and the USEPA methods*).

EXCEEDING CONCENTRATIONS

Due to the very toxic nature of ozone, the national ambient air quality standard for ozone has been set for short-term exposures (one-hour and eight-hour averages), and compliance is measured by the number of days that exceed the standards. For the same reason, its levels at any station should not be averaged out with other stations to report the AQI. A low average concentration level over an extended time frame is not a good measure for assessing risk or the health impact of exposure to ozone for people living around hotspots.

Compliance requires that the standards are met for 98 per cent of the time of the year. It may exceed the limits on two per cent of the days in a year, but not on two consecutive days of monitoring. In other words, there should not be more than eight days in a year when the ozone standard is breeched, and none of those allowed exceedances can be on two consecutive days.

Therefore, this analysis tracks exceedances during the lockdown and compares them with the corresponding period in 2019. Exceedances have been tracked at three levels – city-wide average, long-term worst station, and any station. This also tracks all days on which at least one city station breeched the standard. The intent is not just to understand the impact of the lockdown, but also to understand real magnitude of ozone pollution in cities.

In mega cities

- All mega cities except Hyderabad exceeded the eight-hour standard on at least one day at one of their stations during the lockdown (*see Table 1*).
- At the city-wide level and in terms of a city-wide average, Delhi registered an exceedance on four days and Kolkata, on eight days. However, Delhi witnessed 67 days (every day of lockdown) of exceedance and Kolkata had 17 days when at least one station in the city exceeded the standard.
- The situation was worse in Chennai where the Manali Village station exceeded the standard on 62 days, but the city registered no days with exceedance as the other three stations recorded much less concentrations.
- Almost all stations in Delhi exceeded the standard for two contiguous days. In fact, the Nehru Nagar and Dr Karni Singh Shooting Range stations exceeded the standard for 41 contiguous days during the lockdown. In Chennai, the Manali Village station registered 35 contiguous days of exceedance, while in Kolkata the Victoria station registered 17 contiguous days.

Estimating ozone trends – the CPCB and the USEPA methods

Ozone standards: India has set one-hour and eight-hour standards for ozone. As per the NAAQS, this needs to be complied with 98 per cent of the time – two per cent of the time, the standard can be exceeded, but not on two consecutive days of monitoring.[16] Ozone is monitored as a part of the monitoring done by the continuous ambient air quality monitoring systems (CAAQMS) network that is real-time and collects data for every 15 minutes.

Ozone has been included in the AQI programme, but its AQI sub-category is only linked with its eight-hour standard. Based on discussions with the CPCB, it is understood that for daily AQI reporting, the Board uses the 8 AM-4 PM concentration of ozone, constructed by averaging all the 15-minute data collected for that time period. Further, for all cities with multiple CAAQMS stations, the value used for daily AQI report is based on the spatial average of concentration from every station in the city.

As of now, the protocol for data completeness and construction of eight-hour averages from the 15-minute averages has not been officially defined. During this analysis, it was also noted that no station included in this study has reported 15-minute concentrations that are higher than 199 $\mu g/m^3$ for the period under observation. It was noted that for stations that reported values rising up till the 190s, the notings would go blank (the next few 15-minute entries would be missing) and eventually, data would reappear with values back in the 190s and declining in magnitude. This is difficult to explain – there seems to a cap or filter placed in the system. It needs to be seen if data above 200 $\mu g/m^3$ or higher gets masked by this.

The approach of the USEPA is different. The USEPA has set a one-hour and eight-hour standard just like the CPCB – but the compliance with the standard is measured differently. The eight-hour ozone standard is deemed to be met for an air quality monitoring site when the three-year average of the annual fourth-highest daily maximum eight-hour average ozone concentration is less than or equal to 0.075 ppm (eight-hour standard). The protocol for determining daily maximum eight-hour average ozone concentration is detailed in *Appendix P* to *Part 50 of 40 CFR-Interpretation of the Primary and Secondary National Ambient Air Quality Standards for Ozone*.

To determine daily maximum eight-hour average ozone concentrations, the first running eight-hour averages are computed from the hourly ozone concentration data for each hour of the year. An eight-hour average is considered valid if at least 75 per cent of the hourly averages for the eight-hour period are available. In the event that only six- or seven-hourly averages are available, the eight-hour average shall be computed on the basis of the hours available using six or seven as the divisor. Eight-hour periods with three or more missing hours shall be considered valid as well if, after substituting half of the minimum detectable limit for the missing hourly concentrations, the eight-hour average concentration is greater than the level of the standard.

There are 24 possible running eight-hour average ozone concentrations for each calendar day during the ozone monitoring season. The daily maximum eight-hour concentration for a given calendar day is the highest of the 24 possible eight-hour average concentrations computed for that day. This process is repeated, yielding a daily maximum eight-hour average ozone concentration for each calendar day with ambient ozone monitoring data.

Further, an ozone monitoring day is counted as a valid day if valid eight-hour averages are available for at least 75 per cent of possible hours in the day (that is, at least 18 of the 24 averages). In the event that less than 75 per cent of the eight-hour averages are available, a day shall also be counted as valid if the daily maximum eight-hour average concentration for that day is greater than the level of the standard.[17]

The USEPA has adopted this approach of using the maximum eight-hour average as the daily value based on the review of controlled human exposures and epidemiological studies reporting associations between adverse respiratory effects and six-eight hour ozone concentrations. The Agency's rules have noted that a standard with a maximum eight-hour averaging time gives substantial protection against respiratory effects associated with one-hour peak ozone concentration.[18]

No spatial averaging is allowed for reporting compliance. For cities with more than one ozone monitoring site, average of the worst site is deemed the average of the city.

Table 1: Number of days with ozone levels exceeding the standard – mega cities (March 25-May 31)

City	2019			2020		
	Exceedance: City-wide	Exceedance: Worst station	Exceedance: Any station	Exceedance: City-wide	Exceedance: Worst station	Exceedance: Any station
Bengaluru	8	17	50	0	0	2
Chennai	1	7	11	0	61	61
Delhi	21	57	68	4	52	67
Hyderabad	0	1	24	0	0	0
Kolkata	0	0	0	8	15	17
Mumbai	0	0	0	0	0	5

Note: Long term worst stations: Bengaluru – Bapuji Nagar; Chennai – Manali Village; Delhi – Nehru Nagar; Hyderabad – Sanathnagar; Kolkata – Victoria; Mumbai – Bandra

Source: CSE analysis based on CPCB data.

- During the lockdown in 2020, inland cities were marginally cleaner and coastal cities considerably dirtier compared to the corresponding period in 2019.

In tier-1 cities of Indo-Gangetic Plains

- All cities in the IGP, except Amritsar and Lucknow, exceeded the ozone standard at least on one day at one of their stations during the lockdown (*see Table 2*).
- At the city-wide level, Gurugram (26 days), Faridabad (four days), Noida (12 days), Ghaziabad (15 days), and Howrah (three days) registered exceedance.
- But there is massive undercounting that is evident, as at least one station in each of these cities has exceeded the standard on a higher number of days – Gurugram (57 days), Faridabad (46 days), Noida (42 days), and Ghaziabad (56 days).
- In Faridabad, the Sector 16 A station registered 31 contiguous days of exceedance. Howrah (10 days) had two-11 times more such days compared

Table 2: Number of days with ozone levels exceeding the standard – tier-1 cities in the Indo-Gangetic Plains (March 25-May 31)

City	2019			2020		
	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station
Amritsar	0	0	0	0	0	0
Gurugram	4	4	8	26	49	57
Faridabad	56	56	56	4	46	46
Noida	0	6	7	12	15	42
Ghaziabad	51	56	63	15	38	56
Lucknow	0	7	12	0	0	0
Patna	59	0	59	0	14	34
Howrah	0	0	0	3	9	10

Note: Long-term worst stations: Amritsar – Golden Temple; Gurugram – Vikas Sadan; Faridabad – Sector 16 A; Noida – Sector 62; Ghaziabad – Indirapuram; Lucknow – Lalbagh; Patna – Samanpura; Howrah – Padmapukur

Source: CSE analysis based on CPCB data

Table 3: Number of days with levels exceeding the standard – tier-1 cities outside the Indo-Gangetic Plains (March 25-May 31)

City	2019			2020		
	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station
Ahmedabad	12	-	-	43	-	-
Guwahati	1	-	-	0	-	-
Jaipur	13	14	27	3	6	9
Jodhpur	15	-	-	9	-	-
Kochi	-	-	-	0	-	-
Pune	0	-	-	0	-	-
Ujjain	43	-	-	38	-	-
Visakhapatnam	0	-	-	0	-	-

Note: Long-term worst stations: Only Jaipur has multiple stations and its Shastri Nagar station is deemed the worst.

Source: CSE analysis based on CPCB data

to city-wide exceedances.

- All cities except Amritsar and Lucknow had stations that exceeded the standard for two continuous days. Patna, which had recorded zero days of exceedance at the city-wide level, had the station at Rajbansi Nagar register 18 contiguous days of exceedance.
- 2019 had more days exceeding the standards than the lockdown period in Faridabad, Ghaziabad, Lucknow and Patna; Amritsar had zero exceedances in both the years.

In tier-1 cities outside Indo-Gangetic Plains

- Ahmedabad, with 43 days of exceedance during the lockdown, was the only city to note an increase in number of days exceeding the standard compared to the same period in the previous year – 36 of those exceedance days were contiguous.
- Ujjain, with 38 days exceeding the standard, was the second most polluted among the cities in this pool. But it was five days lesser than the 2019 tally for this Madhya Pradesh city.
- In Rajasthan, both Jaipur and Jodhpur exceeded the standard on multiple days, but the numbers were down from their 2019 tally. Jaipur is the only city in this pool to have more than one monitoring station (*see Table 3*).

OZONE TRENDS DURING SPRING AND SUMMER

One of the aims of this analysis has been to track changes in ozone levels post-winter, and note how it transforms through spring and summer. Sunlight being the catalyst for ozone formation, the sunny Indian summer is the optimum time for ozone concentrations to build up – and it does build up quickly and to dangerous levels. The summer lockdown period has offered an opportunity to understand its behaviour better.

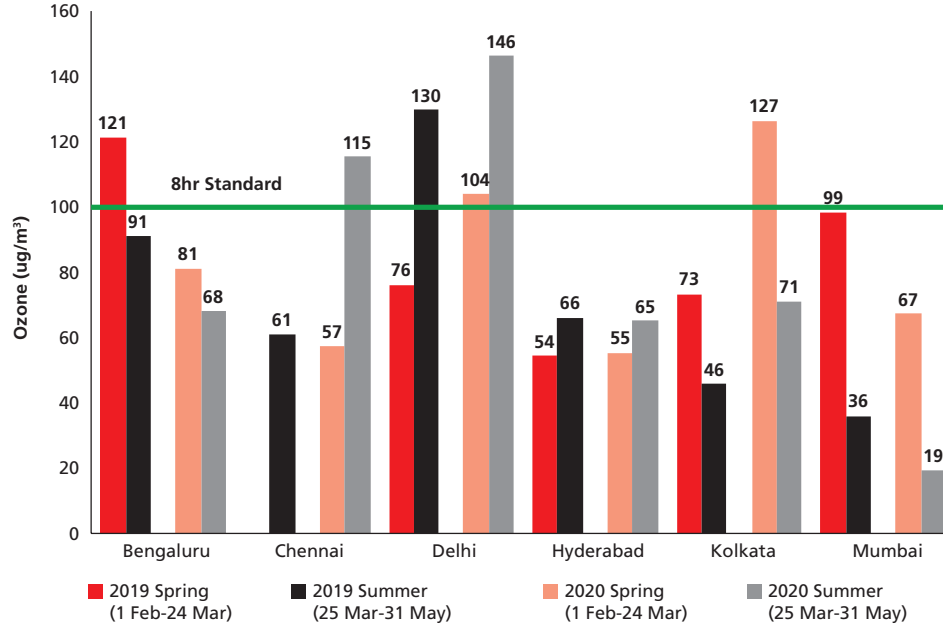
The uniqueness of this phase is that all other criteria pollutants, particularly NO_2 which is a catalyst in the ozone recipe, have dropped to bare minimum levels in most cities. VOCs are the alternate fodder for ozone formation, and may also have reduced though they are also emitted by many natural processes that were unaffected by the lockdown.

For this analysis, ozone level was tracked at the station level in each city. Those stations were selected that have data for both 2019 and 2020. In case there were multiple long-term stations available in a city, the station with the worst (highest) average daily value for the lockdown period was chosen to represent the city.

In mega cities

- The six mega cities represent different climatic zones; there is a distinct seasonal variation among them, especially between spring and summer.
- In 2019, Bengaluru (25 per cent), Kolkata (38 per cent) and Mumbai (63 per cent) have shown relatively higher ozone levels during spring season than in summer. These regions have warm springs, while summer experiences more squalls and rains.
- In Delhi and Hyderabad, the average daily maximum eight-hourly ozone concentration increased by 70 per cent and 22 per cent, respectively, during summer.
- Chennai does not have adequate data for the 2019 spring season to compute the season's average.
- This seasonal trend at the long-term worst station was found to be similar at the city-wide average level as well, albeit with a milder magnitude.
- In 2020, Bengaluru (16 per cent), Kolkata (44 per cent) and Mumbai (71 per cent) registered drops in averages between the two seasons.
- Delhi and Hyderabad showed 41 per cent and 18 per cent increase respectively between the seasons. Chennai registered an impressive 101 per cent increase between the two seasons (*see Graph 2*).
- Chennai, Delhi and Kolkata had higher concentrations of ozone in 2020 than in 2019 in both the seasons; Hyderabad showed negligible difference between the two years. Mumbai and Bengaluru had a cleaner 2020 in comparison.

Graph 2: Ozone: Seasonal variations in average daily maximum eight-hour levels in mega cities – the worst stations



Notes: Average of only one station that has valid data for both 2019 and 2020 has been used for each city. In case a city has multiple such stations, then the station with the worst average for lockdown period has been used. Stations used here: Bengaluru – Bapuji Nagar; Chennai – Manali Village; Delhi – Nehru Nagar; Hyderabad – Sanathnagar; Kolkata – Victoria; Mumbai – Bandra

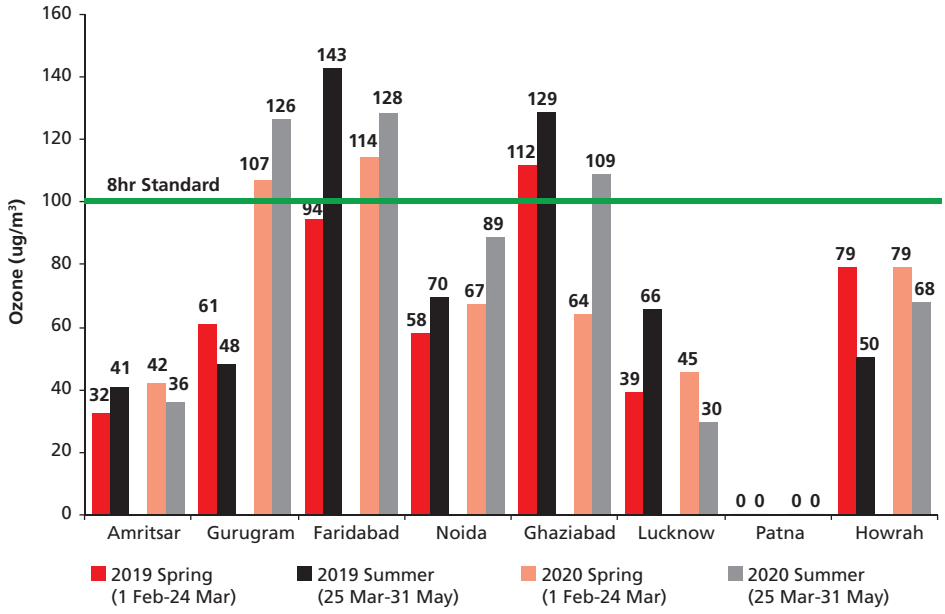
Source: CSE analysis based on CPCB data

- Delhi and Chennai's summer averages were higher than the standard.
- The heterodox nature of ozone concentration behavior across mega cities seems to indicate that the lockdown did not have a pronounced effect on ozone pollution.

In tier-1 cities in Indo-Gangetic Plains

- The cities in IGP show no definite pattern in the behavior of ozone levels.
- In 2019, spring season had higher ozone concentration compared to summer in Gurugram (21 per cent) and Howrah (36 per cent). It was the reverse for the rest of the cities – their average daily maximum eight-hourly ozone concentration increased in summer.
- Lucknow (68 per cent) and Faridabad (51 per cent) had the steepest rise in their concentration averages. Amritsar (26 per cent), Ghaziabad (15 per cent) and Noida (20 per cent) had relatively milder increases between the two seasons.
- This seasonal trend at long-term worst station was found to be similar at the city-wide average level as well except in Gurugram, albeit with a milder magnitude.
- Patna has ozone data for both the years, but it does not have any long-term station. Stations working in 2019 have not been working in 2020.
- In 2020, Howrah (16 per cent) continued to show a drop in ozone levels between spring and summer, but with reduced percentage. The trend reversed for Amritsar, Gurugram, and Lucknow, with the level up by 18 per cent in Gurugram, while Amritsar (15 per cent) and Lucknow (35 per cent) registered drops between the two seasons. Faridabad (12 per cent), Ghaziabad (70 per cent) and Noida (32 per cent) witnessed increases between the two seasons (*see Graph 3*).

Graph 3: Seasonal variations in average daily maximum eight-hour ozone levels in tier-1 cities in the Indo-Gangetic Plains – the worst stations



Notes: Average of only one station that has valid data for both 2019 and 2020 has been used for each city. In case a city has multiple such stations, then the station with the worst average for lockdown period has been used. Stations used: Amritsar – Golden Temple; Gurugram – Vikas Sadan; Faridabad – Sector 16 A; Noida – Sector 62; Ghaziabad – Indirapuram; Lucknow – Lalbagh; Patna – Samanpura; Howrah – Padmapukur

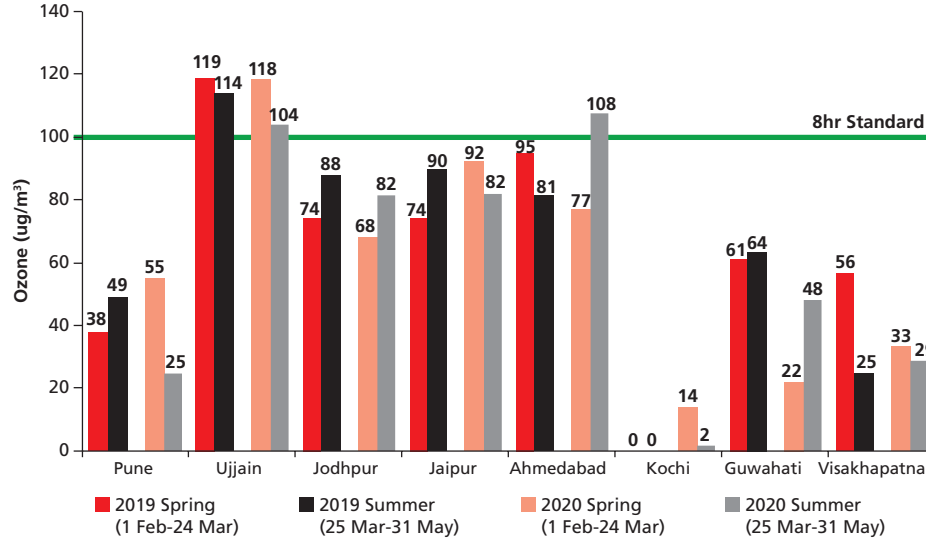
Source: CSE analysis based on CPCB data

- Gurugram, Noida and Howrah had higher concentrations of ozone in 2020 than in 2019, in both the seasons. In 2020, Gurugram and Faridabad had average levels for both seasons more than the eight-hour standard. Ghaziabad's average level breached the standard during the lockdown, but not during the spring.

In tier-1 cities outside Indo-Gangetic Plains

- In 2019, spring season had higher ozone average levels in Ahmedabad (14 per cent), Ujjain (4 per cent), and Visakhapatnam (56 per cent) than in the summer. It was the reverse for the rest of cities in this pool, as they saw averages of their daily maximum eight-hourly ozone level increase in summer.
- Guwahati (4 per cent), Jaipur (21 per cent), Jodhpur (18 per cent) and Pune (30 per cent) had higher ozone levels between the two seasons. All cities in this pool except Jaipur have only one monitoring station; the Kochi station was not functional in 2019.
- In 2020, Guwahati (120 per cent) and Jodhpur (20 per cent) continued to show a rise in ozone levels between the two seasons. The trend reversed for Ahmedabad, Jaipur and Pune. The levels rose by 40 per cent in Ahmedabad, while Jaipur (11 per cent) and Pune (55 per cent) registered a drop between the two seasons.
- Kochi (89 per cent), Ujjain (12 per cent) and Visakhapatnam (14 per cent) had an increase between the two seasons (*see Graph 4*).
- Ahmedabad (32 per cent) and Visakhapatnam (15 per cent) had higher average levels of ozone during lockdown compared to the corresponding period in 2019 – but Ahmedabad also breached the standard. Rest of the cities in this pool were 7-50 per cent cleaner during the lockdown. Ujjain stood out as its average level exceeded the standard for all the four periods examined in this analysis.

Graph 4: Seasonal variations in average daily maximum eight-hour ozone levels in tier-1 cities outside the Indo-Gangetic Plains – the worst stations



Notes: Average of only one station that has valid data for both 2019 and 2020 has been used for each city. In case a city has multiple such stations, then the station with the worst average for the lockdown period has been used. Only Jaipur has multiple stations and its Shastri Nagar station is deemed the long term worst station

Source: CSE analysis based on CPCB

NO_2 AND OZONE: SPATIAL VARIANCES IN BUILD-UP ACROSS CITIES

CSE has mapped out the spatial concentration of ozone and NO_2 to understand how the two co-exist in selected cities. This shows clearly that ozone levels are very low in areas with higher NO_2 levels, but higher in areas with low concentration of NO_2. Spatial variation in ozone and NO_2 build-up according to the monitoring sites in cities is represented in a map. This indicates that overall NO_2 levels are low in cities; ozone is low as well in areas with relatively higher NO_2 levels. But ozone is comparatively higher in low NO_2 areas. There are, however, some variations across cities.

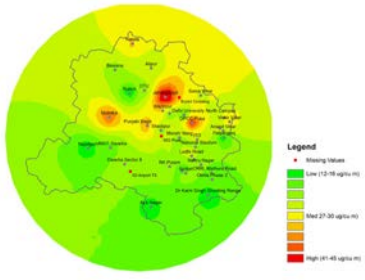
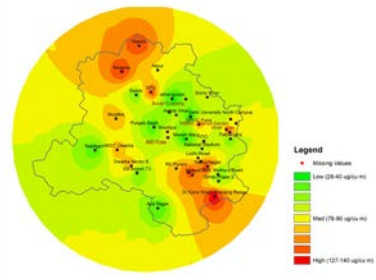
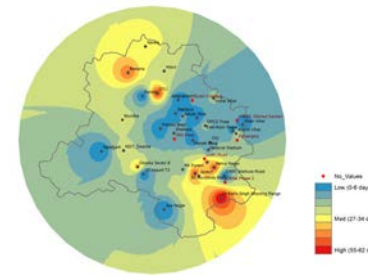
Stations with the highest average ozone concentrations are not always the ones which exceed the standard the most, indicating the volatile and precarious nature of ozone formation and pollution build-up.

Delhi

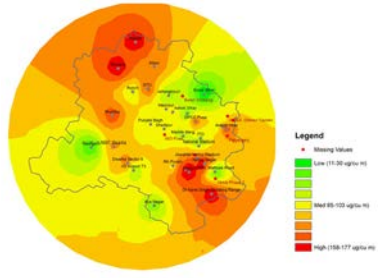
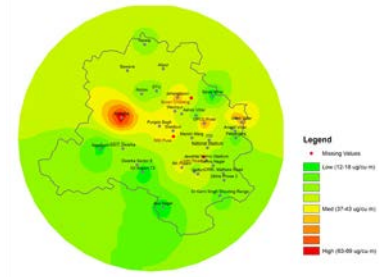
- Concentration during the lockdown was exceptionally low for NO_2, but there was still considerable variation in levels among the 38 monitoring locations in the city (see *Map 1, a: Spatial representation of NO_2 and ozone build-up in Delhi – Lockdown average: March 25-May 31, 2020*).
- Hotspots for NO_2 pollution were concentrated in north Delhi around industrial areas. Jahangirpuri had the highest NO_2 concentration.
- Spatial map changes for ozone as the highest ozone concentrations were seen in south Delhi with Nehru Nagar (152 µg/m^3) and Dr Karni Singh Shooting Range (149 µg/m^3) observed to be the most polluted. Industrial

Map 1: Spatial representation of NO_2 and ozone build-up in Delhi

a. Lockdown average: March 25-May 31, 2020

NO_2 (lockdown average)	Ozone (lockdown average)	Ozone (exceedance)
		

b. Worst ozone pollution day: May 17, 2020

Ozone (max 8-hr average)	NO_2 (24-hr average)
	

Source: CSE analysis based on CPCB data

zones in north Delhi also had relatively higher ozone concentrations and exceedances.

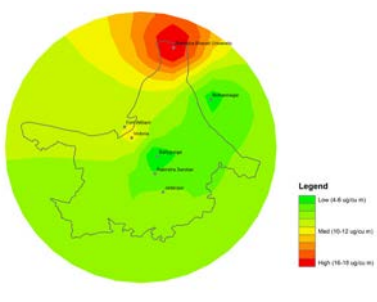
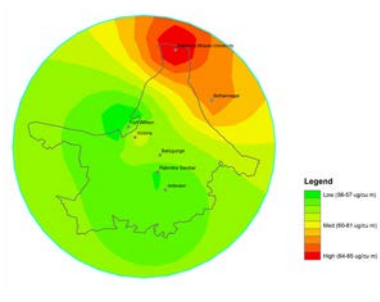
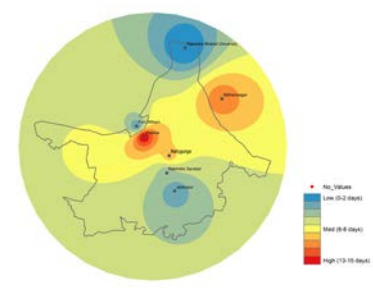
- The worst ozone pollution during lockdown occurred on May 17, 2020 in the city – 15 stations exceeded the eight-hourly standard, with Nehru Nagar registering the highest concentration (see *Map 1, b: Spatial representation of NO_2 and ozone build-up in Delhi – Worst ozone pollution day: May 17, 2020*).
- Spatial map for NO_2 had the same locations showing the lowest concentration spots as in the case of ozone, while most medium-scale NO_2 pollution spots turned into hotspots for ozone.

Kolkata

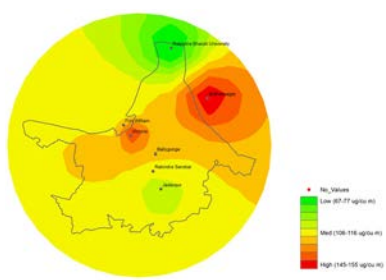
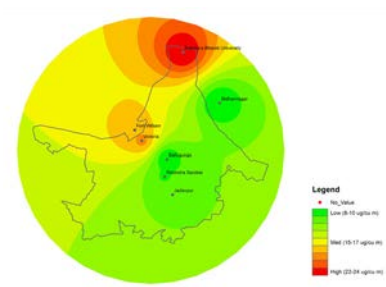
- North of the city was the most polluted for all three pollutants. Rabindra Bharati University had the highest average concentration for all three, while south Kolkata was the cleanest (see *Map 2, a: Spatial representation of NO_2 and ozone build-up in Kolkata – Lockdown average: March 25-May 31, 2020*).
- Most ozone exceedances were reported at Victoria (15 days) followed by Bidhannagar (11 days); Rabindra Bharati University was marked with zero exceedance.
- The worst ozone pollution during the lockdown occurred on April 4, 2020 in the city. Four stations exceeded the eight-hourly standard, with Bidhannagar (157 µg/m^3) being the worst. The cleanest station was Rabindra Bharati University (see *Map 2, b: Spatial representation of NO_2 and ozone build-up in Kolkata – Worst ozone pollution day: April 4, 2020*).

Map 2: Spatial representation of NO_2 and ozone build-up in Kolkata

a. Lockdown average: March 25-May 31, 2020

NO_2 (lockdown average)	Ozone (lockdown average)	Ozone (exceedance)
		

b. Worst ozone pollution day: April 4, 2020

Ozone (max 8-hr average)	NO_2 (24-hr average)
	

Source: CSE analysis based on CPCB data

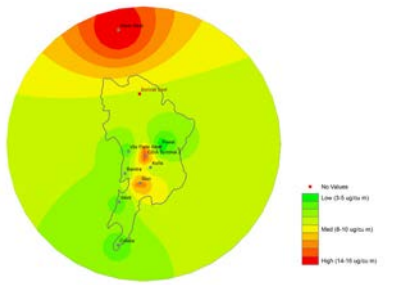
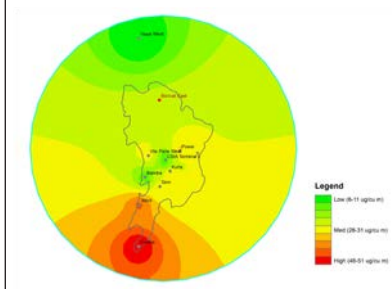
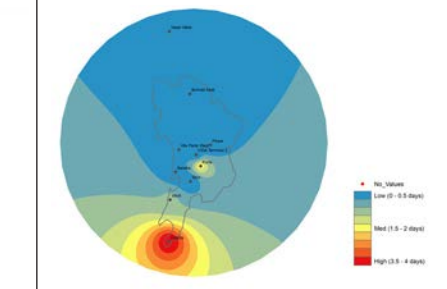
- Spatial map was almost reverse for NO_2, with Bidhannagar recording the lowest 24-hour concentration for the day, while Rabindra Bharati University had the highest.

Mumbai

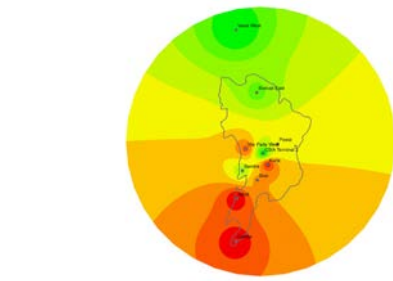
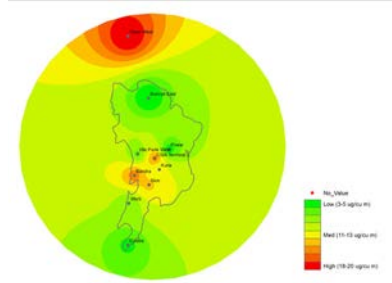
- NO_2 pollution was found to be the highest in Vasai West with a few hotspots in central Mumbai. Ozone concentrations were higher in the south. Though average concentration levels were medium ranged in central Mumbai, multiple days of ozone exceedances happened there as well. The city had distinct hotspots for all three pollutants (see *Map 3, a and b: Spatial representation of NO_2 and ozone build-up in Mumbai*).
- The worst ozone pollution during lockdown occurred on March 29, 2020 in the city. Three station exceeded the ozone standard, with the worst being the stations at Worli and Colaba. Vasai West registered the lowest eight-hour ozone average in the city.
- The spatial map was almost reverse for NO_2, with Colaba recording the lowest 24-hour concentration for the day, while Vasai West had the highest.

Map 3: Spatial representation of NO_2 and ozone build-up in Mumbai

a. Lockdown average: March 25-May 31, 2020

NO_2 (lockdown average)	Ozone (lockdown average)	Ozone (exceedance)
		

b. Worst ozone pollution day: March 29, 2020

Ozone (max 8-hr average)	NO_2 (24-hr average)
	

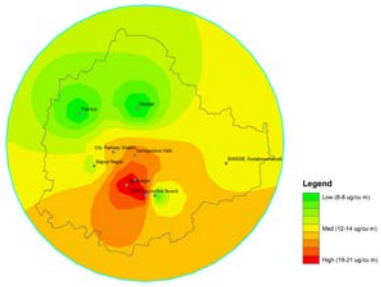
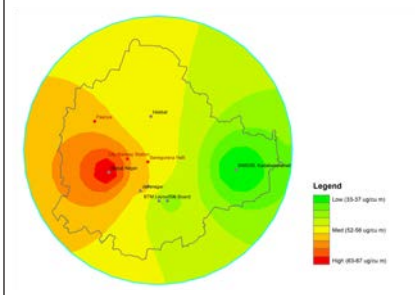
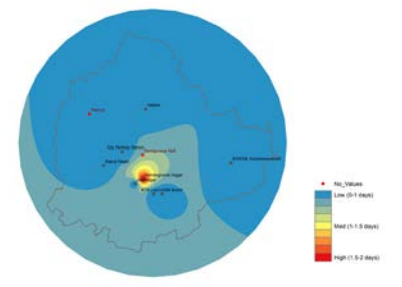
Source: CSE analysis based on CPCB data

Bengaluru

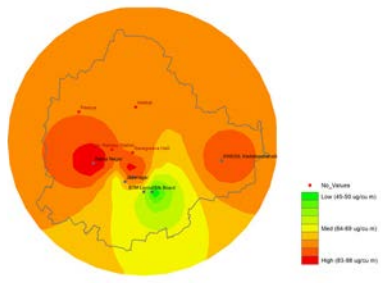
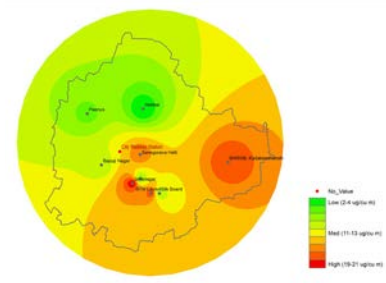
- Concentrations during the lockdown were exceptionally low for NO_2. The central and south-western parts were hotspots for NO_2 pollution. Ozone concentrations were higher in the west, but most of the exceedances happened in central Bengaluru. The city had distinct hotspots for both the pollutants (see *Map 4, a and b: Spatial representation of NO_2 and ozone build-up in Bengaluru).*

Map 4: Spatial representation of NO_2 and ozone build-up in Bengaluru

a. Lockdown average: March 25-May 31, 2020

NO_2 (lockdown average)	Ozone (lockdown average)	Ozone (exceedance)
		

b. Worst ozone pollution day: April 9, 2020

Ozone (max 8-hr average)	NO_2 (24-hr average)
	

Source: CSE analysis based on CPCB data

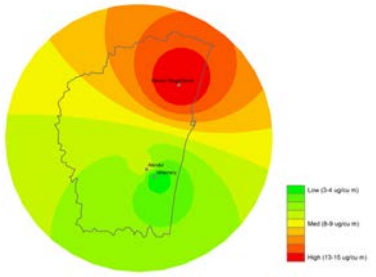
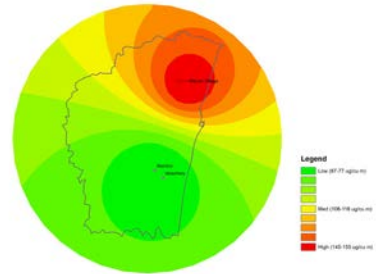
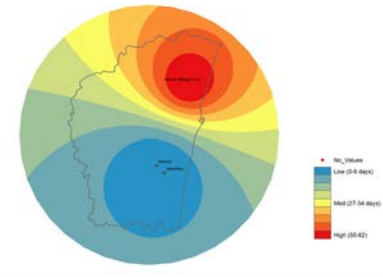
- The worst ozone pollution during lockdown occurred on April 9, 2020. One station, Hombegowda Nagar, exceeded the ozone eight-hour standard while the Silk Board and Jayanagar stations registered the lowest averages.
- The spatial map was almost reverse for NO_2, with Hombegowda Nagar recording the lowest 24-hour concentration for the day, while Jayanagar was the highest.

Chennai

- The city has only four stations of which two are located in the Manali Industrial Area to the north of the core city; the other two are in the southern part, but not far from each other. In other words, it is not the optimal number of stations or spatial distribution to understand pollution hotspots in the city.
- Concentration levels during the lockdown were found to be high in the Manali area for all three pollutants (see *Map 5 a and b: Spatial representation of NO_2 and ozone build-up in Chennai*).
- The worst ozone pollution during the lockdown occurred on May 22, 2020 in the city. Stations at Manali Village and Velachery exceeded the ozone eight-hour standard, while Alandur station had the lowest average.
- The spatial map for NO_2 had Velachery as the lowest 24-hour concentration for the day, while Manali had the highest. The city did not show a clear contrast between the hotspots for these two pollutants.

Map 5: Spatial representation of NO_2 and ozone build-up in Chennai

a. Lockdown average: March 25-May 31, 2020

NO_2 (lockdown average)	Ozone (lockdown average)	Ozone (exceedance)
		

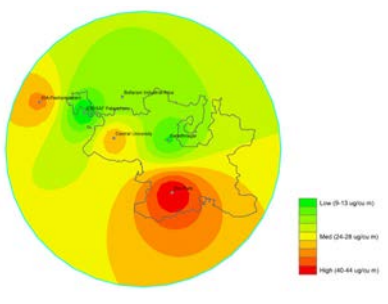
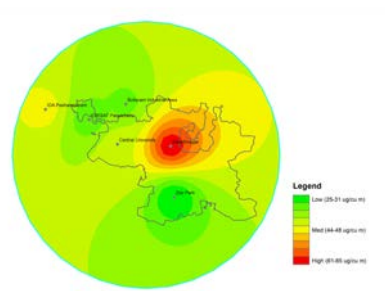
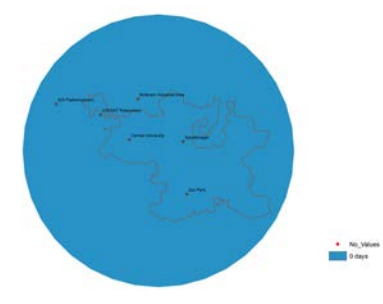
CSE analysis based on CPCB data

Hyderabad

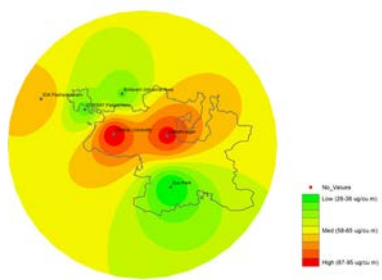
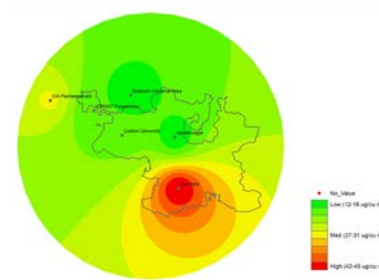
- Concentration levels during lockdown were exceptionally low for NO_2, but there was still considerable variation in levels among the six monitoring locations in the city (see *Map 6 a and b: Spatial representation of NO_2 and ozone build-up in Hyderabad*).
- Zoo Park station in southern Hyderabad was the most polluted for NO_2. ICRISAT was the cleanest among the city stations.
- Ozone concentrations were higher in the central part of the city with Sanathnagar witnessing the highest average concentration. The city recoded

Map 6: Spatial representation of NO_2 and ozone build-up in Hyderabad

a. Lockdown average: March 25-May 31, 2020

NO_2 (lockdown average)	Ozone (lockdown average)	Ozone (exceedance)
		

b. Worst ozone pollution day: May 25, 2020

Ozone (max 8-hr average)	NO_2 (24-hr average)
	

CSE analysis based on CPCB data

zero exceedances during the lockdown, and had different NO_2 and ozone hotspots.

- The worst ozone pollution during the lockdown occurred on May 25, 2020. No station exceeded the eight-hour standard, but the Sanathnagar and Central University stations registered concentrations above 90 µg/m^3. Zoo Park was the cleanest station for ozone on that day.
- The spatial map was almost reverse for NO_2, with Sanathnagar recording the lowest 24-hour concentration for the day, while Zoo Park was the highest.

DAILY OZONE TRENDS THROUGH THE LOCKDOWN

The impact of the lockdown on ozone levels was negligible in terms of daily maximum concentrations. But it is still worthwhile to analyse day-to-day variations in the level among cities. In order to avoid spatial averaging as it undercuts the severity of the problem, this analysis uses the 'maximum of the day' approach. Under this approach, the maximum eight-hourly average recorded among city stations is treated as the ozone value of the city for that day. It is acknowledged that this approach may systematically over-estimate the problem across geography. But it makes the point that given the nature of ozone pollution, it is necessary to take city-wide action to reduce its build-up in smaller pockets within the city.

This daily tracking has been done for all the four lockdown phases. The lockdown phases 1-3 witnessed complete lockdowns whereas phase 4 was a partial lockdown.

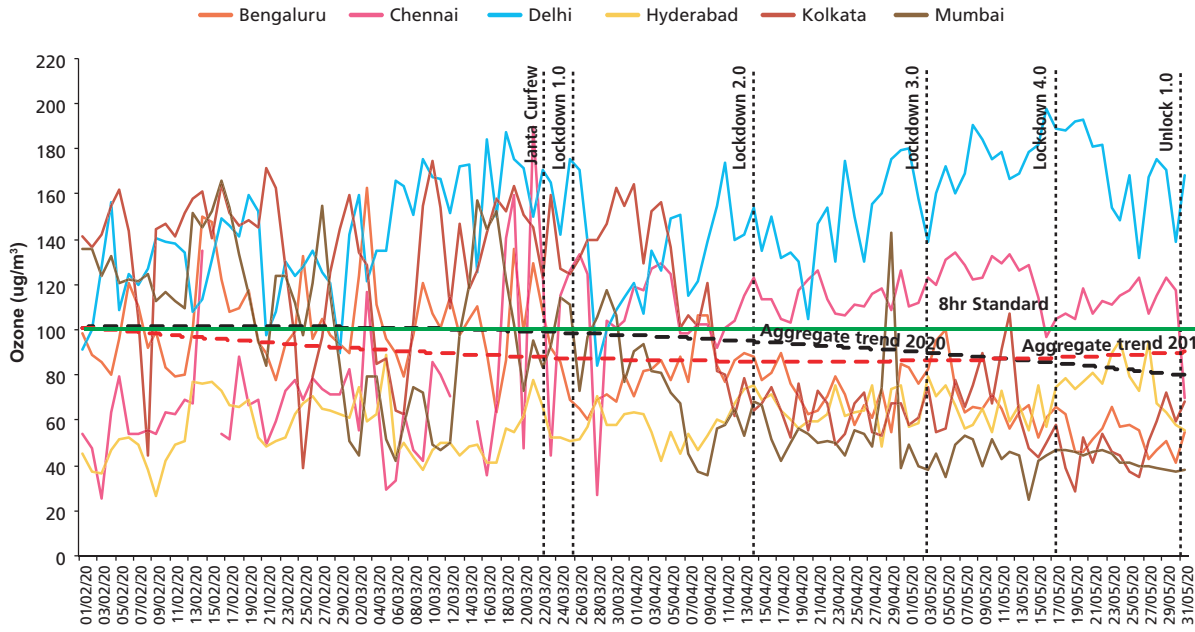
Mega cities

- In Chennai, Delhi and Hyderabad, the average daily maximum eight-hour level of ozone rose during the first three phases of the lockdown with a varied pace. Chennai and Delhi noted 10 per cent and 5 per cent lower levels respectively during lockdown 4.0 compared to their lockdown 3.0 levels. In Hyderabad the level continued to rise with increase in pace during lockdown 4.0. But unlike Delhi and Chennai, which had the daily maximum levels constantly above the standard, Hyderabad never breached the standard.
- Bengaluru and Mumbai had their daily maximum levels hovering around the standard mark during pre-lockdown, started observing a fall in their daily maximum levels with the start of the lockdown. The level continued to drop till the end of lockdown 4.0.
- Kolkata had a similar trend with a slight bump during lockdown 3.0, when it registered an average 6 per cent higher level than during its lockdown 2.0.
- It must be noted that the pre-lockdown period was highly polluted for all cities except Hyderabad. It was also equally chaotic with wild fluctuations among days. Lockdown seems to have reduced the chaos and made cities settle at frequencies and amplitudes unique to themselves (*see Graph 5*).

Tier-1 cities in Indo-Gangetic Plains

- In NCR cities, the average daily maximum eight-hour level of ozone rose for the first three phases of the lockdown at a varied pace. Faridabad and Gurugram noted 55 per cent and 17 per cent lower levels respectively during lockdown 4.0, compared to their lockdown 3.0 levels.

Graph 5: Daily maximum trends in ozone during the lockdown in mega cities



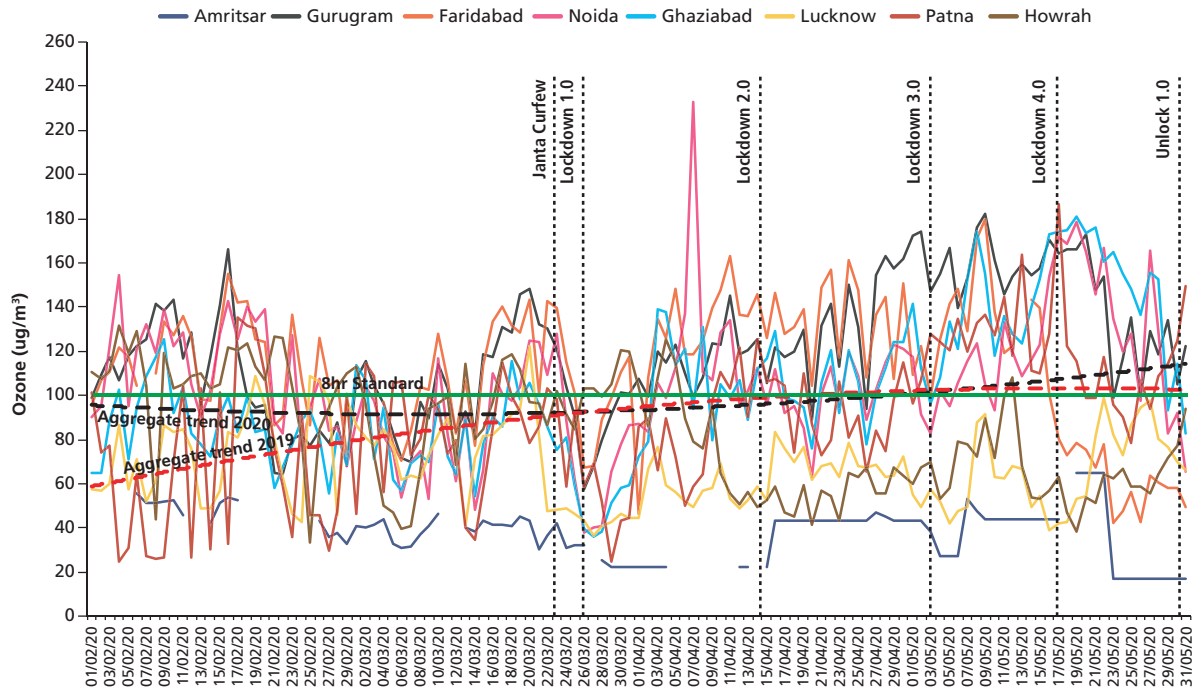
Source: CSE analysis based on CPCB data

- In the Uttar Pradesh side of the NCR, levels continued to rise with increased pace during lockdown 4.0. Gurugram had daily maximum levels constantly above the standard, while the other three NCR towns had their average levels above the standard in three out of four lockdown phases.
- Amritsar's data was poor during the lockdown, with multiple flat-lines.
- Lucknow and Howrah had multiple instances of standard exceedances during the pre-lockdown period, but they mostly remained within the standard during the lockdown.
- Patna stayed within the standard during the first two phases of lockdown, but its average levels were above the standard during lockdown 3.0 and 4.0.
- Just like mega cities, the IGP cities exhibit a pre-lockdown that was highly polluted for all cities except Amritsar. It was also equally chaotic but with synchronised fluctuations among days. In fact, the lockdown seems to have reduced the chaos and removed the synchronisation among cities (*see Graph 6*).

Tier-1 cities outside Indo-Gangetic Plains

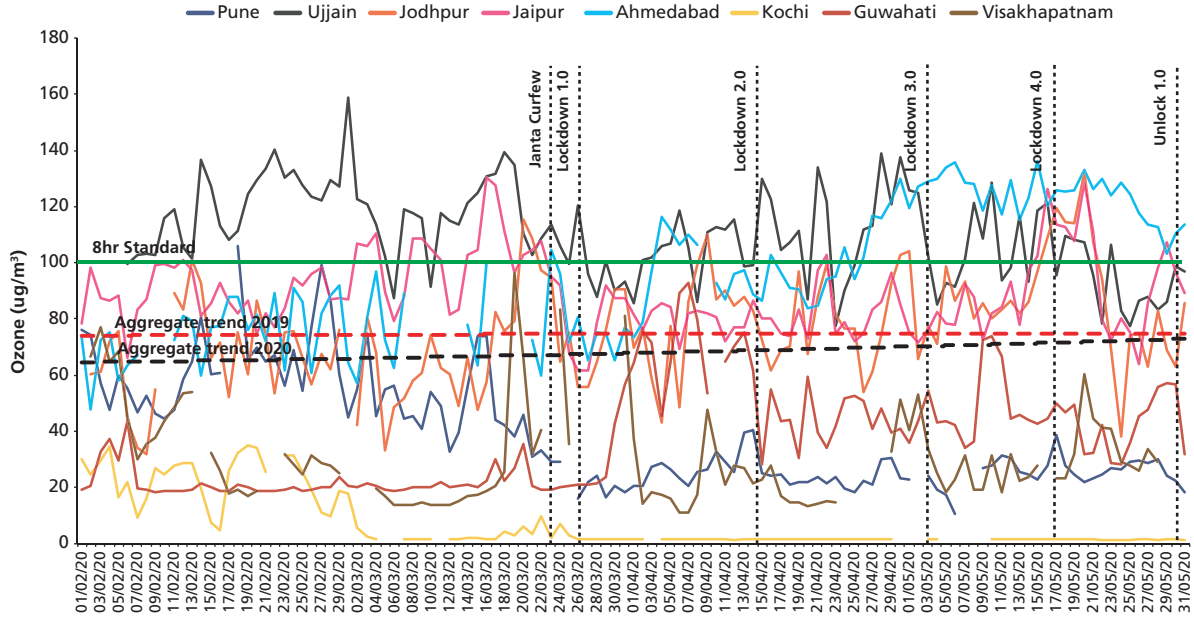
- Ahmedabad and Jodhpur's average daily maximum eight-hour level of ozone rose for the first three phases of lockdown at a varied pace. They marginally dropped by 5 per cent and 6 per cent respectively during lockdown 4.0, compared to their lockdown 3.0 levels.
- Jaipur recorded a 22 per cent drop in its average daily maximum eight-hour level during lockdown 1.0 compared to pre-lockdown, but its levels rose for the next three phases.
- Rest of the cities indicated no pronounced differences among the various phases of lockdown and pre-lockdown.
- Ujjain had the most polluted pre-lockdown period among the cities in this pool. Levels in Ujjain remained above the standard for the first three phases of lockdown and only settled marginally south of the standard in lockdown 4.0 (*see Graph 7*).

Graph 6: Daily maximum trends in ozone during lockdown in tier-1 cities in the Indo-Gangetic Plains



Source: CSE analysis based on CPCB data

Graph 7: Daily maximum trends of ozone during lockdown in tier-1 cities outside the Indo-Gangetic Plains



Source: CSE analysis based on CPCB data

OZONE LEADS DAILY AQI, OTHER POLLUTANTS DROP

Among the most commonly regulated pollutants in India are particulate matter less than 10 micron size and 2.5 micron size (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2) and sulphur dioxide (SO2); there are, however, 13 pollutants listed for ambient regulations. Several of these pollutants often do not meet their respective annual or daily standards in several cities but are masked by the excessively high particulate pollution in urban areas. As a result, the daily AQI is normally led by particulate pollution that indicates the severity of the pollution levels.

But in the summer of 2020, the ranks changed. With the dramatic collapse of concentration levels of particulate matter and also the other pollutants due to the lockdown, ozone has started to show up as the lead pollutant of the day in the daily AQI bulletin of the CPCB. This is evident in several cities. During April and May of 2020, ozone was the lead pollutant in the AQI bulletin in Chennai for 59 days, Delhi for 48 days and in Kolkata for 57 days. This is a considerable upswing from 10, 20 and three days respectively recorded in April and May of 2019 for these cities. In fact, a similar scenario has been noted in all the cities in this study.

But this is just a relative position. The AQI being driven by ozone does not mean its concentration level was exceeding the standard, at least as per the existing AQI reporting protocol. It simply indicates that other pollutants are much lower *vis-à-vis* their respective standards.

Further investigation of AQI data revealed that for most days when the AQI of a city was driven by ozone, AQI itself was in the 'satisfactory' category. This means that authorities need not activate provisions to inform people of health risk and launch measures to reduce its concentration.

NIGHT-TIME OZONE

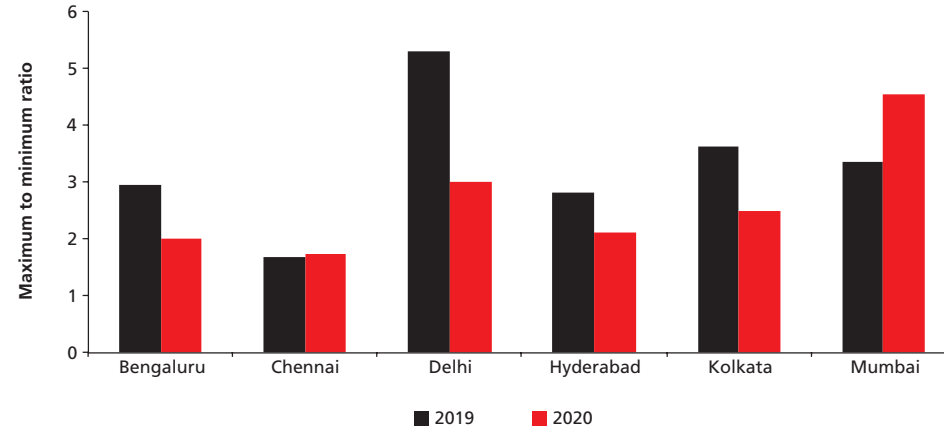
Ozone pollution is a daylight phenomenon. Ozone concentration falls dramatically during the night. But during the lockdown, NO_x formation during the evening traffic rush hour was greatly reduced. This means there was not enough NO_x to cannibalise ozone in most cities after sunset. Therefore, analysing night-time ozone is important to understand the impact of the lockdown.

This analysis uses the ratio of the maximum eight-hour concentration to the minimum eight-hour concentration of ozone recorded on a day in a city. Mean ratio for each station has been computed for the lockdown period and the corresponding period in 2019. These two periods are then compared to understand whether ozone is lingering at relatively higher concentrations during the night due to the lockdown compared to last year. High or low ratio value does not imply that ozone levels are high or low *vis-à-vis* the standard, nor does it tell if the night ozone concentration is at dangerous levels for human health. It simply measures the extent to which ozone is dissipating. But a low ratio does signal extended exposure to this pollutant.

Mega cities

- All inland mega cities show a drop in the ratio at the city-wide level, which implies that the ozone built up during day-time is dissipating at a rate 25-43 per cent lesser compared to 2019.

Graph 8: Lockdown mean ratio of daily maximum and minimum eight-hour average ozone in mega cities



Note: Average of only those stations that have valid data for both years 2019 and 2020 have been used for each city.

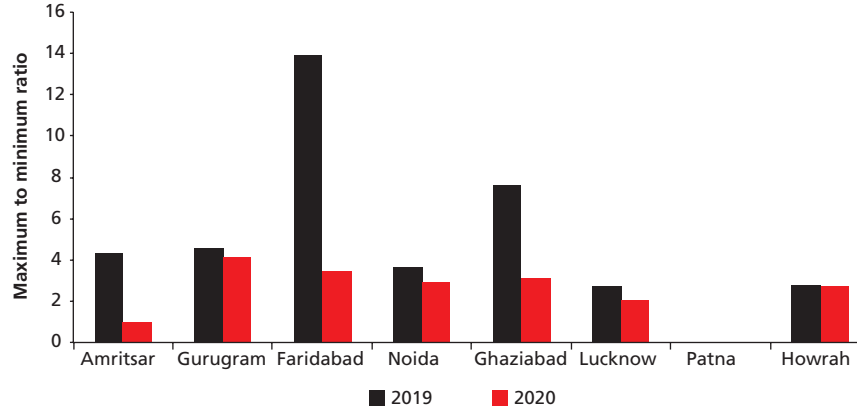
Source: CSE analysis based on CPCB data

- Chennai and Mumbai indicate 4 per cent and 36 per cent drop in the ratio, respectively (*see Graph 8*).
- Station-level analysis shows that the maximum drop is noted at stations located close to arterial roads. For instance, in Delhi, the stations at Jawaharlal Nehru Stadium, National Stadium, and Sri Aurobindo Marg had a ratio of 35, 33 and 29 respectively in April-May of 2019; but during the lockdown, it shrunk to 5.30, 3.07, and 7.78, respectively. Similarly, in Bengaluru, the station at BWSSB had a 7.86 ratio in 2019, but its ratio reduced to 2.99 during the lockdown. Absence of evening rush hour traffic which provided the NO_x needed to neutralise ozone can be attributed as the major reason for this change.

Tier-1 cities in Indo-Gangetic Plains

- All IGP cities show a drop in the ratio, which implies that the ozone built up during day time was dissipating at a 2-80 per cent lesser rate.
- Faridabad (80 per cent) had the highest reduction in the ratio, while Howrah (2 per cent) had the least (*see Graph 9*).
- Patna does not have any stations with data for both the years.

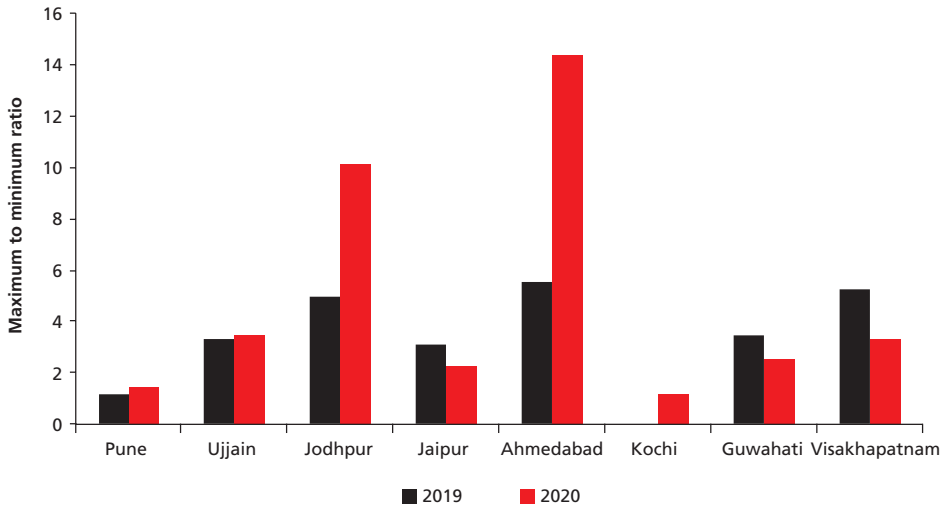
Graph 9: Lockdown mean ratio of daily maximum and minimum eight-hour average ozone – tier-1 cities in the Indo-Gangetic Plains



Note: Average of only those stations that have valid data for both years 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

Graph 10: Lockdown mean ratio of daily maximum and minimum eight-hour average ozone – tier-1 cities outside the Indo-Gangetic Plains



Note: Average of only those stations that have valid data for both years 2019 and 2020 have been used for each city

Source: CSE analysis based on CPCB data

Tier-1 cities outside Indo-Gangetic Plains

- Non-IGP cities are a mixed bag. The ratio dropped in Jaipur, Guwahati and Visakhapatnam, but it increased in the rest (*see Graph 10*).
- Ahmedabad indicated the maximum with the lockdown ratio being 159 per cent higher than its 2019 ratio; Jodhpur with a 105 per cent increase, ranked second.

PARTICULATE MATTER

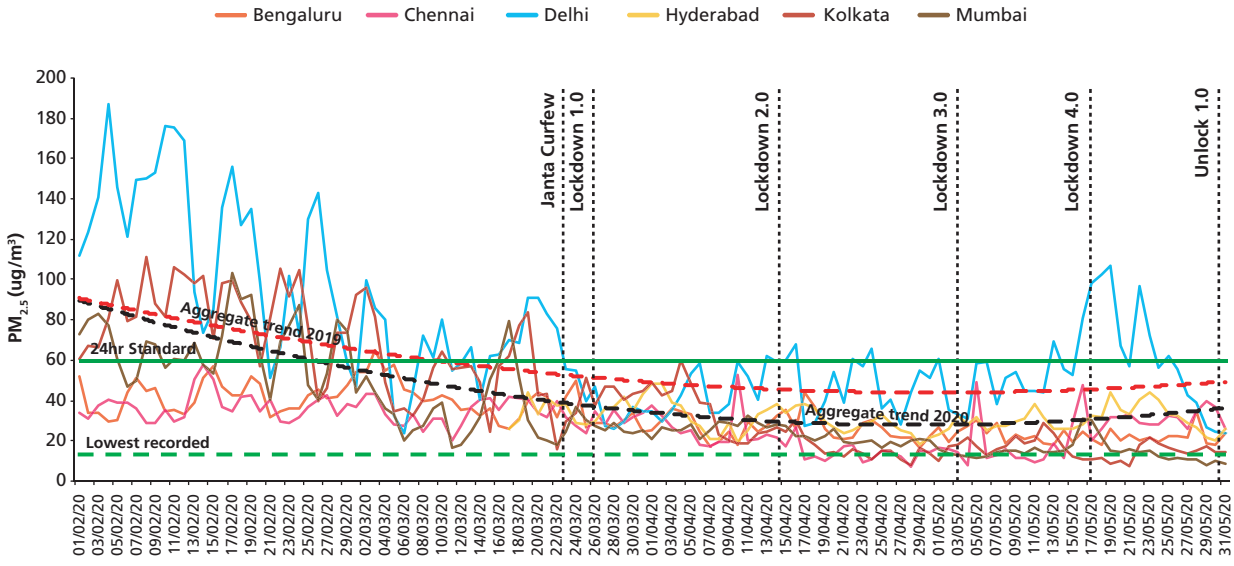
CHANGES IN DAILY $PM_{2.5}$ TRENDS DURING THE LOCKDOWN

The impact of lockdown phases on the daily $PM_{2.5}$ trend has been most dramatic. Local variation has been influenced by local lockdown rules and stringency of enforcement. This analysis has not attempted to establish causation of the $PM_{2.5}$ trends. Local meteorological events are expected to influence the trends; this analysis has not controlled for them. Trends have been established at an aggregate level instead of at the individual city level.

Mega cities

- The impact of the lockdown was felt immediately across all mega cities. The daily $PM_{2.5}$ average level during lockdown 1.0 was considerably lower than the pre-lockdown (March 1-21) average level. Bengaluru had a 35 per cent drop, Chennai 20 per cent, Delhi 37 per cent, Kolkata 34 per cent, and Mumbai had a 27 per cent decrease. Figures for Hyderabad could not be computed since all the six city stations did not have a valid 24-hourly average for the period of February 1 to March 16. Further, since the city went into a partial lockdown from March 17, this undercut the drop in concentration for lockdown 1.0 (*see Graph 11*).
- Levels continued to drop during lockdown 2.0 in Bengaluru (5 per cent), Chennai (48 per cent), Hyderabad (15 per cent), Kolkata (58 per cent), and Mumbai (26 per cent) – but Delhi registered a rise of 12 per cent in average $PM_{2.5}$ levels which can be attributed to a series of dust storms that battered the city during lockdown 2.0.
- All mega cities except Delhi had their average $PM_{2.5}$ levels drop down to

Graph 11: $PM_{2.5}$ daily trends through the lockdown – mega cities



Note: Trendlines are based on the average of only those stations that have valid data for both 2019 and 2020 across all cities.

Source: CSE analysis based on CPCB data

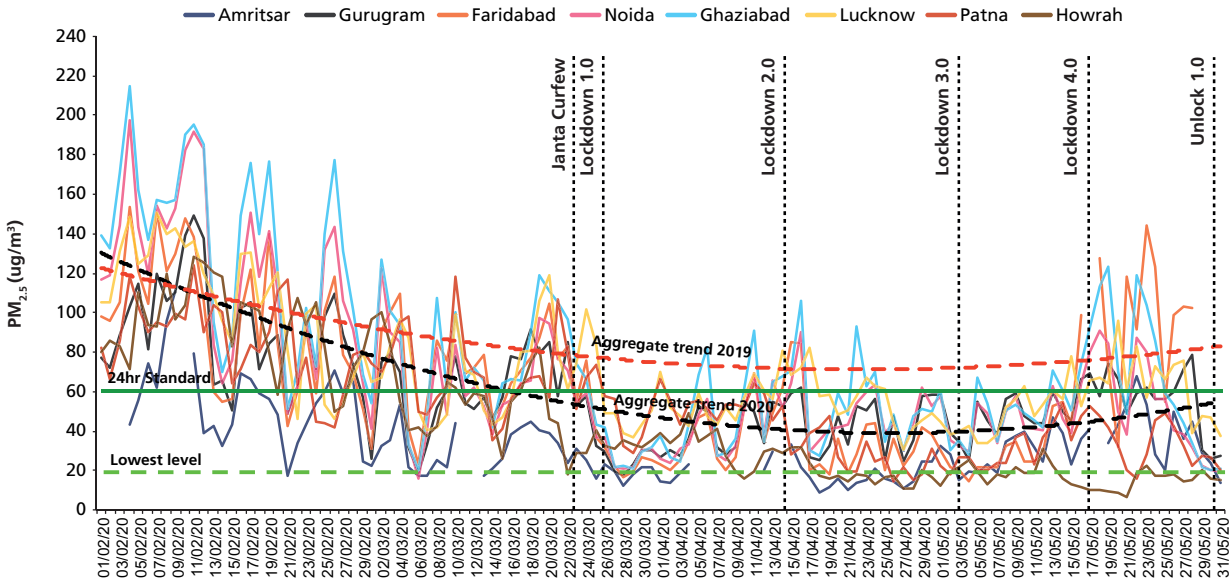
the 'Good' category of AQI (less than half the 24-hourly standard). The level remained in the 'Good' category during lockdown 3.0.

- Lockdown 3.0 allowed private mobility and partial reopening of offices and businesses. This increase in human activities showed up in a further increase in average $PM_{2.5}$ levels in Chennai (35 per cent), Delhi (20 per cent), Hyderabad (3 per cent) and Kolkata (13 per cent).
- Bengaluru and Mumbai did not relax lockdown during phase 3 and, therefore, were found to buck this upward trend; they registered a further drop of 11 per cent and 16 per cent in average $PM_{2.5}$ levels, respectively.
- Restrictions were further relaxed during lockdown 4.0 – Chennai (62 per cent), Delhi (7 per cent) and Hyderabad (12 per cent) got dirtier due to it.
- Delhi's lockdown 4.0 average $PM_{2.5}$ level climbed up to be at level with the 24-hour standard.
- Kolkata joined Bengaluru and Mumbai during lockdown 4.0 with a 19 per cent decline in its $PM_{2.5}$ average, but this was the impact of cyclone Amphan.
- Bengaluru and Mumbai registered a further drop of 5 per cent and 24 per cent in average $PM_{2.5}$ levels, respectively, due to non-adoption of lockdown relaxations.
- Daily fluctuations in $PM_{2.5}$ levels is noted to have reduced in all cities during the lockdown, except in Delhi.
- The cleanest days of the season were noted during lockdown 2.0 in Bengaluru (16 µg/m^3 on April 29), Chennai (7 µg/m^3 on April 28), Hyderabad (18 µg/m^3 on April 29) and Kolkata (8 µg/m^3 on April 28).
- Kolkata registered a marginally cleaner (less than 1 µg/m^3) $PM_{2.5}$ average on May 21, a day after the city was hit by cyclone Amphan.
- Mumbai registered its cleanest day during lockdown 4.0 on May 29 with a 24-hourly average of 8 µg/m^3.
- The cleanest day in Delhi was also recorded in lockdown 4.0 on May 30 when heavy rains washed down the city to a 24 µg/m^3 24-hourly average. Otherwise, the cleanest day without a major rain event was at 26 µg/m^3 that was registered on March 28.

Tier-1 cities in Indo-Gangetic Plains

- As in the mega cities, the impact of the lockdown was felt immediately across all IGP cities as well. The $PM_{2.5}$ average level during lockdown 1.0 was considerably lower than the pre-lockdown (March 1-21) average level.
- Amritsar (38 per cent), Gurugram (41 per cent), Faridabad (53 per cent), Noida (43 per cent), Ghaziabad (44 per cent) and Howrah (44 per cent) noted drops that exceeded the decreases in mega cities.
- Lucknow (23 per cent) and Patna (25 per cent) had relatively milder reductions (*see Graph 12*).
- Levels continued to further drop during lockdown 2.0 in Amritsar (6 per cent), Lucknow (1 per cent), Patna (49 per cent) and Howrah (44 per cent) – but NCR cities registered a rise in average $PM_{2.5}$ levels due to dust storms that battered the region. Gurugram, Faridabad, Noida and Ghaziabad saw a 23 per cent, 2 per cent, 30 per cent, and 22 per cent rise, respectively.
- Lockdown 3.0 allowed private mobility and partial reopening of offices and businesses. This showed up as an increase in average $PM_{2.5}$ levels in Amritsar (70 per cent), Gurugram (16 per cent), Faridabad (5 per cent), Noida (2 per cent), Ghaziabad (5 per cent) and Patna (29 per cent). Howrah and Lucknow saw negligible change in their levels.
- Lockdown 4.0 accelerated the rise of $PM_{2.5}$ with Faridabad registering a 166 per cent worsening of air quality.
- Amritsar (23 per cent), Gurugram (10 per cent), Noida (4 per cent), Ghaziabad

Graph 12: $PM_{2.5}$ daily trends through the lockdown – tier-1 cities in the Indo-Gangetic Plains



Note: Trendlines are based on the average of only those stations that have valid data for both years, 2019 and 2020, across all cities.

Source: CSE analysis based on CPCB data.

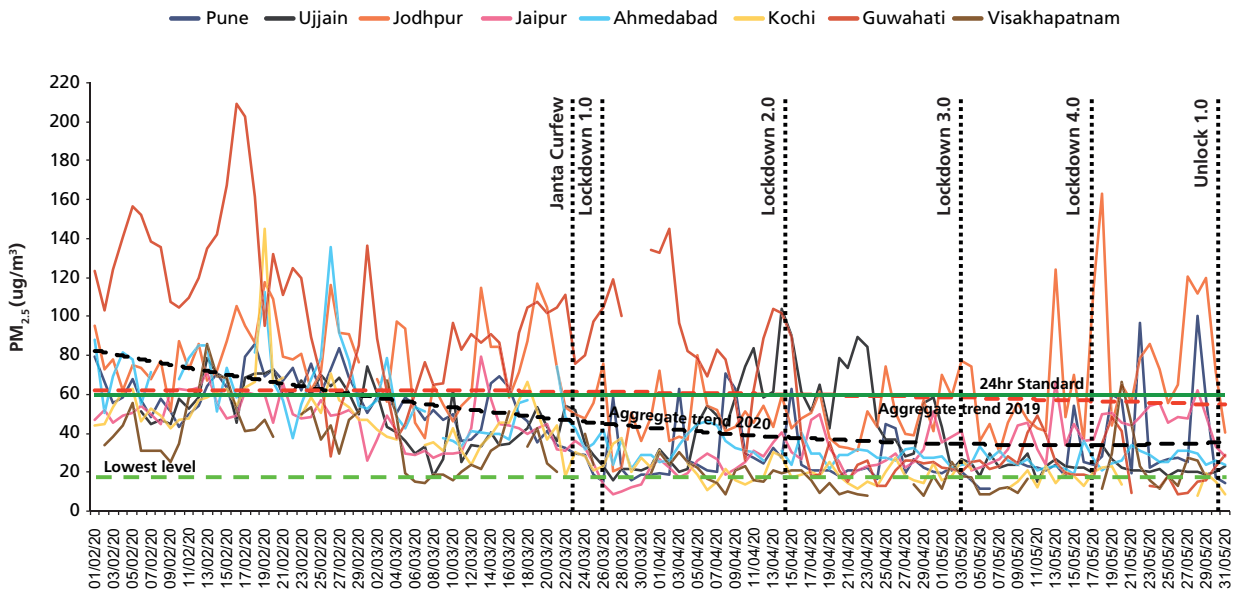
(19 per cent) and Lucknow (21 per cent) saw a rise in $PM_{2.5}$ average levels. The average for Faridabad, Ghaziabad and Lucknow breached the 60 µg/m³ mark.

- Cyclone Amphan impacted Patna and Howrah, resulting in a drop in $PM_{2.5}$ average in them by 7 per cent and 18 per cent, respectively.
- Daily fluctuations in $PM_{2.5}$ levels did not indicate a reduction among most IGP cities during the lockdown.
- The cleanest day of the season was noted during lockdown 1.0 in Gurugram (18 µg/m³ on March 28), Lucknow (31 µg/m³ on March 27), and Patna (14 µg/m³ on March 26).
- Lockdown 2.0 saw Amritsar (9 µg/m³ on April 18) and Faridabad (15 µg/m³ on May 4) register their cleanest days.
- The cleanest day in Noida and Ghaziabad was before the lockdown on May 30, when heavy rains washed the cities to a 20 µg/m³ 24-hourly average, same as in Delhi. Otherwise, the cleanest day without a major rain event was at 21 µg/m³ on March 28.

Tier-1 cities outside Indo-Gangetic Plains

- The lockdown had a varied impact on the non-IGP cities. The $PM_{2.5}$ average level during lockdown 1.0 was considerably lower than the pre-lockdown (March 1-21) average level in Ahmedabad (32 per cent), Jaipur (43 per cent), Jodhpur (34 per cent), Kochi (45 per cent), Pune (39 per cent), and Visakhapatnam (26 per cent).
- Guwahati and Ujjain, which had bucked the trend of the fall in $PM_{2.5}$ levels, registered an increase of 12 per cent and 5 per cent, respectively (*see Graph 13*).
- During lockdown 2.0, Guwahati (72 per cent) joined Ahmedabad (14 per cent), Kochi (17 per cent), Pune (15 per cent) and Visakhapatnam (34 per cent) as cities where $PM_{2.5}$ levels dropped.
- Meanwhile, a series of dust storms in north India made Jaipur (39 per cent) and Jodhpur (2 per cent) join Ujjain (27 per cent) in worsening of $PM_{2.5}$

Graph 13: $PM_{2.5}$ daily trends through the lockdown – tier-1 cities outside the Indo-Gangetic Plains



Note: Trendlines are based on the average of only those stations that have valid data for both years 2019 and 2020 across all cities.

Source: CSE analysis based on CPCB data

levels over lockdown 1.0.

- Lockdown 3.0's relaxations showed up as an increase in average $PM_{2.5}$ levels only in Guwahati (3 per cent), Jaipur (11 per cent) and Jodhpur (17 per cent). Rest continued to register cleaner air with $PM_{2.5}$ levels further down 7-56 per cent.
- Ujjain (56 per cent) finally registered a drop in $PM_{2.5}$ level, while Ahmedabad (9 per cent), Kochi (7 per cent), Pune (10 per cent), and Visakhapatnam (15 per cent) had relatively milder reductions.
- Lockdown 4.0 accelerated the rise of $PM_{2.5}$ with Visakhapatnam registering a 106 per cent worsening of air quality, followed by Pune (80 per cent), Jodhpur (42 per cent), Jaipur (35 per cent), and Ahmedabad (5 per cent).
- $PM_{2.5}$ levels continued to drop in Guwahati (21 per cent), Kochi (4 per cent) and Ujjain (4 per cent).
- The cleanest day of the season was noted during lockdown 1.0 for Jodhpur (20 µg/m³ on March 27) and Jaipur (9 µg/m³ on March 27). Visakhapatnam (8 µg/m³ on April 29) registered its cleanest day during lockdown 2.0.
- Pune (12 µg/m³ on May 6), Ujjain (15 µg/m³ on May 11) and Ahmedabad (19 µg/m³ on May 15) registered their cleanest days during lockdown 3.0. Kochi (8 µg/m³ on May 28), and Guwahati (8 µg/m³ on May 26) registered their cleanest days during lockdown 4.0.

CHANGE IN $PM_{2.5}$ EXCEEDANCES BETWEEN 2019 AND 2020

Low $PM_{2.5}$ concentration averages at city-wide levels over a season generally do not present a complete picture of short-term $PM_{2.5}$ exposure which has critical health implications. To understand the impacts of the lockdown, a short-term exposure assessment of daily $PM_{2.5}$ levels *vis-à-vis* the 24-hour standard was carried out for each city. This assessment compares the March 25-May 31 period for both 2019 and 2020. The assessment does not take into account the severity of the exceedance that is usually captured as AQI levels.

City-wide exceedance is also kept agnostic to variations in the number of stations represented in a given day, and is based on combined datasets for the whole city. This is reflective of the current CPCB practice of computing city-wide AQI. We acknowledge that it is not the most scientific method for this assessment, as a city-wide average is not a good measure of the extent of $PM_{2.5}$ exposure as it masks pollution hotspots. Therefore, an additional assessment of station-level exceedances has been incorporated. The worst long-term station's performance has been tracked to understand the trend. To further understand short-term exposures, city stations registering exceedances each day have been documented.

Mega cities

- Except Delhi, no mega city exceeded the $PM_{2.5}$ daily standard during the lockdown at a city-wide level. The number of days in Delhi when the standard was exceeded, however, went down by 75 per cent. But station-level data shows that all mega cities except Mumbai observed at least one day of exceedance. Delhi stood out with 50 days where at least one of the city stations exceeded the $PM_{2.5}$ daily standard – however, this was still a 25 per cent reduction over last year.
- Other cities recorded much higher reductions. Bengaluru, Chennai, Hyderabad, and Kolkata had 91 per cent, 88 per cent, 91 per cent, and 76 per cent lesser number of days respectively, with at least one city station exceeding the daily standard (*see Table 4*).

Tier-1 cities in Indo-Gangetic Plains

- Except Howrah, all IGP cities exceeded the $PM_{2.5}$ daily standard during lockdown at the city-wide level.
- Lucknow and Ghaziabad stood out with over 20 days of exceedances.
- Nevertheless, the number in these cities was still down by 62-95 per cent (*see Table 5*). Station-level data shows lesser improvement with a 26-63 per cent drop in the number of days that observed at least one day of exceedance.
- NCR cities, interestingly, noted considerably lesser number of such days than Delhi, which might be a function of the difference in the number of stations among these cities.
- Lucknow with 47 such days was comparable to Delhi.

Table 4: Change in number of days with $PM_{2.5}$ levels exceeding the standard – mega cities (March 25-May 31, 2020)

City	2019			2020		
	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station
Bengaluru	7	34	45	0	3	4
Chennai	4	25	33	0	2	4
Delhi	56	62	67	14	33	50
Hyderabad	1	10	11	0	1	1
Kolkata	11	17	17	0	2	4
Mumbai	0	0	0	0	0	0

Note: Long-term worst stations: Bengaluru – BTM Layout; Chennai – Manali; Delhi – Bawana; Hyderabad – Zoo Park; Kolkata – RB University; Mumbai – Bandra.

Source: CSE analysis based on CPCB data

Table 5: Change in number of days with $PM_{2.5}$ levels exceeding the standard – tier-1 cities in the Indo-Gangetic Plains (March 25-May 31, 2020)

City	2019			2020		
	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station
Amritsar	21	-	-	1	-	-
Gurugram	59	48	61	10	13	26
Faridabad	44	44	44	14	5	19
Noida	57	53	57	13	10	21
Ghaziabad	61	62	63	23	20	32
Lucknow	63	63	68	24	43	47
Patna	27	27	27	3	10	20
Howrah	8	7	10	0	1	1

Note: Long-term worst stations: Amritsar – Golden Temple; Gurugram – Gwal Pahari; Faridabad – Sector 16 A; Noida – Sector 62; Ghaziabad – Sanjay Nagar; Lucknow – Talkatora; Patna – IGSC; Howrah – Ghusuri

Source: CSE analysis based on CPCB data

Tier-1 cities outside Indo-Gangetic Plains

- Ahmedabad and Kochi do not show any day exceeding the daily average standard during the lockdown in 2020. Guwahati and Ujjain registered an increase in the number of days exceeding the standards compared to 2019 (*see Table 6*).
- Jaipur, Jodhpur, Pune and Visakhapatam registered 88 per cent, 67 per cent, 54 per cent, and 67 per cent reduction respectively in the number of days with exceedance, compared to the same period in 2019.
- Ahmedabad numbers came down from 42 days in 2019 to zero this year. Kochi did not have 2019 data.
- Jaipur is the only city with multiple stations in this pool, and recorded an 80 per cent reduction in the number of days when at least one of its three stations registered an exceedance.

Table 6: Change in number of days with $PM_{2.5}$ levels exceeding the standard – tier-1 cities outside Indo-Gangetic Plains (March 25-May 31, 2020)

City	2019			2020		
	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station	Exceedance: city-wide	Exceedance: worst station	Exceedance: any station
Ahmedabad	42	-	-	0	-	-
Guwahati	15	-	-	18	-	-
Jaipur	17	32	41	2	7	8
Jodhpur	64	-	-	21	-	-
Kochi	NA	-	-	0	-	-
Pune	13	-	-	6	-	-
Ujjain	9	-	-	11	-	-
Visakhapatnam	3	-	-	1	-	-

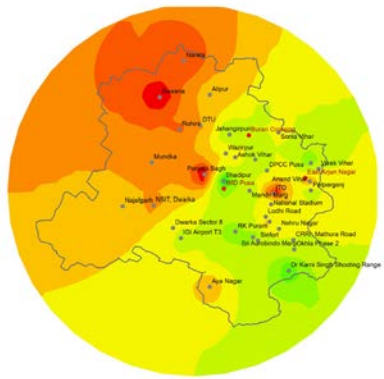
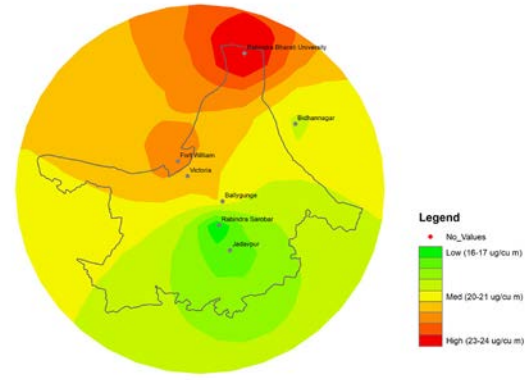
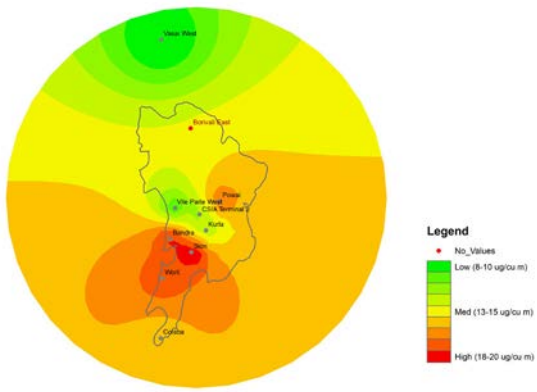
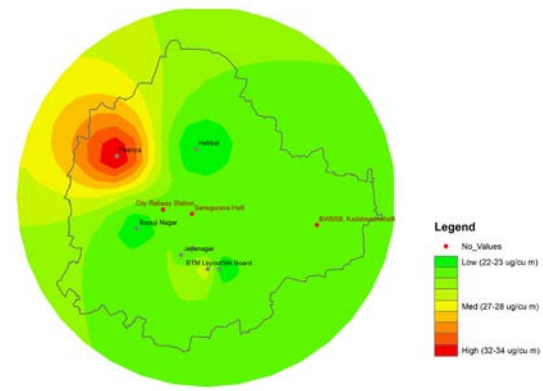
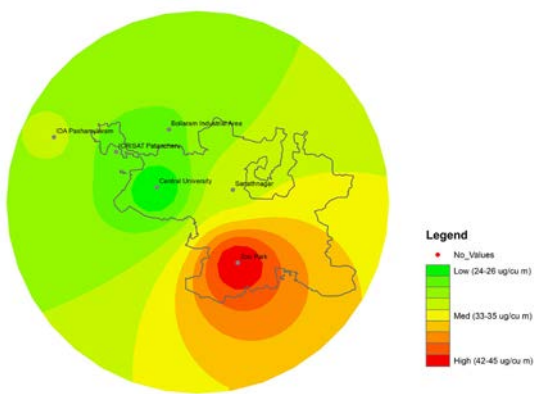
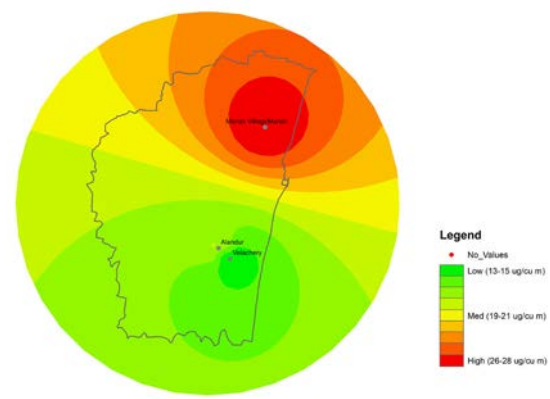
Note: Long-term worst stations: Only Jaipur has multiple stations and its Police Commissionerate station was deemed the worst station.

Source: CSE analysis based on CPCB data

Spatial mapping of $PM_{2.5}$ in mega cities

Mapping and visualisation of the particulate build-up across the city based on the average levels of $PM_{2.5}$ for the lockdown period brings out a certain pattern across cities (see *Map 7*). This shows that some parts of the city are still affected, while most of the city is a lot cleaner. Even though the overall pollution is low, some parts are more affected than others.

Map 7: $PM_{2.5}$ spatial build-up – average of March 25 to May 31, 2020

Delhi: $PM_{2.5}$ (lockdown average)	Kolkata: $PM_{2.5}$ (lockdown average)
	
Mumbai: $PM_{2.5}$ (lockdown average)	**Bengaluru: $PM_{2.5}$ (lockdown average)**
	
Hyderabad: $PM_{2.5}$ (lockdown average)	**Chennai: PM2.5 (lockdown average)**
	

Source: CSE analysis based on CPCB data

CHANGES IN LEVELS THROUGH THE SEASONS

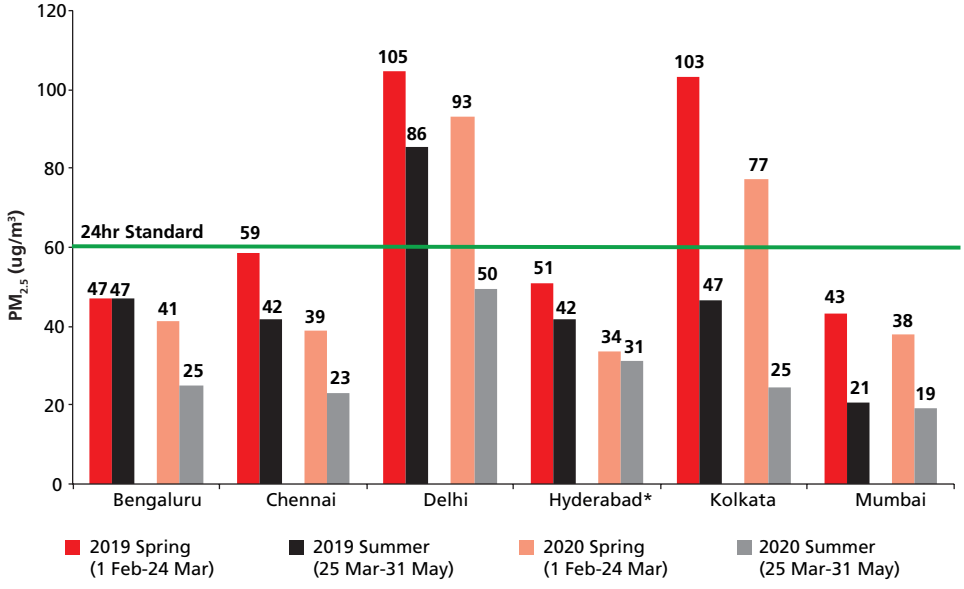
In most cities, spring (February and March) generally have higher $PM_{2.5}$ concentration levels compared to summer (April and May) due to changed weather conditions. Moreover, 2020 has been meteorologically abnormal with a delayed onset of summer and high rainfall that has resulted in considerable variations in $PM_{2.5}$ levels – this makes a comparison between 2019 and 2020 difficult.

Therefore, to access the impact of lockdown on $PM_{2.5}$ levels in cities, it was deemed useful to access the rate of change in pollution levels between the two seasons along with absolute concentration values. The study has not done modeling to statistically establish how much of the rate of change is due to various factors, but it assumes that it would be reasonable to attribute the variation in the rate of change between 2019 and 2020 to the lockdown.

Mega cities

- Overall, the year 2020 so far has been cleaner than 2019. The lockdown seems to have further reduced $PM_{2.5}$ average levels, which are 7-47 per cent lower in comparison to the same period in 2019.
- Bengaluru noted an astounding 62 times deeper reduction in $PM_{2.5}$ level during lockdown than in 2019. Chennai, Delhi and Kolkata witnessed 1.4 times, 2.6 times, and 1.2 times deeper reductions.
- Mumbai recorded a marginally lesser reduction (0.94 times) – but since the analysis for Mumbai is limited to just the Bandra station as it was the only station working in the spring and summer of 2019 (it has considerable data gaps in 2020), results for the city needed to be supplemented with other analysis.
- Similarly, the data for Hyderabad is not complete for this analysis (*see Graph 14*).

Graph 14: Seasonal variation in average daily $PM_{2.5}$ levels in mega cities



Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

The seasonal $PM_{2.5}$ pattern in mega cities

In 2019, the difference between spring and summer season was in the range of 1-55 per cent for mega cities. Bengaluru (1 per cent) recorded the least and Kolkata (55 per cent) the maximum change in $PM_{2.5}$ average levels between the two seasons. The difference in Chennai, Delhi, Hyderabad and Mumbai was 28 per cent, 18 per cent, 18 per cent, and 52 per cent, respectively.

This year (2020), the difference has been amplified to 39-68 per cent, with Bengaluru (39 per cent) recording the least and Kolkata (68 per cent) the maximum change. The difference in Chennai, Delhi, and Mumbai was 40 per cent, 47 per cent, and 49 per cent, respectively.

The levels could not be computed for Hyderabad, since all the six stations in the city did not have a valid 24-hourly average for the period February 1 to March 16, 2020; the city went into a partial lockdown from March 17. Therefore, the pre-lockdown data for the city is limited to just one week – even this data is related to partial lockdown conditions. The drop that has been noted between this and the lockdown period has been 8 per cent.

Tier-1 cities in Indo-Gangetic Plains

- 2020 has been cleaner than 2019 for most IGP cities. Pre-lockdown (spring of 2020) levels were lower in Amritsar (10 per cent), Gurugram (4 per cent), Noida (14 per cent), Ghaziabad (9 per cent), Lucknow (12 per cent), Patna (14 per cent) and Howrah (9 per cent).
- Faridabad bucked the trend as its pre-lockdown $PM_{2.5}$ average level was 7 per cent higher than its 2019 level.
- $PM_{2.5}$ average levels were also recorded as lower during the lockdown in comparison to the same period in 2019 in the seven cities. Amritsar, Gurugram, Faridabad, Noida, Ghaziabad, Lucknow and Howrah was 52 per cent, 53 per cent, 53 per cent, 46 per cent, 48 per cent, 40 per cent, and 38 per cent cleaner, respectively. The data for Patna was not complete for this comparison.

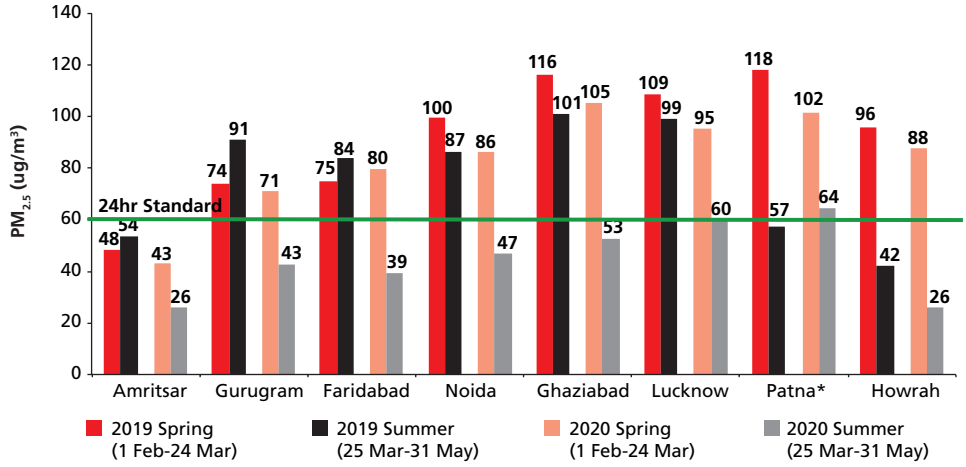
The seasonal $PM_{2.5}$ pattern in IGP cities

The 2019 data for cities in the IGP shows a marked difference in $PM_{2.5}$ trends between spring and summer as one moves from Amritsar to Howrah. The summer season in Punjab and Haryana was found to be dirtier than the spring of 2019. Amritsar, Gurugram and Faridabad had their April-May averages at 11 per cent, 23 per cent, and 12 per cent higher than their February-March averages, respectively. Neighboring Uttar Pradesh recorded a reverse trend in line with the one observed in Delhi and other mega cities. Noida, Ghaziabad and Lucknow's summer averages were 13 per cent, 13 per cent, and 9 per cent lower than the spring averages, respectively. The fall amplified as it travelled east with Patna and Howrah recording 51 per cent and 56 per cent lower averages for summer, respectively.

In 2020, the west-east divide disappeared – all cities registered a huge fall in their averages between spring and summer (lockdown). Howrah (67 per cent) recording the highest while Amritsar (20 per cent) had the lowest drop in $PM_{2.5}$ concentration levels between the two seasons. The difference in Gurugram, Faridabad, Noida, Ghaziabad, Lucknow and Patna was 43 per cent, 51 per cent, 48 per cent, 54 per cent, 40 per cent and 37 per cent, respectively (*see Graph 15*).

Patna registered a lower percentage drop this year compared to 2019: but it must be noted that the comparison has been based on a single station (IGSC), as it is the only station with data for both the years. This year, it stopped working from April 10, so the summer's average is limited to the lockdown 1.0 period.

Graph 15: Seasonal variation in average daily $PM_{2.5}$ levels in tier-1 cities in the Indo-Gangetic Plains



Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

- Amritsar, Gurugram and Faridabad noted an astounding reversal of 2019's rising trends to register a more than 40 per cent dip in $PM_{2.5}$ levels during the lockdown.
- Noida, Ghaziabad, Lucknow and Howrah noted 3.5 times, 3.8 times, 4.1 times, and 1.3 times deeper reductions, respectively. The data for Patna was incomplete.

Tier-1 cities outside Indo-Gangetic Plains

- Unlike in most mega cities and cities of the IGP, 2020 was not cleaner than 2019 for half of the cities in this pool. The spring (pre-lockdown) levels in 2020 were higher than those in 2019 summer in Guwahati (10 per cent), Jaipur (6 per cent), Jodhpur (15 per cent) and Ujjain (1 per cent).
- Pune and Ahmedabad were just marginally better with a 5 per cent and 2 per cent cleaner 2020, respectively. Visakhapatnam was 27 per cent cleaner (*see Graph 16*).

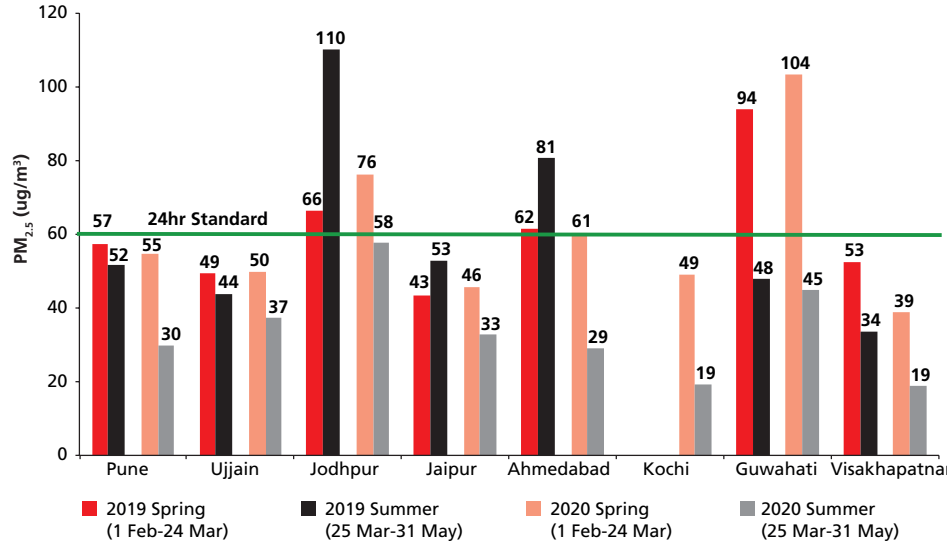
The seasonal $PM_{2.5}$ pattern in non-IGP cities

The summer season is dirtier than spring in Rajasthan and Gujarat, much like in Punjab and Haryana. In 2019, Ahmedabad, Jaipur and Jodhpur had their summer averages at 31 per cent, 22 per cent, and 66 per cent higher than their spring averages respectively. Rest of the non-IGP cities exhibited the trends seen in mega cities. Guwahati, Pune, Ujjain and Visakhapatnam's summer averages were 49 per cent, 9 per cent, 11 per cent and 36 per cent lower than their spring averages, respectively. Kochi did not have archival data for 2019 for this assessment.

In 2020, the divide between arid and non-arid has disappeared: all cities registered a massive fall in their $PM_{2.5}$ averages in summer as the lockdown brought all economic activities to a standstill. Kochi (61 per cent) recorded the highest drop, while Ujjain and Jodhpur (25 per cent) witnessed the lowest drops in $PM_{2.5}$ concentration levels between the two seasons. The drop in Ahmedabad, Guwahati, Jaipur, Pune and Visakhapatnam was 52 per cent, 57 per cent, 29 per cent, 45 per cent, and 52 per cent, respectively. Visakhapatnam and Kochi were the cleanest among the cities with a lockdown average $PM_{2.5}$ level at 19 $\mu g/m^3$.

- Kochi did not have data for 2019.
- The lockdown seems to have resulted in a considerably cleaner summer compared to 2019 in Ahmedabad (64 per cent), Guwahati (44 per cent), Jaipur (38 per cent), Jodhpur (48 per cent), Pune (42 per cent), Ujjain (6 per cent) and Visakhapatnam (44 per cent).
- Ahmedabad, Jaipur and Jodhpur noted an astounding reversal of 2019's rising trend to register a 25-52 per cent reduction in $PM_{2.5}$ levels during the lockdown.
- Guwahati, Pune, Ujjain and Visakhapatnam noted 1.2 times, 4.8 times, 2.4 times, and 1.4 times deeper reductions, respectively. Data from Kochi was incomplete for this comparison.

Graph 16: Seasonal variation in average daily $PM_{2.5}$ levels in tier-1 cities in the Indo-Gangetic Plains



Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

HOW TOXIC IS PARTICULATE POLLUTION?

Particulate matter has both natural and anthropogenic origins. Crustal PM or dust has higher component of PM_{10} and is generally non-toxic in its chemical composition. Anthropogenic PM is mostly $PM_{2.5}$ coming from fossil fuel combustion (directly or indirectly via chemical precipitation of gaseous pollutants) and is toxic in its chemical composition. What percentage of PM_{10} is $PM_{2.5}$ is, therefore, a good indicator of the toxicity level of any given PM concentration value. For instance, a low $PM_{2.5}$ percentage indicates dusty air quality with relatively high airborne crustal PM; the same $PM_{2.5}$ concentration with a higher $PM_{2.5}$ percentage indicates smoggy air quality with relatively higher toxicity coming mostly from anthropogenic PM. The former is registered during dust storms common in the summer season, while the latter is registered during winter smog episodes.

The $PM_{2.5}$ percentage varies with the season based on weather conditions that may influence amount of fugitive airborne dust in the atmosphere. The CSE study has computed average $PM_{2.5}$ percentage levels in 2019 and their standard deviations for each city. The study then looks at the average $PM_{2.5}$ percentage during the lockdown and compares it to the same period in 2019 and last

winter (December 1, 2019-January 31, 2020). The intent has been to understand the relative toxicity of PM pollution among cities, and how it was affected by the lockdown.

Mega cities

- $PM_{2.5}$ percentages in all mega cities during the lockdown were lower by 2-22 percentage points than observed during the winter season. The difference was the maximum in Delhi (22 percentage points) which has the most polluted winter among all the mega cities (*see Table 7*).
- Chennai does not have real-time PM_{10} data – therefore, this analysis could not be conducted for the city.
- Delhi (20-82 per cent) and Mumbai (17-62 per cent) had the highest range of daily $PM_{2.5}$ percentages observed within a year, implying the summer weather conditions in these cities significantly alter their crustal PM concentrations.
- Rest of the mega cities had relatively stable $PM_{2.5}$ percentage across the season, which is lower than Delhi's winter peak but considerably higher than Delhi's summer low.

Table 7: $PM_{2.5}$ percentage in PM_{10} – mega cities

	March 25-May 31, 2020 (lockdown)	March 25-May 31, 2019	December 1, 2019-January 31, 2020	Mean 2019
Bengaluru	45%	48%	47%	48% (+8%)
Chennai	-	-	-	-
Delhi	43%	36%	65%	47% (+13%)
Hyderabad	44%	37%	52%	47% (+9%)
Kolkata	46%	47%	50%	54% (+8%)
Mumbai	31%	25%	48%	34% (+11%)

Note: Value in parenthesis is standard deviation for the year 2019

Source: CSE analysis based on CPCB data

Tier-1 cities in Indo-Gangetic Plains

- The $PM_{2.5}$ percentage in all IGP cities during the lockdown was significantly lower by 7-36 percentage points than observed during winter. The difference was the most in Patna (36 percentage points) followed by Ghaziabad (32 percentage points) (*see Table 8*).
- Faridabad and Lucknow did not have real-time PM_{10} data – therefore, this analysis could not be conducted for either of the cities.
- Much like Delhi, IGP cities had a very high range (58-75 percentage points) of daily $PM_{2.5}$ percentages observed within a year, implying the summer weather conditions in these cities significantly alter their crustal PM concentrations. Howrah stood out with relatively a lower seasonal variation.

Tier-1 cities outside Indo-Gangetic Plains

- The $PM_{2.5}$ percentage in non-IGP cities during the lockdown was lower by 0-16 percentage points than observed during their winter season. The difference was the most in Ahmedabad (16 percentage points), but Jodhpur (0 percentage points), Jaipur (4 percentage points) and Kochi (2 percentage points) showed insignificant change (*see Table 9*).
- Pune's real-time PM_{10} data is of poor quality and therefore was not used in this analysis.

Table 8: $PM_{2.5}$ percentage in PM_{10} – IGP cities

	March 25-May 31, 2020 (lockdown)	March 25-May 31, 2019	December 1, 2019-January 31, 2020	Mean 2019
Amritsar	34%	48%	64%	53% (+11%)
Faridabad	-	-	-	-
Gurugram	41%	40%	58%	48% (+11%)
Noida	39%	34%	67%	46% (+14%)
Ghaziabad	38%	32%	70%	47% (+18%)
Lucknow	-	-	-	-
Patna	37%	-	73%	-
Howrah	45%	46%	52%	51% (+7%)

Note: Value in parenthesis is the standard deviation for the year 2019

Source: CSE analysis based on CPCB data

Table 9: $PM_{2.5}$ percentage in PM_{10} – non-IGP cities

	March 25-May 31, 2020 (lockdown)	March 25-May 31, 2019	December 1, 2019-January 31, 2020	Mean 2019
Ahmedabad	36%	30%	52%	46% (+13%)
Guwahati	57%	56%	65%	56% (+12%)
Jodhpur	49%	47%	49%	47% (+8%)
Jaipur	39%	37%	43%	44% (+7%)
Kochi	52%	-	54%	-
Pune	-	-	-	-
Ujjain	34%	28%	55%	44% (+14%)
Visakhapatnam	27%	30%	46%	40% (+12%)

Note: Value in parenthesis is the standard deviation for the year 2019.

Source: CSE analysis based on CPCB data

- Winter $PM_{2.5}$ percentage in non-IGP cities, except Guwahati (65 per cent), was considerably lower than in IGP cities. Non-IGP cities outside Rajasthan had a high range (50-69 percentage points) of daily $PM_{2.5}$ percentages observed within a year, implying the summer weather conditions in these cities significantly alter their crustal PM concentrations. Rajasthan cities stood out with relatively lower seasonal variations.

WAS THE LOCKDOWN PERIOD CLEANER THAN THE MONSOON SEASON?

$PM_{2.5}$ levels are naturally at their lowest during the monsoon season for all cities as long and frequent rain spells wash down the air. The lockdown happened during the summer season which is not the cleanest of the seasons for $PM_{2.5}$ pollution. This study has already established that for all cities, this summer – with its lockdown conditions – was significantly cleaner than the 2019 summer.

Nevertheless, the study did not control for changed meteorological conditions between the two years; therefore, it was considered worthwhile to compare the lockdown period with the monsoon season of 2019 to understand the impact. For this analysis, an average daily $PM_{2.5}$ concentration for 54 days of the first three phases of lockdown – from March 25 to May 17 – has been taken as a benchmark. Lockdown 4.0 has not been included as most cities resumed economic activities during this phase and $PM_{2.5}$ levels rose significantly compared to the earlier phases of lockdown. But in a few cities that did not relax restrictions for lockdown 4.0, the average dropped further.

To establish the cleanest contiguous 54 days before the lockdown during 2019-20, a rolling average of 54 days was computed and the lowest value was used for comparison. The study also noted the dirtiest contiguous 54 days before the lockdown.

Mega cities

- Chennai and Kolkata's average daily $PM_{2.5}$ for the contiguous 54 days during lockdown was the cleanest contiguous 54 days observed since January 1, 2019. It was cleaner than their monsoon season as well.
- Bengaluru and Delhi came within 20 per cent of their monsoon levels, while Mumbai and Hyderabad were significantly off from their monsoon lows (*see Table 10*).
- Lockdown was 54-91 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

Table 10: Average $PM_{2.5}$ analysis of 54 days – mega cities

	Dirtiest in 2019-20	Cleanest in 2019	Cleanest in lockdown
Bengaluru	52	21	24 (26)
Chennai	64	29	20 (21)
Delhi	205	38	46 (47)
Hyderabad	69	17	30 (31)
Kolkata	178	19	17 (25)
Mumbai	83	12	18 (22)

Notes: Values are in µg/m³. Number in parenthesis is the average of first three phases of lockdown (March 25-May 17, 2020)

Source: CSE analysis based on CPCB data

Tier-1 cities in Indo-Gangetic Plains

- Amritsar and Howrah were the cities in this pool whose average daily $PM_{2.5}$ for the contiguous 54 days during lockdown was the cleanest contiguous 54 days observed since January 1, 2019, including the monsoon season.
- Gurugram and Patna came within 20 per cent of their monsoon levels, while other NCR cities were observed to be 25-35 per cent higher than the monsoon level.
- Lucknow was significantly off from its monsoon lows (*see Table 11*).
- The lockdown was 68-88 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

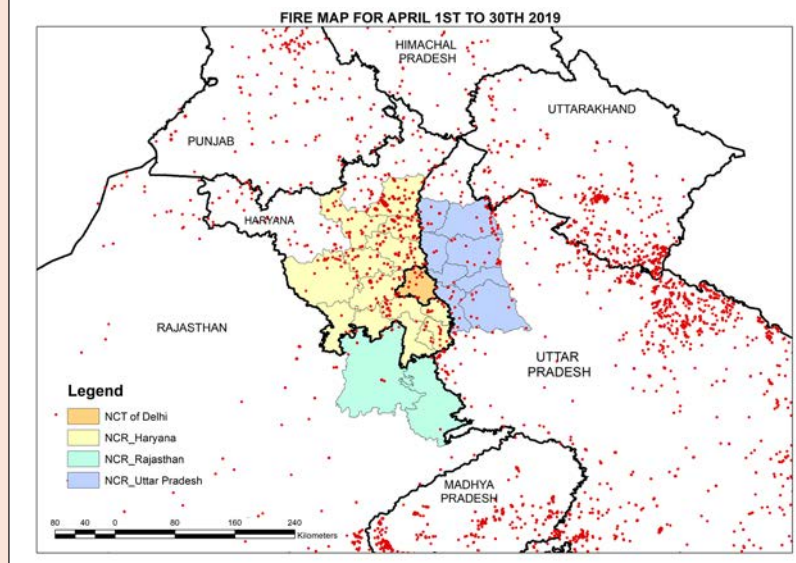
No one felt the crop fires during lockdown

Every winter, crop residue burning during the time of harvest hogs attention: this episodic pollution has a larger regional impact, especially under the influence of inversion and a cold and calm weather. Crop residues are also burnt in April when the rabi crop is harvested – however, during summer, high winds help with dispersion, though it still has an impact on air pollution levels in the region.

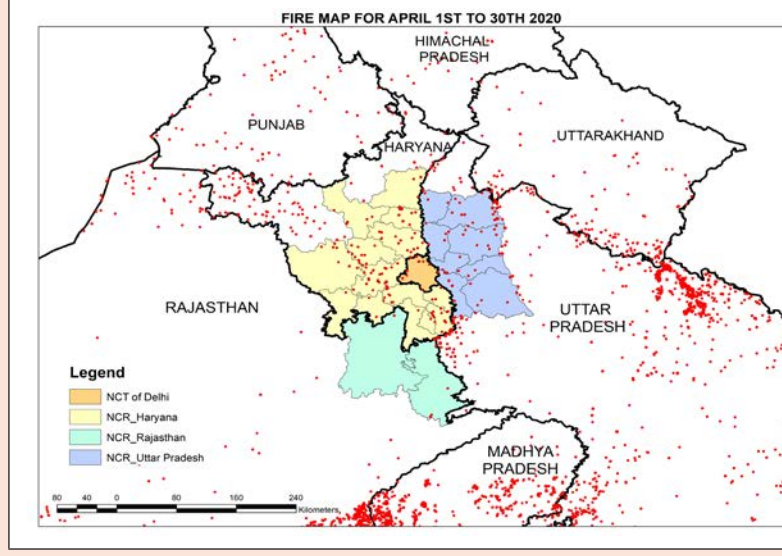
This year, the impact of crop residue burning during April went unnoticed by the general public, though it showed up in the air quality data. Despite extensive burning, the overall lower pollution levels regionally and within cities helped accommodate this periodic spurt.

Wind and clean air made the smoke disappear – farm fires (April 2019 vs April 2020 – cumulative for the month)

2019: NCR and beyond



2020: NCR and beyond



Source: NASA Fire Map (FIIRMS):

https://firms.modaps.eosdis.nasa.gov/map/#d:2020-05-09..2020-05-10;@71.1,7.8,3z

Table 11: Average $PM_{2.5}$ analysis of 54 days – IGP cities

	Dirtiest in 2019-20	Cleanest in 2019	Cleanest in lockdown
Amritsar	91	30	22 (22)
Gurugram	175	36	42 (42)
Faridabad	195	27	35 (35)
Noida	227	35	44 (44)
Ghaziabad	252	36	49 (50)
Lucknow	166	33	53 (54)
Patna	210	33	34 (39)
Howrah	157	27	18 (24)

Notes: Values are in µg/m³. Number in parenthesis is the average of first three phases of lockdown (March 25-May 17, 2020)

Source: CSE analysis based on CPCB data

Table 12: Average $PM_{2.5}$ analysis of 54 days – non-IGP cities

	Dirtiest in 2019-20	Cleanest in 2019	Cleanest in lockdown
Ahmedabad	94	41	28 (30)
Guwahati	144	22	32 (51)
Jaipur	69	28	28 (29)
Jodhpur	118	53	50 (51)
Kochi	53	-	18 (20)
Pune	80	20	27 (27)
Ujjain	77	18	39 (41)
Visakhapatnam	100	24	16 (17)

Notes: Values are in µg/m³. Number in parenthesis is the average of first three phases of lockdown (March 25-May 17, 2020)

Source: CSE analysis based on CPCB data

Tier-1 cities outside Indo-Gangetic Plains

- Ahmedabad, Jaipur, Jodhpur and Visakhapatnam were the cities in this pool whose average daily $PM_{2.5}$ for the contiguous 54 days during lockdown was the cleanest contiguous 54 days observed since January 1, 2019, including the monsoon season. Ahmedabad and Visakhapatnam were over 30 per cent cleaner during the lockdown compared to their monsoon lows – which was the highest among all cities in the study.
- Guwahati, Pune and Ujjain were significantly off from their monsoon lows, with Ujjain's lockdown average being more than double its monsoon low (*see Table 12*).
- The lockdown was 58-84 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

NITROGEN DIOXIDE

Nitrogen dioxide comes entirely from combustion sources. Therefore, closure of industry and stopping of traffic are expected to have a dramatic impact on its ambient concentration.

THE LEVELS AND HOW THEY FELL

To assess the impact of the lockdown on NO_2 levels in cities it was deemed useful to assess the rate of change in pollution levels between the two seasons – spring (February and March) and summer (April and May), in 2019 and 2020, along with absolute concentration values. The study has not done modeling to statistically establish how much of the rate of change is due to the lockdown. It is useful to see the difference between the same months in 2019 and 2020. The study does not attempt to statistically establish seasonal background levels, but has investigated how the levels recorded in these cities fared during the lockdown vis-à-vis the standard and monsoon levels (usually the lowest concentration noted in a year).

When the spring and summer seasons of 2019 and 2020 are compared, it shows that in 2019, the spring season generally had a higher NO_2 concentration level compared to the summer in most cities. Meteorology does redistribute the NO_2 concentration. However, the overall drop during these seasons in 2020 is quite substantial.

Mega cities

- The lockdown was observed to have abated the cleaning up of air between the seasons, with NO_2 average levels being recorded as 29-56 per cent lower during lockdown in comparison to the same period in 2019.
- Bengaluru, Chennai, Delhi, Hyderabad, Kolkata and Mumbai were cleaner by 56 per cent, 44 per cent, 54 per cent, 29 per cent, 47 per cent, and 53 per cent respectively.
- The trend reversed in Delhi: instead of a 5 per cent increase, it registered a 48 per cent reduction from spring to summer this year.

The seasonal NO_2 pattern in mega cities

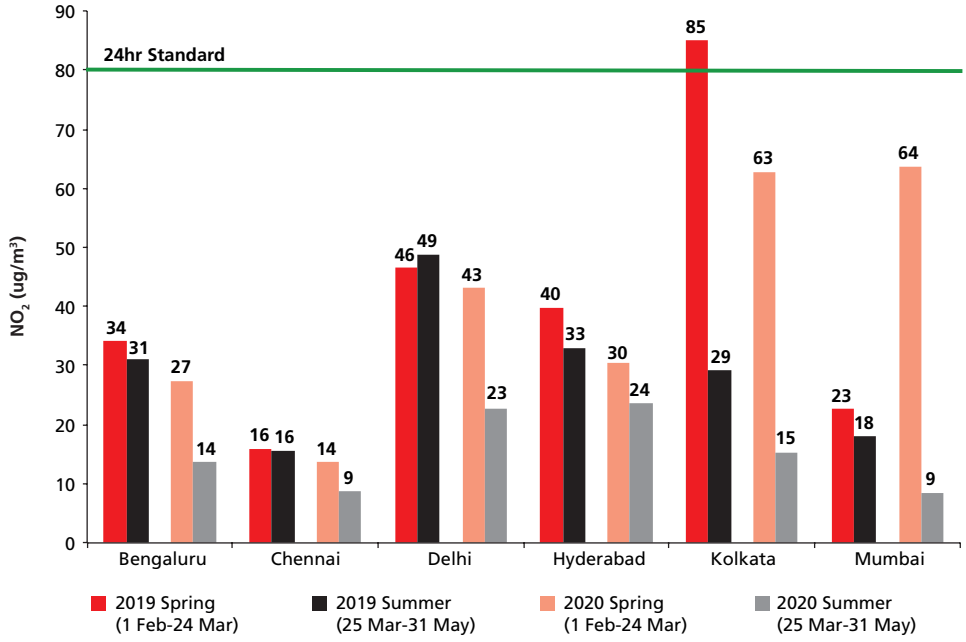
In 2019, all mega cities except Delhi registered a drop in average NO_2 levels between spring and summer. Kolkata saw a 66 per cent drop in levels, while Delhi witnessed a marginal increase of 5 per cent. The drop in Bengaluru, Chennai, Hyderabad and Mumbai was 9 per cent, 2 per cent, 17 per cent, and 20 per cent, respectively.

In 2020, the difference has been amplified to 27-87 per cent, with Hyderabad (23 per cent) recording the least and Mumbai (87 per cent) the most. The difference in Bengaluru, Chennai, Delhi and Kolkata was 51 per cent, 36 per cent, 48 per cent, and 75 per cent, respectively.

2020 has been a cleaner year than 2019 for all mega cities except Mumbai, with spring levels lower by 7-26 per cent. Bengaluru, Chennai, Delhi, Hyderabad and Kolkata were observed to be cleaner by 19 per cent, 14 per cent, 7 per cent, 24 per cent, and 26 per cent, respectively. Mumbai levels were observed to be an astounding 183 per cent higher compared to 2019 – the reasons for this have not been investigated as part of this analysis.

- Chennai noted an impressive 17.3 times deeper reduction in NO_2 level during lockdown than noted in 2019.
- Bengaluru, Hyderabad, Kolkata and Mumbai noted 5.9 times, 1.3 times, 1.15 times, and 4.3 times deeper reductions, respectively. The levels during the lockdown were the lowest recorded in each city among the four time periods analysed in the study (*see Graph 17*).

Graph 17: Seasonal variation in average daily NO_2 levels in mega cities



Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

Tier-1 cities in Indo-Gangetic Plains

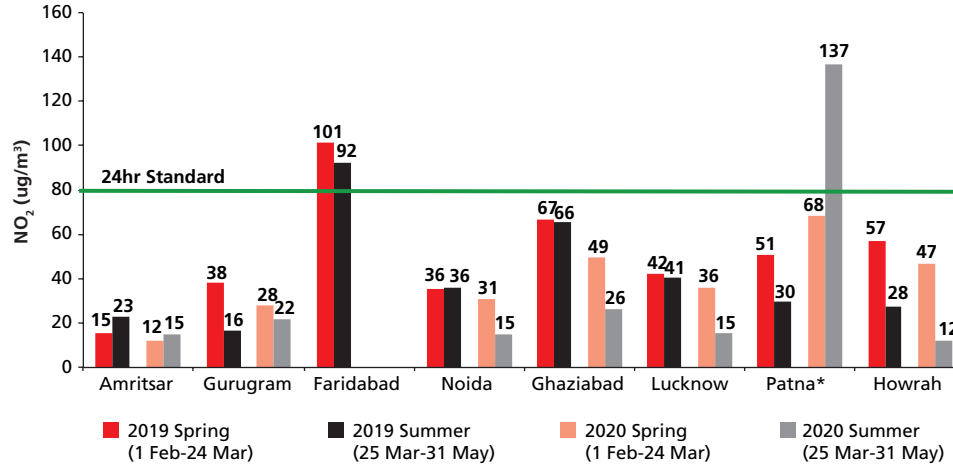
- 2020 has been a cleaner year than 2019 for all IGP cities, with the spring levels lower by 13-28 per cent (except in Patna, which was observed to have its 2020 levels 35 per cent higher).
- The lockdown has had a varied impact. Amritsar (35 per cent), Noida (58 per cent), Ghaziabad (60 per cent), Lucknow (63 per cent) and Howrah's (55 per cent) NO_2 average levels were recorded during the lockdown in comparison to the same period in 2019.
- Gurugram levels were found to be 32 per cent higher. Faridabad and Patna do not have adequate data in 2020 for comparable.
- The rising trend in Amritsar slowed down by 54 per cent between spring and summer this year.
- Noida noted over 38 times deeper reduction in NO_2 level during lockdown than in 2019.
- Ghaziabad, Lucknow and Howrah noted 26.2 times, 19.1 times, and 1.4 times deeper reductions respectively.
- Gurugram saw over 60 per cent slowing of reduction rate from its 2019 level (*see Graph 18*).

The seasonal NO_2 pattern in IGP cities

In 2019, Amritsar registered a 47 per cent increase in average NO_2 levels between spring and summer (probably due to burning of farm waste). Faridabad, Noida, Ghaziabad and Lucknow had noted marginal changes (less than 10 per cent) in their average NO_2 levels between the two seasons, while Gurugram and Patna saw a 57 per cent and 41 per cent drop in levels, respectively.

This year, the difference between the two seasons has been amplified for most IGP cities. Howrah (74 per cent) recorded the maximum drop in NO_2 levels, while Gurugram, Noida, Ghaziabad and Lucknow saw a drop of 22 per cent, 51 per cent, 47 per cent, and 58 per cent between the seasons, respectively (see Graph 18). Amritsar still noticed a rise in NO_2 level, though it was down to 21 per cent. Patna saw an increase in NO_2 at its long-term station (it stopped working after April 10) compared to 2019, but it must be noted that the comparison here is based on a single station (IGSC) as it is the only station with data for both the years – since it stopped working this year, the summer average is limited to lockdown 1.0 data. At the city-wide level, the average fell 51 per cent (this is with reference to the spatial average of all its current stations). Faridabad's long-term station at Sector 16 A has no NO_2 data for 2020.

Graph 18: Seasonal variation in average daily NO_2 levels in tier-1 cities in the Indo-Gangetic Plains



Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

Tier-1 cities outside Indo-Gangetic Plains

- 2020 has been dirtier than 2019 for most non-IGP cities.
- Guwahati, Jaipur, Jodhpur and Pune had higher spring levels than in 2019 – by 36 per cent, 43 per cent, 10 per cent, and 29 per cent respectively.
- Ahmedabad (32 per cent), Ujjain (14 per cent) and Visakhapatnam (21 per cent) had lower NO_2 levels during spring, as in the case of most of the mega cities and IGP cities.
- Nevertheless, in the summer of 2020, the NO_2 average level in all the cities of this pool was 16-71 per cent lower in comparison to same period in 2019.
- Ahmedabad had the maximum change: its summer was 71 per cent cleaner than the 2019 summer.
- Guwahati, Jaipur, Jodhpur, Pune, Ujjain and Visakhapatnam registered 27 per cent, 49 per cent, 43 per cent, 16 per cent, 23 per cent, and 18 per cent cleaner summer this year compared to 2019 (*see Graph 19*).

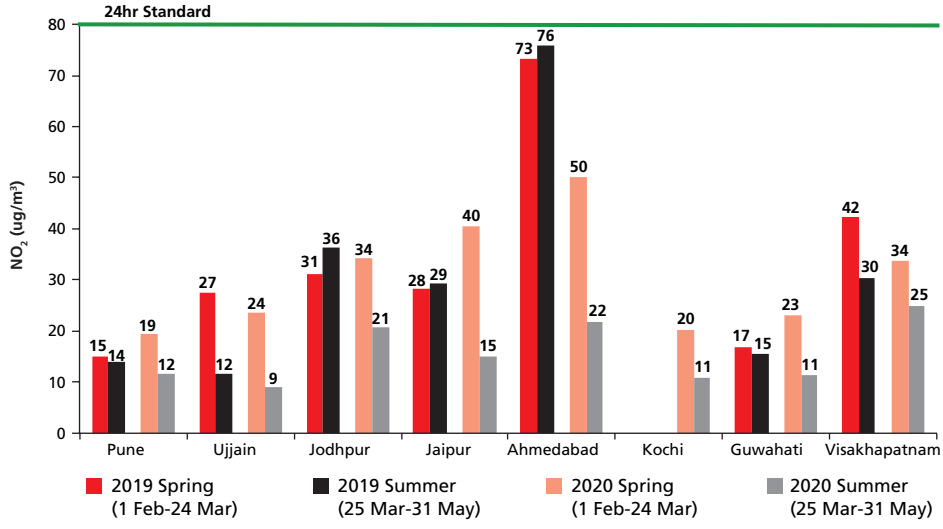
The seasonal NO_2 pattern in non-IGP cities

In 2019, Ahmedabad, Jaipur and Jodhpur registered a 3 per cent, 4 per cent and 17 per cent increase in average NO_2 levels between spring and summer. Cities outside the western arid zone noted a fall in their average NO_2 levels between the two seasons. Guwahati, Pune, Ujjain and Visakhapatnam saw an 8 per cent, 7 per cent, 58 per cent and 28 per cent drop in levels, respectively.

In 2020, all non-IGP cities registered a drop of 26-63 per cent. Jaipur (63 per cent) and Ujjain (62 per cent) recorded the maximum decreases, while Visakhapatnam saw the lowest drop of 26 per cent between the two seasons.

- The trend reversed in cities of the arid region. Ahmedabad, Jaipur and Jodhpur, instead of witnessing an increase in their summer NO_2 levels, r egistered a 56 per cent, 63 per cent and 39 per cent reduction, respectively, from spring to summer this year.
- Guwahati, Pune and Ujjain noted 6.2 times, 5.9 times, and 1.1 times deeper reductions. Visakhapatnam had no change in its rate of reduction, while Kochi did not have any data for 2019.
- The levels during the lockdown were the lowest recorded in each city among the four time periods analysed in the study.

Graph 19: Seasonal variation in average daily NO_2 levels in tier-1 cities outside the Indo-Gangetic Plains



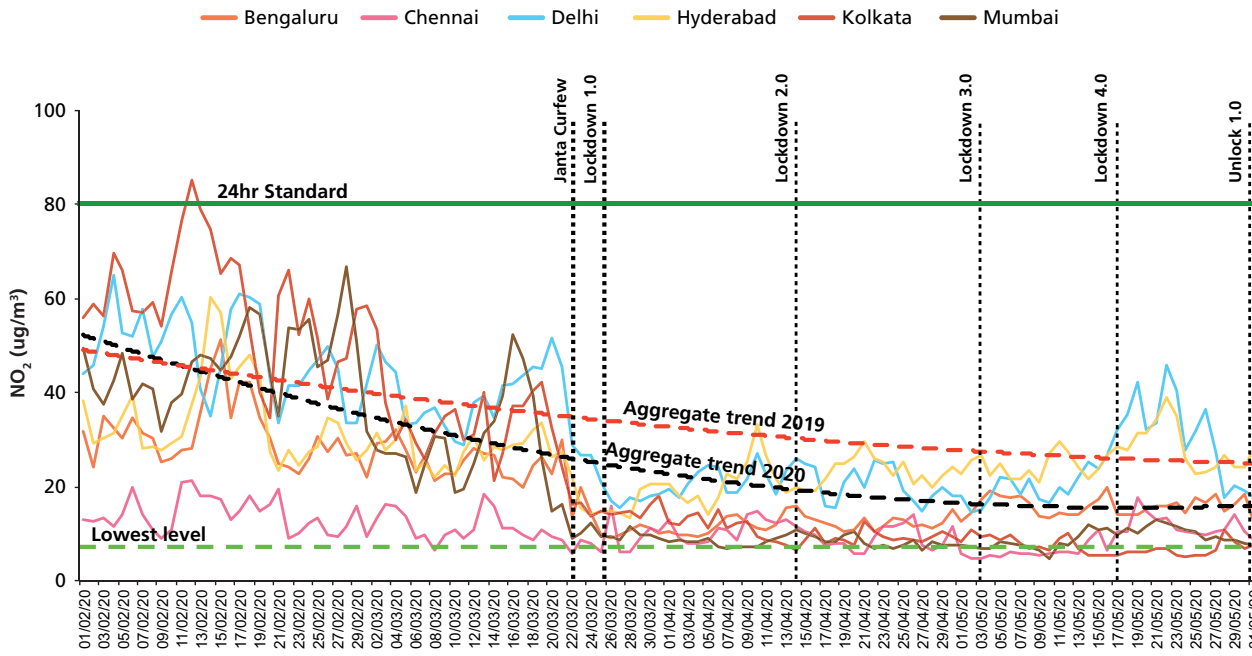
Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

DAILY NO_2 TRENDS DURING THE LOCKDOWN

Local variations in lockdown rules and stringency of its enforcement have shaped each city's NO_2 trends. NO_2 in cities is primary driven by vehicular traffic and industries (if there are any in and around the city). It is not influenced by weather-related dust sources, as is the case with particulate matter. Episodic burning can have a temporal impact on its trend. Thus, the impact of the lockdown on NO_2 levels is expected to be more pronounced than that observed on $PM_{2.5}$.

Graph 20: NO_2 daily trends through the lockdown – mega cities



Note: Trend lines are based on the average of only those stations that have valid data for both years, 2019 and 2020, across all cities.

Source: CSE analysis based on CPCB data

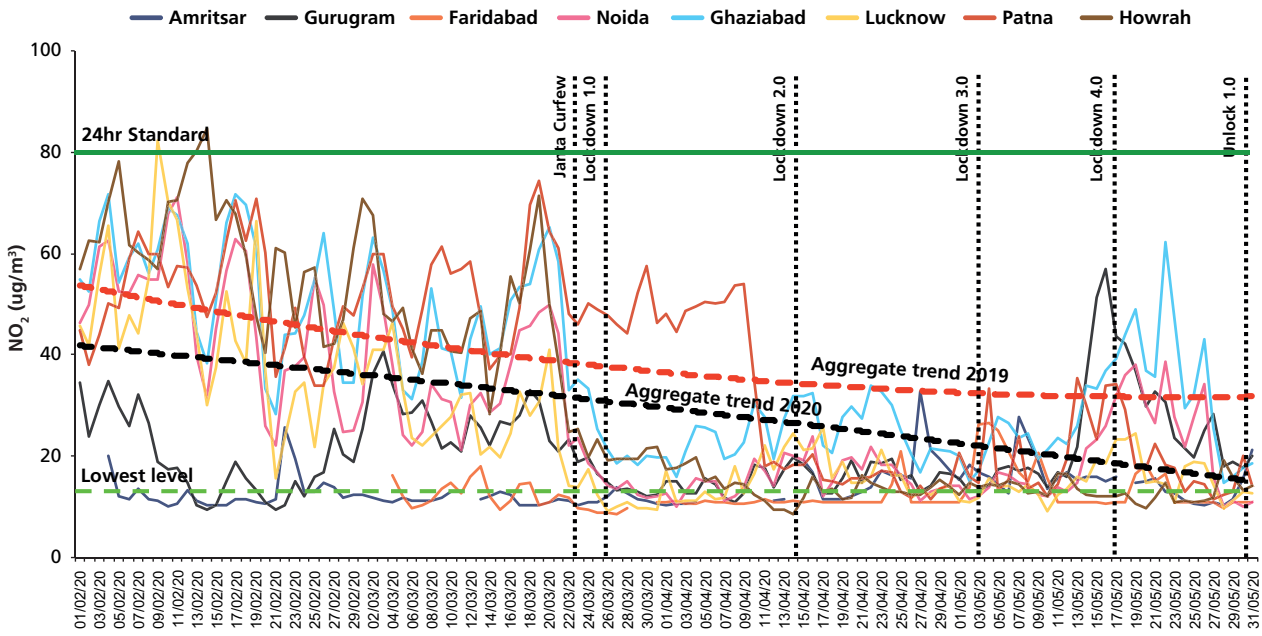
Mega cities

- The impact of the lockdown was felt immediately across all mega cities. The NO_2 average level during lockdown 1.0 was considerably lower than the pre-lockdown (March 1-24) average level.
- Bengaluru (55 per cent), Chennai (7 per cent), Delhi (49 per cent), Hyderabad (30 per cent), Kolkata (65 per cent), and Mumbai (70 per cent) – all noted a drop (*see Graph 20*).
- Levels continued to further drop during lockdown 2.0 in Chennai (19 per cent), Delhi (4 per cent), Kolkata (25 per cent), and Mumbai (8 per cent); but Bengaluru and Hyderabad registered a rise of 11 per cent and 20 per cent in average NO_2 levels, respectively.
- Lockdown 3.0 allowed private mobility and partial reopening of offices and business. This showed up as an increase in average NO_2 levels in Bengaluru (28 per cent), Delhi (10 per cent), Hyderabad (4 per cent) and Mumbai (3 per cent).
- Chennai and Kolkata bucked the increasing trend and registered further fall of 20 per cent and 21 per cent, respectively, indicating that people in the city did not really step out to take advantage of the easing of restrictions.
- Lockdown 4.0 saw a further relaxation of restrictions, which showed up as an aggressive rise in NO_2 levels in Chennai (77 per cent), Delhi (41 per cent), Hyderabad (16 per cent) and Mumbai (21 per cent).
- Bengaluru experienced negligible change, while Kolkata registered a further drop of 10 per cent. The continuing dip in Kolkata can be seen as an impact of cyclone Amphan which halted the reopening of the city.

Tier-1 cities in Indo-Gangetic Plains

- The NO_2 average level during lockdown 1.0 was lower than that in the pre-lockdown (March 1-21) period in all IGP cities.
- Amritsar (1 per cent), Gurugram (48 per cent), Faridabad (18 per cent),

Graph 21: NO_2 daily trends through the lockdown – tier-1 cities in the Indo-Gangetic Plains



Note: Trend lines are based on the average of only those stations that have valid data for both years, 2019 and 2020, across all cities.

Source: CSE analysis based on CPCB data

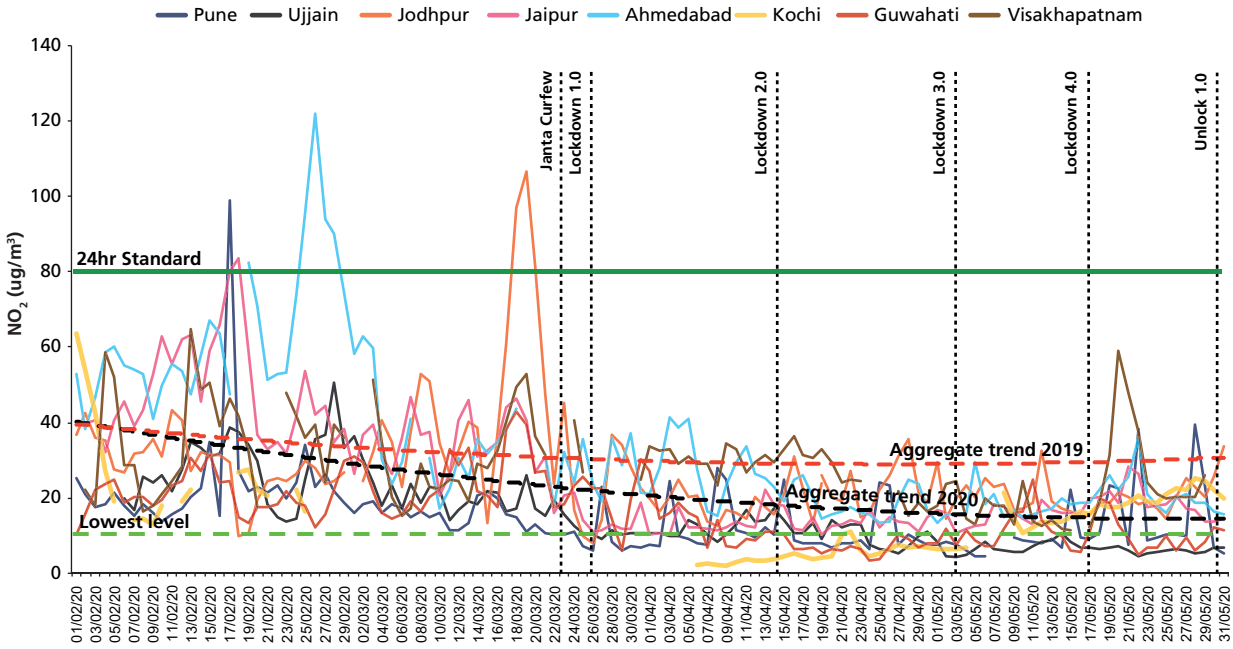
Noida (59 per cent), Ghaziabad (53 per cent), Lucknow (53 per cent), Patna (20 per cent), and Howrah (67 per cent) – all noted a drop (*see Graph 21*).

- Levels started to rise during lockdown 2.0 in all the northern IGP cities led by Amritsar with a 47 per cent increase in its NO_2 average from the lockdown 1.0 level. Others noted a 9-20 per cent increase.
- The eastern IGP cities of Patna (64 per cent) and Howrah (17 per cent) witnessed further drops.
- Lockdown 3.0 allowed private mobility and partial reopening of offices and businesses. This showed up as an increase in average NO_2 levels in most IGP cities.
- Gurugram (61 per cent), Faridabad (23 per cent), Noida (9 per cent), Ghaziabad (11 per cent) and Patna (34 per cent) noted an increase in the levels. Amritsar, Lucknow and Howrah had negligible change.
- Lockdown 4.0 saw a further relaxation of restrictions, but IGP cities had a highly varied reaction *vis-à-vis* change in their NO_2 levels. Noida (39 per cent) and Ghaziabad (24 per cent) were the only cities that showed a significant rise in their levels. Gurugram and Lucknow registered marginal increases.
- Amritsar (21 per cent), Faridabad (19 per cent), Patna (25 per cent) and Howrah (7 per cent) witnessed a drop in levels. Continuing drop in Howrah can be seen as impact of cyclone Amphan, but the deep cut in the northern cities needs further investigation (changes in farm waste burning can be one of the probable reasons).

Tier-1 cities outside Indo-Gangetic Plains

- The NO_2 average level during lockdown 1.0 was lower than that in the pre-lockdown period (March 1-21) in all the non-IGP cities.
- Ahmedabad (22 per cent), Guwahati (40 per cent), Jaipur (62 per cent), Jodhpur (58 per cent), Pune (26 per cent), Ujjain (44 per cent) and Visakhapatnam (4 per cent) noted a drop.

Graph 22: NO_2 daily trends through the lockdown – tier-1 cities outside the Indo-Gangetic Plains



Note: Trend lines are based on the average of only those stations that have valid data for both years, 2019 and 2020, across all cities.

Source: CSE analysis based on CPCB data

- Kochi had no data for March 1-24, 2020, but if compared with NO_2 levels of February 2020, lockdown 1.0 in the city was 84 per cent cleaner (*see Graph 22*).
- Levels rose during lockdown 2.0 in Jaipur (2 per cent), Jodhpur (18 per cent), and Kochi (92 per cent). Levels continued to drop in Ahmedabad (36 per cent), Guwahati (53 per cent), Pune (10 per cent), Ujjain (19 per cent) and Visakhapatnam (14 per cent).
- Lockdown 3.0 allowed private mobility and partial reopening of offices and businesses. This showed up in the most dramatic way in Kochi, where the average NO_2 level jumped up by 124 per cent compared to lockdown 2.0 levels.
- Ahmedabad (1 per cent), Guwahati (58 per cent) and Jaipur (15 per cent) noted an increase as well.
- But Jodhpur (10 per cent), Pune (16 per cent), Ujjain (24 per cent) and Visakhapatnam (40 per cent) registered a drop in average NO_2 levels.
- Lockdown 4.0 saw a further relaxation of restrictions and the NO_2 levels reflected it in most of the cities in this pool. Visakhapatnam, with an 89 per cent jump, led the pack followed by Pune with an 81 per cent increase.
- Ahmedabad (16 per cent), Jaipur (21 per cent), Jodhpur (4 per cent) and Kochi (49 per cent) registered a rise in their levels as well. Guwahati (12 per cent) and Ujjain (15 per cent) saw a drop.

THE HOURLY NO_2 PATTERN DURING LOCKDOWN

NO_2 levels are known to mimic the traffic volume curve in urban centers through the day. This is because vehicles are among the key contributors of NO_2 in cities. This build-up in NO_2 levels during rush hours worsens public exposure to its harmful effects, as people are forced to breathe it while they are

stranded in traffic. With the lockdown removing most non-essential vehicles and movement from the city roads, the measure was expected to flatten the NO_2 curve as well.

To understand this impact of the lockdown, the study wangled hourly pollution concentration data for the month of April for 2019 and 2020 to create a typical April day. Basically, all the readings for a specific hour of the day for all days of April were calculated as average, to arrive at the average pollution level at that given hour of the day. Only April data was used instead of data from the entire lockdown because restrictions on vehicular movement were eased in lockdown 3.0 (which started on May 4, 2020).

This analysis benchmarks and documents variations in hourly NO_2 levels within and among cities – a comparison with 2019 helps understand the clean air potential of non-combustion transportation.

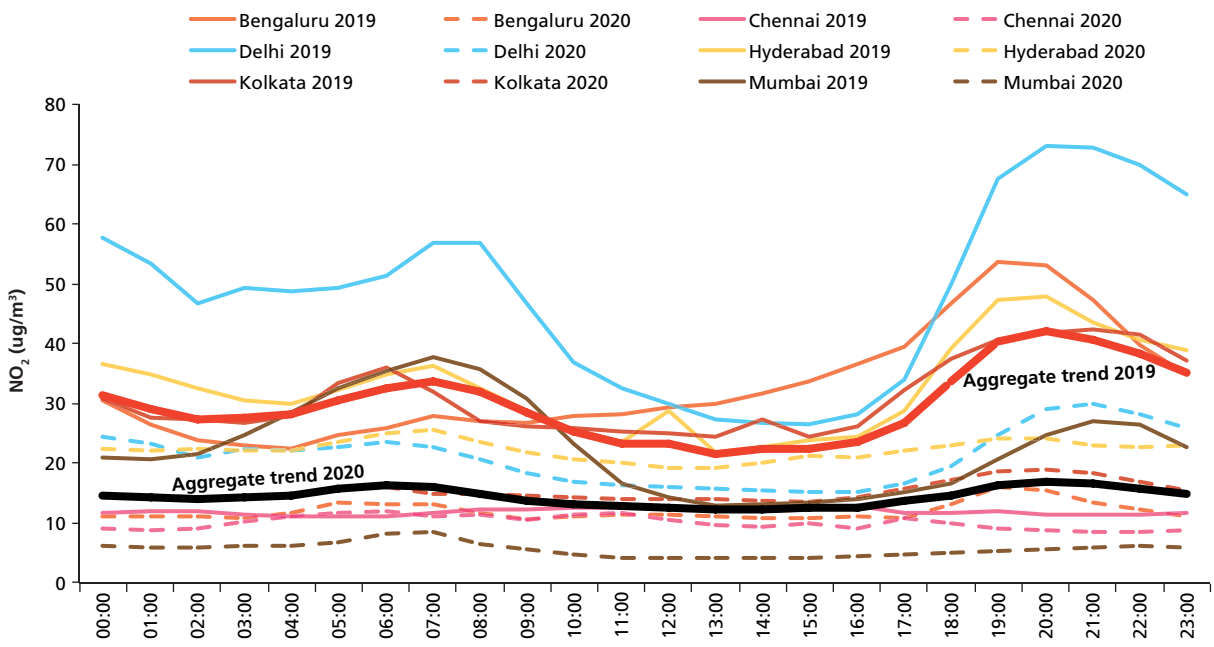
Mega cities

- All mega cities, except Chennai, registered their morning peak of NO_2 during 6-8 AM, and had another peak in the evening during 8-10 PM. Both peaks corresponded to the traditional rush hours, but a few hours removed from the traffic volume peaks.
- Chennai did not show any pronounced peak: this might be due to the fact that all stations of the city are located in the suburban industrial belt and they do not really capture the air quality of the city's core area.
- Evening peak was about 30-90 per cent higher than the morning peak in Bengaluru, Delhi, Hyderabad and Kolkata; but in Mumbai, the morning peak was higher by 34 per cent.
- The lockdown removed almost all traffic from the roads and flattened the traffic volume curve. This is reflected in the hourly pattern of NO_2. The morning peak (7-8 AM) collapsed by 78 per cent in Mumbai and 60 per cent in Delhi.
- Kolkata and Bengaluru both saw a 53 per cent drop in the morning, while Hyderabad and Chennai registered a 29 per cent and 5 per cent drop, respectively.
- The evening peak (8-9 PM) dropped in Mumbai by 77 per cent and in Bengaluru by 71 per cent.
- Delhi, Kolkata and Hyderabad saw drops of 60 per cent, 55 per cent, and 50 per cent, respectively (*see Graph 23*).

Tier-1 cities in Indo-Gangetic Plains

- All IGP cities, except Amritsar, registered their morning peak of NO_2 during 6-9 AM. Amritsar's peak was at around 9-10 AM. The evening peak was around 8-10 PM in Amritsar, Ghaziabad, Noida, Lucknow and Howrah.
- Gurugram and Faridabad had their peaks later in the evening, at around 11 PM, while Patna's peak was around 6-8 PM. The evening peak was about 6-169 per cent higher than the morning peak for IGP cities.
- The lockdown made the morning peak (7-8 AM) collapse by 88 per cent in Faridabad and 63 per cent in Lucknow.
- Noida and Ghaziabad saw 56 per cent and 53 per cent drops in morning peaks respectively, while Patna and Amritsar registered a 21 per cent and 22 per cent drop, respectively.
- The evening peak (8-9 PM) dropped in Faridabad by 90 per cent and in Ghaziabad by 64 per cent.
- Amritsar, Noida, Lucknow and Patna witnessed drops of 51 per cent, 57 per cent, 54 per cent and 60 per cent, respectively (*see Graph 24*). Data

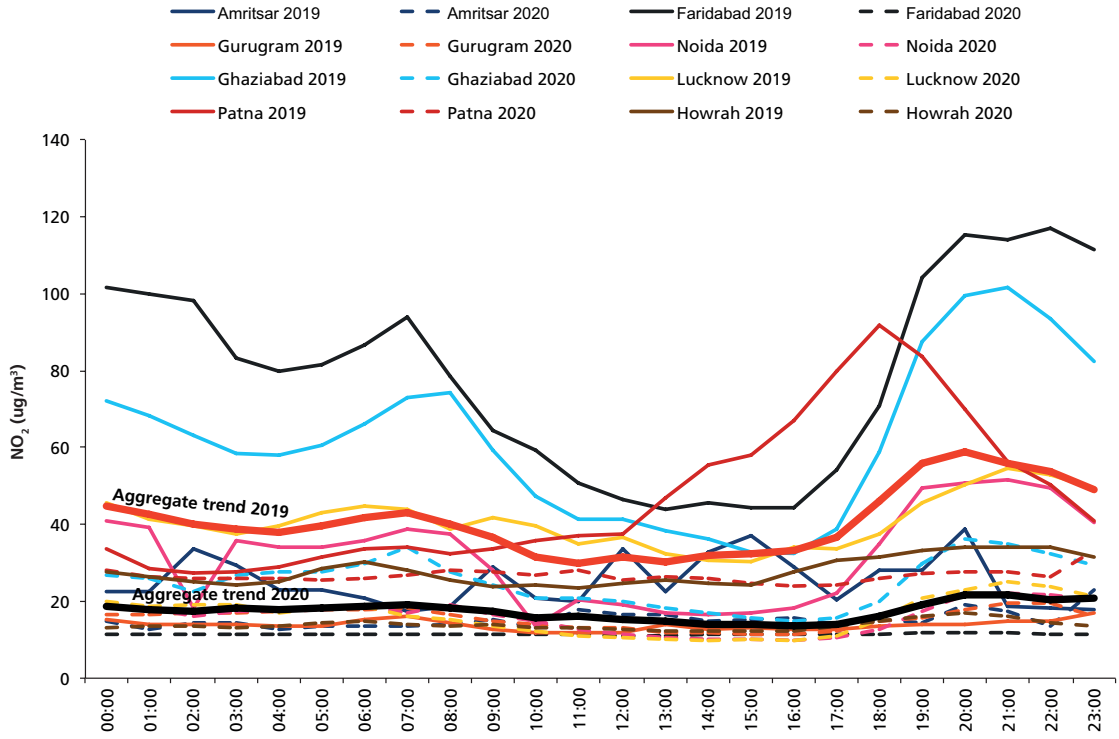
Graph 23: Flattening of the hourly curve of NO_2 (typical day in April) – mega cities



Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

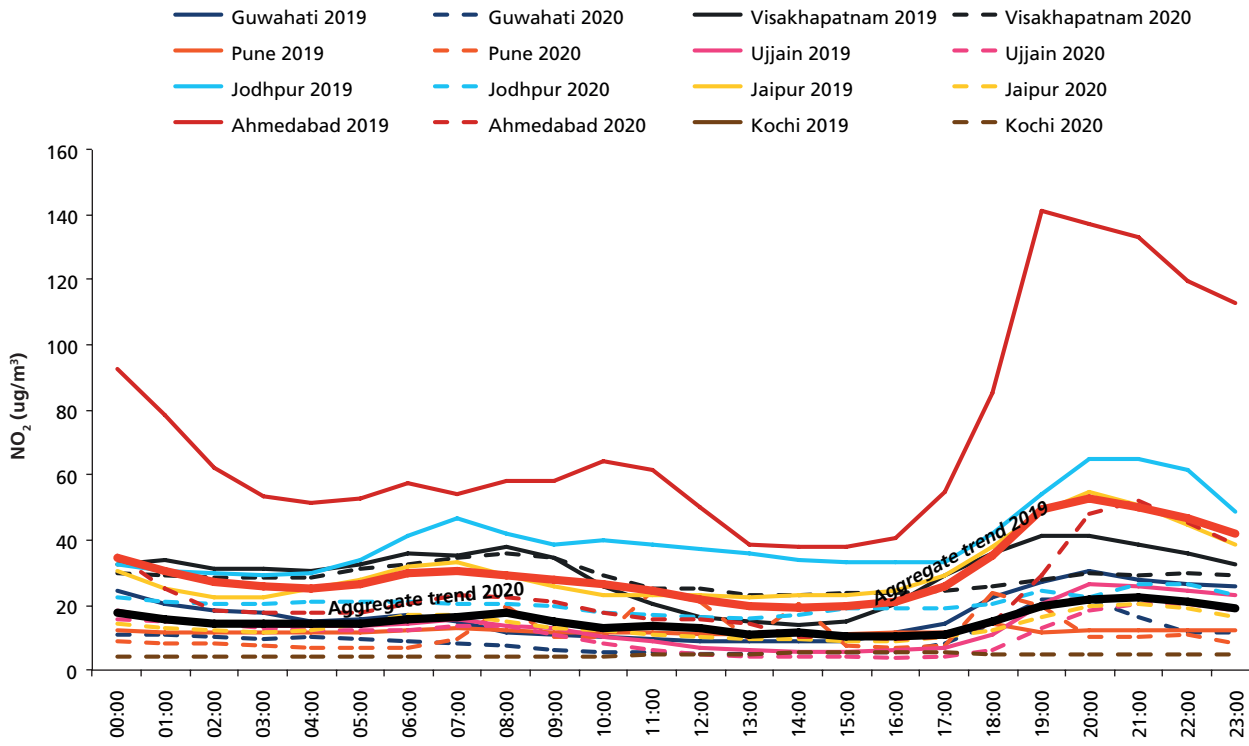
Graph 24: Flattening of the hourly curve of NO_2 (typical day in April) – tier-1 cities in the Indo-Gangetic Plains



Note: Average of only those stations that have valid data for both years, 2019 and 2020, have been used for each city.

Source: CSE analysis based on CPCB data

Graph 25: Flattening of the hourly curve of NO_2 (typical day in April) – tier-1 cities outside the Indo-Gangetic Plains



Note: Average of only those stations that have valid data for both 2019 and 2020 have been used for each city.

Source: CSE analysis based on CPCB data

for Gurugram and Howrah was incomplete, and therefore, could not be analysed comparatively.

Tier-1 cities outside Indo-Gangetic Plains

- Except Ahmedabad, the rest of the non-IGP cities registered their morning peak of NO_2 during 6-9 AM. Ahmedabad peaked at around 10-11 AM.
- The evening peak was around 8-10 PM in Guwahati, Jaipur, Jodhpur and Ujjain. Ahmedabad, Pune and Visakhapatnam had their peaks earlier in the evening, at around 5-7 PM.
- The evening peak was about 9-118 per cent higher than the morning peak for the cities in this pool.
- During lockdown, the morning peak collapsed by 64 per cent in Ahmedabad and by 55 per cent in Jodhpur – it also moved two-three hours earlier in the morning. Visakhapatnam had only 5 per cent lowering of the morning peak.
- The evening peak shifted one-two hours later in the evening and collapsed by over 60 per cent in Ahmedabad, Jaipur and Jodhpur.
- Guwahati, Ujjain and Visakhapatnam registered a 28 per cent, 22 per cent, and 29 per cent drop in their evening peaks, respectively (*see Graph 25*).
- Pune exhibited an abnormal pattern during the lockdown, with multiple peaks spread through the day – the reason for this has not been investigated in this analysis.
- The data for Kochi was incomplete.

WAS THE LOCKDOWN CLEANER THAN THE MONSOON SEASON?

As in the case of $PM_{2.5}$, NO_2 levels are naturally at their lowest during the monsoon season for all cities as long and frequent rain spells wash down the air. The lockdown happened during the summer season, which is not the cleanest of the seasons for NO_2 pollution. The study has already established that the summer of 2020 – with its lockdown conditions – was a lot cleaner for all cities than the 2019 summer. Nevertheless, the study did not control for changed meteorological conditions between the two years; therefore, it was considered worthwhile to compare the lockdown period with the monsoon season of 2019 to understand the impacts.

For this analysis, an average daily NO_2 concentration for 54 days of the first three phases of lockdown – March 25 to May 17 – has been taken as a benchmark. Lockdown 4.0 has not been included as most cities resumed economic activities during this phase and the NO_2 level rose significantly compared to the earlier phases. But for a few cities which didn't relax restrictions for lockdown 4.0, the average dropped further and that has been noted separately. To establish the cleanest contiguous 54 days before the lockdown during 2019-20, a rolling average of 54 days was computed and the lowest value was used for comparison. The study also noted the dirtiest contiguous 54 days before the lockdown.

Mega cities

- During lockdown, all mega cities except Hyderabad registered the cleanest contiguous 54 days observed since January 1, 2019 for average daily NO_2. It was 26-50 per cent cleaner than their earlier cleanest period that were naturally found during the monsoon season.
- Hyderabad was the only mega city that had observed a cleaner time before the lockdown (*see Table 13*).
- The lockdown was 52-92 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

Table 13: NO_2 analysis for mega cities – average of 54 days

	Dirtiest in 2019-20	Cleanest in 2019	Cleanest in lockdown
Bengaluru	38	19	13.1 (13.0)
Chennai	20	12	8.9 (8.8)
Delhi	58	30	20.8 (20.5)
Hyderabad	46	14	22.5 (22.3)
Kolkata	107	16	8.1 (10.0)
Mumbai	45	11	8.4 (8.4)

Notes: Values are in µg/m³. Number in parenthesis is the average of first three phases of lockdown (March 25-May 17 May, 2020)

Source: CSE analysis based on CPCB data

Tier-1 cities in Indo-Gangetic Plains

- Noida, Ghaziabad, Lucknow and Howrah were the cities in this pool whose average daily NO_2 for the contiguous 54 days during lockdown was the cleanest contiguous 54 days observed since January 1, 2019, including the monsoon season.
- Amritsar, Gurugram and Patna were significantly off from their monsoon lows (*see Table 14*).

Table 14: NO_2 analysis for IGP cities – average of 54 days

	Dirtiest in 2019-20	Cleanest in 2019	Cleanest in lockdown
Amritsar	25	10	15.3 (15.2)
Gurugram	47	8	18.3 (17.8)
Faridabad*	105	68	12.7 (12.7)
Noida	76	28	16.2 (15.9)
Ghaziabad	84	34	24.9 (24.5)
Lucknow	62	20	15.1 (14.9)
Patna	56	15	19.7 (28.0)
Howrah	78	23	13.1 (14.7)

Notes: Values are in µg/m³. Number in parenthesis is the average of first three phases of lockdown (March 25-May 17 May, 2020)

Source: CSE analysis based on CPCB data

Table 15: NO_2 analysis for non-IGP cities – average of 54 days

	Dirtiest in 2019-20	Cleanest in 2019	Cleanest in lockdown
Ahmedabad	152	23	(22.1)
Guwahati	23	9	(11.5)
Jaipur	48	20	(14.1)
Jodhpur	39	19	(20.7)
Kochi	36		(7.6)
Pune	23	6	(10.6)
Ujjain	33	5	(9.7)
Visakhapatnam	57	26	(24.0)

Notes: Values are in µg/m³. Number in parenthesis is the average of first three phases of lockdown (March 25-May 17 May, 2020)

Source: CSE analysis based on CPCB data

- Faridabad did not have data for the 2019 monsoon season; therefore, it was not possible to conclude if the levels during lockdown were cleaner than during the monsoons. But the levels were lower than the lowest recorded without the monsoon data.
- The lockdown was 38-88 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

Tier-1 cities outside Indo-Gangetic Plains

- Ahmedabad, Jaipur and Visakhapatnam were the cities in this pool whose average daily NO_2 for the contiguous 54 days during lockdown was the cleanest contiguous 54 days observed since January 1, 2019, including in the monsoon season.
- Guwahati and Jodhpur's lockdown levels were almost the same as the lowest recorded during 2019 monsoons.
- Pune and Ujjain were significantly off from their monsoon lows, with their lockdown average being 74 per cent and 68 per cent higher than their monsoon lows, respectively (*see Table 15*).
- The lockdown was 48-87 per cent cleaner than the dirtiest contiguous 54 days observed since January 1, 2019.

THE WAY AHEAD: AN AGENDA FOR ACTION

The message from this analysis of summer air quality during the lockdown is clear. The experience has helped us understand the scale and speed at which change is needed to clean up the air in our cities and regions. But the entire exercise has required enormous disruption at a huge human cost. How, then, do we move forward? There is a need for an agenda for blue skies and clear lungs for the post-pandemic period.

This period has helped us understand the lowest level of pollution that is possible to achieve under the current scenario. It has also helped us understand how important it is to address regional influences. A big reduction in cities is possible only if the entire region cleans up together. But the change has to happen at scale and speed across all critical sectors including vehicles, industry, power plants, waste, construction, use of solid fuels for cooking and episodic burning. This has to inform action across all non-attainment cities under the ongoing National Clean Air Programme (NCAP), as well as in the regions.

This analysis has also put the spotlight on the seasonal nature of the pollution problem in India. Winter months, when cold and calm weather conditions and inversion traps pollution resulting in severe smog episodes, attract a lot of attention. These episodes are largely driven by the accumulated particles in the air. But the summer pollution that gets further complicated by the ozone build-up is not yet very well understood. Global experience shows that ozone is the new generation problem and needs equally strong attention – if left uncontrolled, it can lead to significant health issues.

This essentially means that the action plans that are being framed and implemented across the cities of India need to ensure co-benefit of reducing both particulate and gaseous emissions, with a special focus on ozone.

At the same time, we need good science to assess air quality based on the ever expanding monitoring grid for a better understanding of the changing trends in different pollutants, as well as their compliance with the national ambient air quality standards. The method and protocol needed to report compliance for different pollutants must be specified urgently for cities need to establish compliance with their targets under NCAP and the national ambient air quality standards.

Today, we are re-opening the country without any plans to hold on to the clean air benefits of the lockdown. But locally and regionally, appropriate action plans are taking shape and getting implemented across 122 cities in India. This process can be informed better for multi-sectoral interventions. However, at the national level, it is important to link the new overarching but priority reform agenda more specifically with the economic stimulus and reform packages that will work for both economy and environment. This is needed for an upscaled, nation-wide transition.

Priority action agenda

This agenda cannot wait anymore. It is long-term, but change must start now.

Vehicles

- **Do not delay the BSVI emission norms for vehicles – use this opportunity to put in place a double-win strategy: Scrap heavy vehicles and replace them with BSVI, and support this with financial stimulus**. We need to urgently replace old diesel trucks and buses with their BSVI versions that are 90 per cent less polluting than BSIV. Wherever possible, phase in electric buses. The government should use financial stimulus to scrap old trucks and heavy duty diesel buses and replace them with BSVI versions. This will give the economy/auto-industry a boost and help retain the clean air benefits. But scrappage must be planned well so that old vehicles do not turn up in other cities/regions.
- Move at scale to introduce **cleaner battery vehicles for para-transit and public transport.** Mandate and pay for the change starting with autorickshaws, taxis, buses and trams. Link this with economic stimulus and clean electricity.
- **Use the financial stimulus to provide funds for a switch-over to cleanest vehicles**. Change this quickly and at scale to provide both benefits to industry and for clean air.

Mobility and transport

- **Start public transport and incorporate global best experience of ensuring safety.** Learn from the best practices across the world and re-start public transport so that it ensures safety.
- **Use financial stimulus package to augment public transport service in cities** – bus, metro and light-rail, as appropriate. Do this at scale and speed. Public transport is critical for a city to run. It is time we recognised this and made it a part of our initial planning.
- **Cycle and walk must become a part of the 'new-normal'**. Incentivise people to reduce travel, and take cycles to work. We must plan/implement cycle-walk for our cities.
- **Do everything to reduce travel needs**. Adopt strategies like work-from-home, staggered timings, and roster-based attendance.

Clean fuel transition in industry: natural gas

- **Ensure availability of natural gas for combustion in industries (especially in Delhi-NCR and other cities).** The problem is not supply – the problem is the price. Dirty fuel (coal) is covered under GST, and has a lower tax burden; industries get credit. Coal has been placed under open general license (OGL) so that it can be imported. But clean fuel – natural gas – is heavily taxed: it attracts over 40 per cent tax**.** This needs a favourable taxation policy.
- **Bring natural gas under GST to reduce the tax burden and to incentivise clean fuel over its dirty versions.** Remove coal from OGL so that imports can be regulated and use can be monitored.

Clean power

- **All power plants need to meet the new standards by 2022.** CSE's recent report (https://www.cseindia.org/coal-based-power-norms-coal-based-10125) finds that many power plants in the NCR did not meet the 2019 deadline and will not meet the 2022 deadline either. This is Delhi, for instance, has closed all its coal power plants.
- **Need a first-run policy –** only those plants that meet the emission notification should be allowed to sell power.
- **Need affordable-reliable power policy as industry needs to switch from dirty fuel to cleaner fuel.** Power plants must meet the 2015 standards within the deadline; accelerate natural gas-based power and renewable power.
- **Ensure all households and eateries have access to clean energy –** LPG, natural gas or renewable power.

Access to clean energy

- **Ensure all households and eateries have access to clean energy** for cooking (LPG, natural gas or electricity). Scale up the current programmes and adopt appropriate strategies for households for sustained and continuous use of clean energy.

Circular economy around waste

- **Eliminate waste burning.** Ensure that no municipal waste is burnt and adopt household- level segregation and recycling facilities for all streams of municipal waste including solid waste, plastic waste and e-waste. A strategy is needed for safe disposal of industrial waste and to exercise stringent controls for incinerators. Move towards a zero-landfill policy.
- **Ensure stringent control on construction and demolition waste.** Need enforcement of rules and facilities for dust control at construction sites; recycling facilities for construction and demolition waste; and quick uptake of the recycled material by the construction industry.
- **Strengthen strategies for stubble burning.** Need stringent enforcement of strategies designed for controlling farm fires at scale – further strengthen the strategies including subsidy for farm implements to promote mulching; recycling of the stubble for producing other products and energy; and change in cropping patterns according to local agro- climatic conditions.

ANNEXURE

LIST OF CAAQM STATIONS USED IN THE STUDY

	State	City	Station Name	
1	**Andhra Pradesh**	Visakhapatnam	1	GVM Corporation, Visakhapatnam - APPCB
2	**Assam**	Guwahati	1	Railway Colony, Guwahati - APCB
3	**Bihar**	Patna	1	IGSC Planetarium Complex, Patna - BSPCB
			2	Muradpur, Patna - BSPCB
			3	Samanpura, Patna - BSPCB
			4	Rajbansi Nagar, Patna - BSPCB
			5	DRM Office Danapur, Patna - BSPCB
			6	Govt. High School Shikarpur, Patna - BSPCB
4	**Delhi**	Delhi	1	Alipur, Delhi - DPCC
			2	Shadipur, Delhi - CPCB
			3	IHBAS, Dilshad Garden, Delhi - CPCB
			4	NSIT Dwarka, Delhi - CPCB
			5	DTU, Delhi - CPCB
			6	ITO, Delhi - CPCB
			7	Siri Fort, Delhi - CPCB
			8	Mandir Marg, Delhi - DPCC
			9	Anand Vihar, Delhi - DPCC
			10	R K Puram, Delhi - DPCC
			11	Punjabi Bagh, Delhi - DPCC
			12	Aya Nagar, Delhi - IMD
			13	Lodhi Road, Delhi - IMD
			14	North Campus, DU, Delhi - IMD
			15	Burari Crossing, Delhi - IMD
			16	CRRI Mathura Road, Delhi - IMD
			17	Pusa, Delhi - IMD
			18	IGI Airport (T3), Delhi - IMD
			19	East Arjun Nagar, Delhi - CPCB
			20	Ashok Vihar, Delhi - DPCC
			21	Jawaharlal Nehru Stadium, Delhi - DPCC
			22	Nehru Nagar, Delhi - DPCC
			23	Dwarka-Sector 8, Delhi - DPCC
			24	Dr. Karni Singh Shooting Range, Delhi - DPCC
			25	Patparganj, Delhi - DPCC
			26	Sonia Vihar, Delhi - DPCC
			27	Jahangirpuri, Delhi - DPCC
			28	Rohini, Delhi - DPCC
			29	Najafgarh, Delhi - DPCC
			30	Vivek Vihar, Delhi - DPCC

	State	City	Station Name	
			31	Major Dhyan Chand National Stadium, Delhi - DPCC
			32	Narela, Delhi - DPCC
			33	Okhla Phase-2, Delhi - DPCC
			34	Wazirpur, Delhi - DPCC
			35	Bawana, Delhi - DPCC
			36	Sri Aurobindo Marg, Delhi - DPCC
			37	Pusa, Delhi - DPCC
			38	Mundka, Delhi - DPCC
5	**Gujarat**	Ahmedabad	1	Maninagar, Ahmedabad - GPCB
6	**Haryana**	Faridabad	1	Sector- 16A, Faridabad - HSPCB
			2	New Industrial Town, Faridabad - HSPCB
			3	Sector 11, Faridabad - HSPCB
			4	Sector 30, Faridabad - HSPCB
		Gurgaon	1	Vikas Sadan, Gurugram - HSPCB
			2	NISE Gwal Pahari, Gurugram - IMD
			3	Sector-51, Gurugram - HSPCB
			4	Teri Gram, Gurugram - HSPCB
7	**Karnataka**	Bangalore	1	Sanegurava Halli, Bengaluru - KSPCB
			2	City Railway Station, Bengaluru - KSPCB
			3	BWSSB Kadabesanahalli, Bengaluru - CPCB
			4	Peenya, Bengaluru - CPCB
			5	BTM Layout, Bengaluru - CPCB
			6	Bapuji Nagar, Bengaluru - KSPCB
			7	Silk Board, Bengaluru - KSPCB
			8	Hebbal, Bengaluru - KSPCB
			9	Hombegowda Nagar, Bengaluru - KSPCB
			10	Jayanagar 5th Block, Bengaluru - KSPCB
8	**Kerela**	Kochi	1	Vyttila, Kochi - Kerala PCB
9	**Madhya Pradesh**	Ujjain	1	Mahakaleshwar Temple, Ujjain - MPPCB
10	**Maharasthra**	Mumbai	1	Bandra, Mumbai - MPCB
			2	Chhatrapati Shivaji Intl. Airport (T2), Mumbai - MPCB
			3	Powai, Mumbai - MPCB
			4	Vasai West, Mumbai - MPCB
			5	Vile Parle West, Mumbai - MPCB
			6	Kurla, Mumbai - MPCB
			7	Worli, Mumbai - MPCB
			8	Borivali East, Mumbai - MPCB
			9	Sion, Mumbai - MPCB
			10	Colaba, Mumbai - MPCB
		Pune	1	Karve Road, Pune - MPCB
11	**Punjab**	Amritsar	1	Golden Temple, Amritsar - PPCB

	State	City	Station Name	
12	**Rajasthan**	Jaipur	1	Shastri Nagar, Jaipur - RSPCB
			2	Adarsh Nagar, Jaipur - RSPCB
			3	Police Commissionerate, Jaipur - RSPCB
		Jodhpur	1	Collectorate, Jodhpur - RSPCB
13	**Tamil Nadu**	Chennai	1	Manali, Chennai - CPCB
			2	Velachery Res. Area, Chennai - CPCB
			3	Alandur Bus Depot, Chennai - CPCB
			4	Manali Village, Chennai - TNPCB
14	**Telangana**	Hyderabad	1	Central University, Hyderabad - TSPCB
			2	ICRISAT Patancheru, Hyderabad - TSPCB
			3	Bollaram Industrial Area, Hyderabad - TSPCB
			4	IDA Pashamylaram, Hyderabad - TSPCB
			5	Zoo Park, Hyderabad - TSPCB
			6	Sanathnagar, Hyderabad - TSPCB
15	**Uttar Pradesh**	Ghaziabad	1	Vasundhara, Ghaziabad - UPPCB
			2	Indirapuram, Ghaziabad - UPPCB
			3	Sanjay Nagar, Ghaziabad - UPPCB
			4	Loni, Ghaziabad - UPPCB
		Lucknow	1	Talkatora District Industries Center, Lucknow - CPCB
			2	Central School, Lucknow - CPCB
			3	Lalbagh, Lucknow - CPCB
			4	Nishant Ganj, Lucknow - UPPCB
			5	Gomti Nagar, Lucknow - UPPCB
		Noida	1	Sector - 62, Noida - IMD
			2	Sector - 125, Noida - UPPCB
			3	Sector-1, Noida - UPPCB
			4	Sector-116, Noida - UPPCB
16	**West Bengal**	Howrah	1	Ghusuri, Howrah - WBPCB
			2	Padmapukur, Howrah - WBPCB
			3	Belur Math, Howrah - WBPCB
		Kolkata	1	Rabindra Bharati University, Kolkata - WBPCB
			2	Victoria, Kolkata - WBPCB
			3	Fort William, Kolkata - WBPCB
			4	Jadavpur, Kolkata - WBPCB
			5	Rabindra Sarobar, Kolkata - WBPCB
			6	Ballygunge, Kolkata - WBPCB
			7	Bidhannagar, Kolkata - WBPCB

Note: Stations are placed under each city as reported by Central Pollution Control Board (CPCB) on its Central Control Room for Air Quality Management. The study uses CPCB's reported city boundaries. It is noted that CPCB's reported city boundaries are not consistent with state and local government. For instance, CPCB reports Kochi, Ernakulum, and Eloor as three separate cities but Kerala government considers them part of a single city governed by Kochi Municipal Corporation.

References

1. Anon 2020. *Airborne Particle Levels Plummet in Northern India*, The Earth Observatory, NASA, U.S.A. Available at *https://earthobservatory.nasa.gov/images/146596/airborne-particle-levels-plummet-in-northern-india*, accessed on 13 May 2020
2. Press release 2020. *Coronavirus lockdown leading to drop in pollution across Europe,* European Space Agency, France. Available at *https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Coronavirus_lockdown_leading_to_drop_in_pollution_across_Europe,* accessed on 13 May 2020
3. Anon 2019. *State of Global Air 2019, Special Report,* Health Effects Institute, Boston, U.S.A.
4. Press release 2020. *Coronavirus threat greater for polluted cities,* European Public Health Alliance, Brussels. Available at *https://epha.org/coronavirus-threat-greater-for-polluted-cities/,* accessed on 13 May 2020
5. Bindu Shajan Perappadan 2020. *Coronavirus | Air pollution may further impact patients, say doctors,* The Hindu, New Delhi. Available at *https://www.thehindu.com/sci-tech/health/coronavirus-air-pollution-may-further-impact-patients-say-doctors/article31092789.ece#:~:text=A%20collective%20of%20doctors%20working,coronavirus%20(COVID%2D19)* , accessed on 13 May 2020
6. Xiao Wu and Rachel C. Nethery 2020. *Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study*, Department of Biostatistics, Harvard T.H. Chan School of Public Health, U.S.A. Available at *https://projects.iq.harvard.edu/covid-pm*, accessed on 16 May 2020
7. Yaron Ogen 2020. 'The link between air pollution and COVID-19 deaths', *Science of the Total Environment Volume 726*, Elsevier, Netherlands
8. Edoardo Conticini, Bruno Frediani and DarioCaro 2020. 'Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?', *Environmental Pollution Volume 261,* Elsevier, Netherlands
9. *Ibid*
10. Daniele Contini and Francesca Costabile 2020. 'Does Air Pollution Influence COVID-19 Outbreaks?', *Atmosphere 2020, 11(4), 377*, MDPI, Switzerland
11. Leonardo Setti et al 2020. *The Potential role of Particulate Matter in the Spreading of COVID-19 in Northern Italy: First Evidence-based Research Hypotheses*, medRxiv, U.S.A.
12. Yongjian Zhu et al 2020. 'Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China', *Science of The Total Environment Volume 727*, Elsevier, Netherlands
13. University Of California - Los Angeles 2003. *SARS Death Rate Doubles In Polluted Cities,* ScienceDaily, U.S.A. Available at *www.sciencedaily.com/releases/2003/11/031120073707.htm,* accessed on 16 May 2020
14. Mukesh Sharma and Onkar Dikshit 2016. *Comprehensive Study on Air Pollution and Greenhouse Gases (GHGs) in Delhi,* Indian Institute of Technology Kanpur, Kanpur
15. M. R. Saraf, Sumit Sharma, et al 2018. *Source Apportionment of PM2.5 & PM10 of Delhi NCR for Identification of Major Sources,* The Automotive Research Association of India, Pune and The Energy and Resources Institute, New Delhi
16. Anon 2009. *National Ambient Air Quality Standards Notification*, Central Pollution Control Board, New Delhi
17. Federal Registry 2015. *Final rule, National Ambient Air Quality Standards for Ozone*, United States Environmental Protection Agency, U.S.A.
18. *Ibid*

The summer of 2020 has been quite different.

The ongoing public health crisis, besides having caused unprecedented disruption to business-as-usual, has also given us a new prism through which we can view the air pollution crisis. The economic slowdown and implementation of lockdown measures have bent the pollution curve dramatically – blue skies have reappeared over cities where smog used to rule the roost.

This report from Centre for Science and Environment (CSE) delves deep into an examination of how clean the air actually became. CSE has put the available air quality data under scanner to understand the different dimensions of the change in air quality during the lockdown period. This granular view of pollutant-wise local trends across cities gives an insight into the challenges and how the new normal needs to be shaped.

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