# Ground-level ozone in Delhi-NCR: Unmasking the hidden and growing health risk

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Centre for Science and Environment (CSE) has alerted from time to time about the growing problem of ground level ozone in Indian cities. While policy and public attention is nearly fully drawn towards very high level of particulate pollution, the challenge of this emerging toxic gas has not attracted adequate policy attention for mitigation and prevention. Inadequate monitoring, limited data and inappropriate methods of trend analysis have weakened the understanding of this growing toxic risk.

Yet the insidious link between ozone and premature deaths representing growing health risk is beginning to get documented in health literature. The most recent 2020 State of Global Air report states that age-standardized rates of death attributable to ozone is among the highest in India and the seasonal 8-hour daily maximum concentrations have recorded one of the highest increases in India between 2010 and 2017– about 17 per cent. This requires deeper understanding of what is going on in different cities and regions to inform mitigation.

City and region specific analysis remains a challenge as ozone monitoring is still very limited in India. Therefore, some of the regions like Delhi-NCR that has relatively better network of monitoring, particularly Delhi with 40 monitoring stations, is an opportunity to understand the ozone behavior. This is an emerging concern in India and requires deeper assessment and insight.

**Why ozone needs special attention?** Complex chemistry of ozone makes it a difficult pollutant to track and mitigate. Ground level ambient ozone is not directly emitted from any source. It is produced from complex interaction between nitrogen oxides (NOx) and volatile organic compounds (VOCs) that are emitted from vehicles, power plants, factories, and other combustion sources and undergo cyclic reactions in the presence of sunlight to generate ground level ozone. VOCs can also be emitted from natural sources, such as plants. Ozone is also a heat trapping greenhouse gas. Ozone not only builds up in cities but also drifts long distances to form a regional pollutant that makes both local and regional action necessary. Mitigation demands stringent control of gases from all combustion sources. It is therefore necessary that while designing mitigation of particulate matter the action strategy is also calibrated for reduction of ozone precursors.

This highly reactive gas has serious health consequences. Those with respiratory conditions, asthma, chronic obstructive pulmonary disease, and particularly children with premature lungs and older adults are at serious risk. This can inflame and damage airways, make lungs susceptible to infection, aggravate asthma, emphysema, and chronic bronchitis and increase the frequency of asthma attacks leading to increased hospitalisation. This demands exposure management wherever ozone build up is happening. This is the reason why the standard for ground level ozone have been set for hourly and eight-hourly duration unlike 24-hourly and annual standard set for other pollutants.

**The investigation:** In view of this rising toxic threat and the past data on rising ozone levels, CSE has therefore, embarked on this new assessment of the ozone trends in different regions to understand the varying nature of this problem. The first in this series is the assessment of ozone behaviour over the past three years (2018-2021) in Delhi and the National Capital Region (NCR) which is the hotbed of pollution action.

As part of this air quality tracker initiative, the Urban Data Analytics of Centre for Science and Environment (CSE) seeks to understand the nature of ozone pollution in the region over the last three years and how it has been impacted by the extraordinary pandemic year of 2020 that has witnessed one of the biggest disruptions in the recent times. This is an inflexion point but also an indicator of what may change and yet not changed despite the disruption. This helps to address some of the basic curiosities related to how ozone pollution has persisted even with stopping of activities, and deeper seasonal patterns that unmask the high

local pollution that may have been triggered due to the forced change during the lockdown phases. Also if ozone trend analysis is appropriate to capture the growing risk.

**Method and data**: This assessment has traced trends during different seasons – summer (March-June), winter (October-February) and monsoon (July-September), between 2018 to 2021 July (upto July 18th). The analysis is based on publicly available granular real time data (15-minute averages) from the Central Pollution Control Board's (CPCB) official online portal Central Control Room for Air Quality Management. The data has been captured from 81 official stations under the Continuous Ambient Air Quality Monitoring System (CAAQMS) spread across Delhi-NCR. Delhi (40), Gurugram (4), Faridabad (4), Noida (4), Ghaziabad (4), Meerut (3), and Greater Noida (2) that have more than one real-time station. More than 55 million data points have been sourced and analysed from the CPCB portal for this analysis.

Given the volatile and highly localized nature of ozone pollution build-up and its variability across space, and consistent with the global good practice, this analysis has considered station level trends in terms of number of days exceeding the 8-hour standard over time. As ozone formation depends on complex atmospheric chemistry and on photochemical reaction its level varies across time and space horizon. Meteorological parameters such as sunny and warm weather, stagnant wind patterns etc have bearing on its formation.

This has considered global good practice and taken on board the USEPA approach of computing eight-hour averages for a day and then checking for the maximum value among them to capture the daily ozone pollution level. USEPA assesses city-wide or regional AQI based on highest value recorded among all city stations. Thus, trends have been calculated in terms of number of days when the daily level has exceeded the 8-hr standard (referred as exceedance days hereafter). Being a highly reactive gas ozone does not have a 24-hourly or annual standard. A simple city-wide spatial averaging has not been considered for the trend analysis though it has been assessed. It is also not an adequate indicator to understand the health risk from local build up and spatial variation.

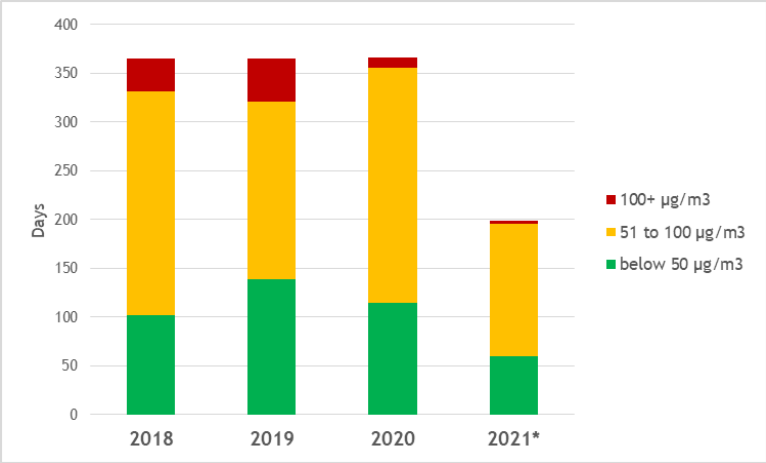
While analysing the data it has also been noted that the ozone data available on CPCB portal never exceeds 200µg/$m^3$, while data for the corresponding time on Delhi Pollution Control Committee may show higher levels. Therefore, due to this capping of data it is not possible to understand the nature of peaking in the city. This needs to be addressed as there are two sets of standard for ozone – 8-hourly standard of 100 µg/$m^3$ and one hourly standard at 180 µg/$m^3$. Capping can make assessment of one-hourly standard challenging. This study has assessed trends only based on 8 hourly standard.

## Key highlights of the analysis

### Citywide averages hide risk from ozone pollution. Need focus on the pollution build-up across the city to communicate and reduce health risk

The current regulatory practice of computing average of all stations to derive the city-wide average for ozone hugely underestimates the risk. This is also not consistent with the global good practice. The city-wide average shows little exceedance of standards (See *Graph 1: Citywide average of ozone in Delhi*). Even from that yardstick the good air days – that is 50 per cent below the daily 8-hr concentration standard ('good' category under Air Quality Index - AQI) – has started to decline in the city. There were 115 good days in 2020 which is 24 days less than 2019; but higher than 2018 when 'good' ozone days were just 102. As ozone is an emerging problem it is important to adopt appropriate method of trend analysis and risk assessment.

**Graph 1: Citywide average of ozone pollution in Delhi**

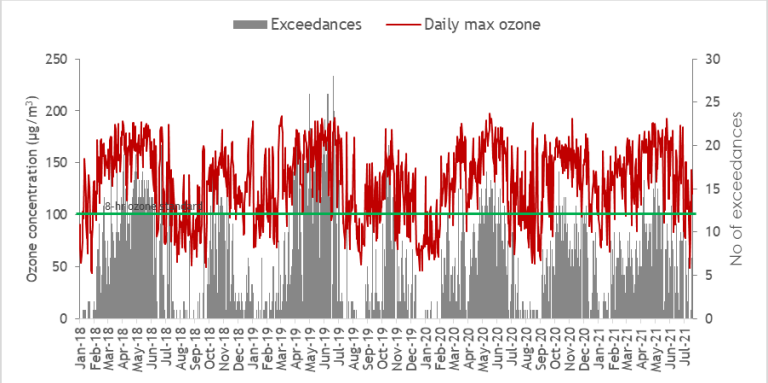



Note: Citywide average was calculated as mean of all stations in the city.
Source: CSE analysis of CPCB real-time data

Globally regulators focus on capturing the worst levels recorded in a day in the city to communicate risk and plan mitigation. USEPA for instance has moved away from spatial averaging even for reporting AQI. According to 40 CFR Appendix G to Part 58 - Uniform Air Quality Index (AQI) and Daily Reporting, the AQI for a region with multiple monitoring stations has to be calculated based on "the highest concentration among all of the monitors within each reporting area". By this method, Delhi city's AQI has to be based on most polluted or the worst station of the day and not the average of all stations (See *Graph 2: Ozone pollution in Delhi if calculated using USEPA method*). This is needed to capture the health risk from ozone.

Citywide average is not a good measure of ozone pollution and severely undermines the AQI's objective of providing health advisory to people sensitive to ozone pollution. Unlike $PM_{2.5}$, ozone build-up is a hyper-local phenomenon (there is recorded evidence of over 100 µg/m$^3$ difference in ozone level between neighbouring stations) and health impact of it is almost immediate (reason why it has only 1-hourly and 8-hourly standard). Given the fact that on most days more than half of the stations don't exceed the standards, the citywide average systematically water-downs the health risk posed to public living around ozone hotspots and denies them benefit of prevention and action under the AQI system.

**Graph 2: Ozone pollution in Delhi if calculated using USEPA method**




Note: Daily max ozone for Delhi is calculated as the highest daily value recorded among city stations. The daily value is based on the maximum 8-hr average recorded in a day at a station from a rolling 8-hr average.
Source: CSE analysis of CPCB real-time data using USEPA method

At this moment it is not possible to compute the peak pollution in the city as the data that is available from CPCB portal is capped at 200 µg/m$^3$ for daily AQI reporting purpose. Ozone data available on CPCB portal never exceeds 200 µg/m$^3$. But there are timestamps for corresponding time and date for which Delhi Pollution Control Committee has reported values higher than 200 µg/m$^3$. For instance, during last week of April, 2021, DPCC has reported hourly concentrations exceeding 200 µg/m$^3$ at Dr Karni Singh Shooting Range AQM station for four continuous days i.e. 26-29 April 2021 that varied between 209 µg/m$^3$ to 255.2 µg/m$^3$. Considering the real time data on peak levels is particularly important in the case of ozone pollution as this has immediate trigger effect on vulnerable population, real time data reporting has to be more robust and transparent.

## Frequency, distribution and intensity of exceedance of ozone standard

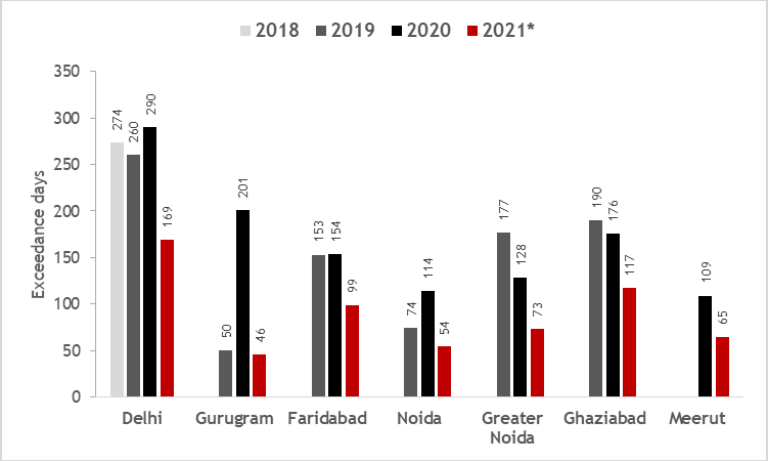
It is the frequency of exceedance in any part of the city and intensity of the pollution that matters more from health and mitigation perspective. Therefore, this analysis has tracked the individual stations and number of days in each station that have exceeded the standard over the years. This has captured three prominent trends – i) exceedance at least in one stations per day over the years; ii) exceedance in multiple stations changing over time - 0 station, 1-5, 6-10, 11-15, 16-20 and 20+ (Note that only Delhi has 40 stations; other cities in NCR have only 1- 4 stations); and; iii) extreme events when all or more than 16 or 20 stations have reported exceedance together on the same day.

- **Exceedance at least in one station per day over the years**: 8-hourly standard for ground-level ozone exceeded at least in one station in Delhi on 290 days in 2020 (this also includes days with multiple stations exceeding standard). It is up by 30 days compared to 2019 and 26 days more than 2018 (See *Graph 3: Annual trend in Ozone pollution in Delhi and major NCR cities*). This year has already recorded 169 days of exceedance during the first six month (Jan-June), increase of 21 days for same period last year.

  Among major cities of NCR, Gurugram saw maximum jump in number of exceedance days between 2019 and 2020. Its tally of 201 days in 2020 was an increase by over 300 per cent from previous year. Nodia also registered a jump but at a relatively moderate 54 per cent. Faridabad recorded no change between 2019 and 2020. Ghaziabad and Greater Noida saw decline in number of exceedance days. Ghaziabad registered 7 per cent lesser exceedance days in 2020 compared to 2019. The drop was of 28 per cent for Greater Noida. Meerut does not have adequate data for 2019 to carry out comparative trend but with 109 days of exceedance in 2020, it was the least polluted major city in NCR.

  Data for 2021 so far shows that exceedance numbers for Ghaizabad, Greater Noida, and Meerut have already crossed last year level in the first six months this year. Faridabad is showing no change this year as well. Noida and Gurugram show drop in their numbers.

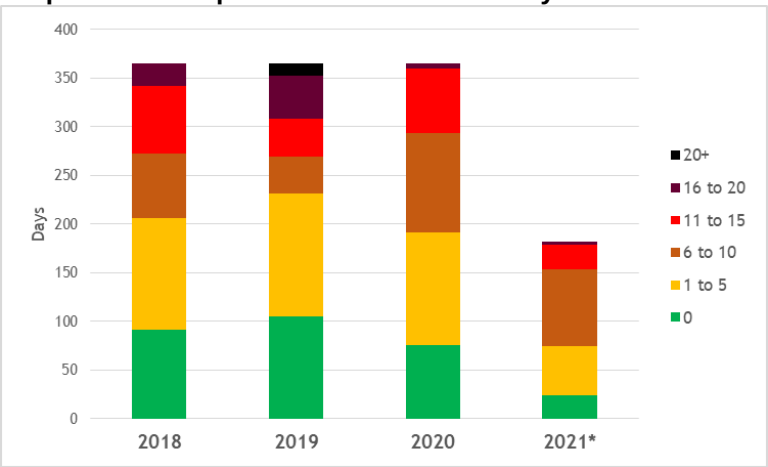
**Graph 3: Annual trend in exceedance in at least one station in Delhi and major NCR cities**




Note: City level exceedance is based at least one station in the city exceeding the 8-hr ozone standard on a particular day.
Source: CSE analysis of CPCB real-time data

- **Days with multiple stations exceeding the standard are on the rise:** This is a worrying trend. Not only some part of the city is breaching the standard daily, but now multiple locations have also started to breach indicating wider distribution of the risk. Break-up of annual data by number of stations reveals that there are more days when multiple stations exceed the standard. 2020 had 30 per cent more days when six or more stations exceeded the standard compared to 2019. This year already in its first half has registered 108 days when six or more stations exceeded the standard, higher than previous years (See *Graph 4: Break-up of annual exceedance by number of stations for Delhi*).

**Graph 4: Break-up of annual exceedance by number of stations for Delhi**




Note: Break-up of city level exceedance is based on number of stations in the city exceeding the 8-hr ozone standard on a day.
Source: CSE analysis of CPCB real-time data

- **Extreme events declining:** Despite the overall increase and more distributed instances of exceedance in the cities, extreme events (more than 20 stations exceeding the standard on a single day) have declined. Most instances of extreme event was recorded during the summer of 2019. This roughly coincided with one of the hottest and longest heat wave in North India since the weather reporting started in the region. Both 2020 and 2021 summers have been lighter on heat waves in comparison. Interestingly, even in 2019 the maximum ozone levels were not recorded on the hottest days, in fact the peak of 28 stations exceeding the standard fell on 20th June, 2019, a good week after the heat wave ended. Therefore, it is safe to say that ambient heat is not the primary driver of ozone build-up as generally perceived.

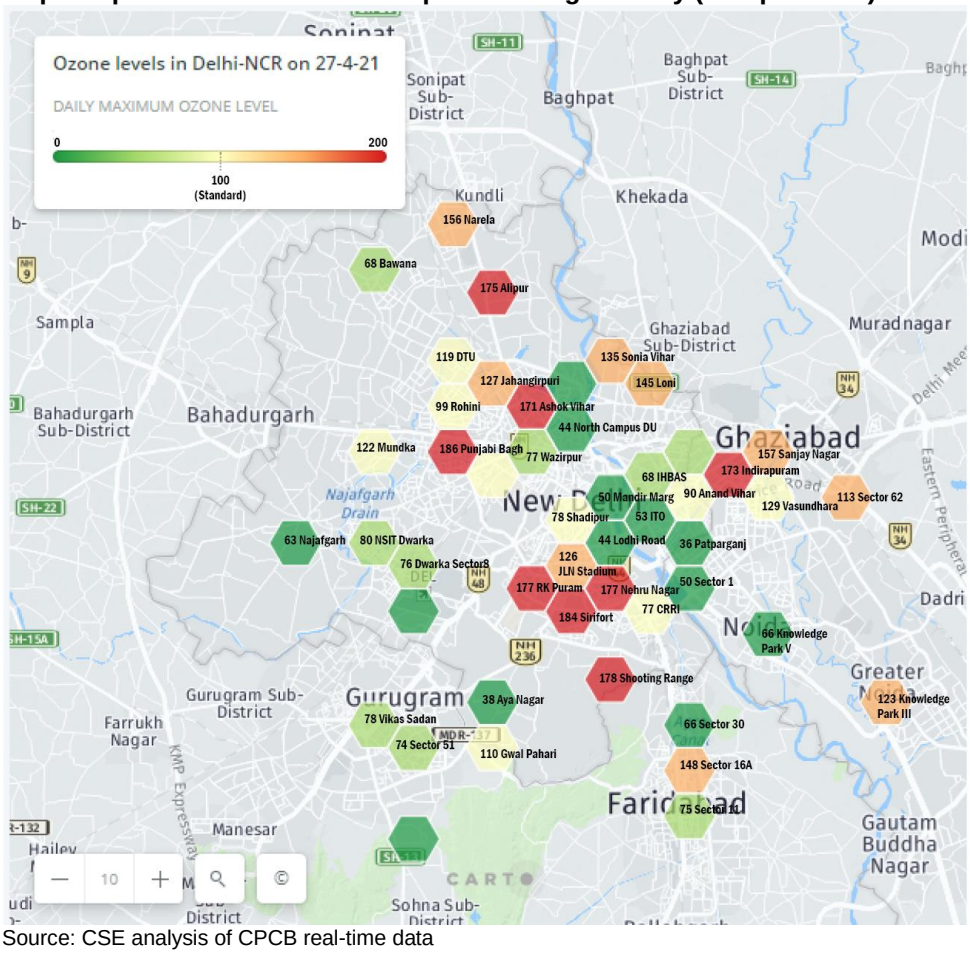
The summer of 2020 and 2021 have been unique due to pandemic lockdowns that drastically reduced non-ozone pollution and also ozone precursors in the city that form ozone. Taking this into account and considering that there were no major heat waves since 2019 in the city, the significant increase in number of days with exceedance at six or more stations in 2020 and 2021 is a major concern. It shows that ozone build-up in the city is happening at higher frequency with a wider geographical spread even with considerably lower supply of anthropogenic and environmental ingredients perceived to be necessary for ozone generation.

## Daily levels vary widely cross the city

The ozone level can vary dramatically within the city on any given day. This needs to be tracked on a daily basis.

Illustratively, on 27 April, 2021 Delhi saw high variation between locations – the difference could be as high as 150 µg/m3 (See *Map 1: Spatial variation in ozone pollution a given day*). On this day while the areas adjoining Yamuna, Lyuten's Delhi and west Delhi showed low ozone levels, the levels in south, central, and north Delhi recorded substantially higher levels. South-east Delhi had the highest levels that day. While some locations regularly appear as high ozone pollution zone in the city with high levels and prolonged duration, several other locations experience sporadic instances of exceedance.

**Map 1: Spatial variation in ozone pollution a given day (27 April 2021)**



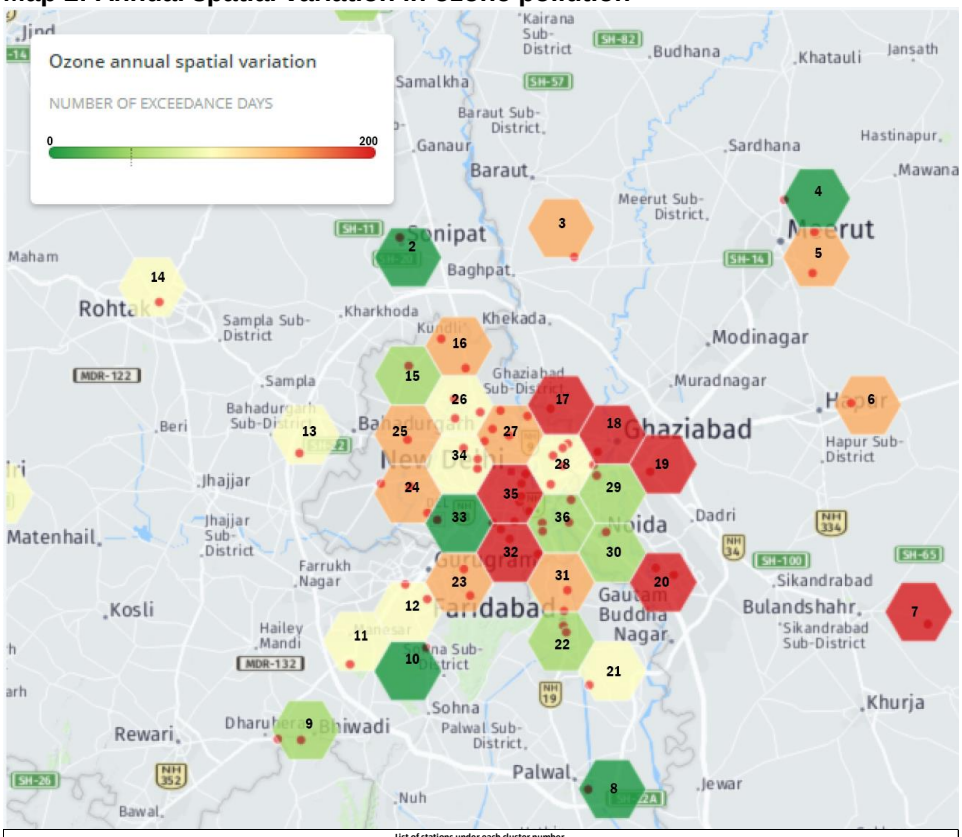

Source: CSE analysis of CPCB real-time data

## Cluster of ozone hotspots in South Delhi and Lutyen Delhi

If looked at from the perspective of the number of days exceeding the standard in a year, south, central and north Delhi along with Ghaziabad have recorded higher number of exceedance days. Comparatively the number of days in East Delhi, Nodia, and West Delhi have recorded lesser number of days. (See *Map 2: Annual spatial variation in ozone pollution*).

In South Delhi Dr KS Shooting Range (233 days), Sirifort (150 days), Nehru Nagar (174 days), and Sri Aurobindo Marg (126 days) have more than 120 exceedance days during 2020. They make up four of the top 5 most polluted spots within Delhi. In Lyuten's Delhi JNL Stadium (116 days) and National Stadium (82 days) have relatively high numbers of exceedance days as well. Both have recorded over 80 days of exceedance in 2020. North, East and West Delhi also have few stations recording high exceedance (Sonia Vihar in east Delhi had 142 days of exceedance) but these are not closely clustered as seen in South Delhi-Luyten Delhi region.

**Map 2: Annual spatial variation in ozone pollution**




List of stations under each cluster number.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Sonipat, HR | 15 | Bawana, DL | 23 | TeriGram, Gurugram, HR | 28 | IHBAS Dilshad Garden, DL | 34 | Pusa IMD, DL |
| 3 | Bagpat, UP | 16 | Narela, DL | 24 | Najafgarh, DL | 28 | ITO, DL | 34 | Shadipur, DL |
| 4 | Pallavpuram, Meerut, UP | 16 | Alipur, DL | 24 | Dwarka Sector 8, DL | 28 | Chandni Chowk IITM, DL | 34 | Mandir Marg, DL |
| 5 | Jaibhimnagar, Meerut, UP | 17 | Loni, , Ghaziabad, UP | 24 | NSIT Dwarka, DL | 29 | Patparganj, DL | 35 | Sirifort, DL |
| 5 | Ganganagar, Meerut, UP | 18 | Indirapuram, Ghaziabad, UP | 25 | Mundka, DL | 29 | Vivek Vihar, DL | 35 | Nehru Nagar, DL |
| 6 | Hapur, UP | 18 | Vasundhara, Ghaziabad, UP | 26 | DTU, DL | 29 | Sector 62, Noida, UP | 35 | JLN Stadium, DL |
| 7 | Bulandshahr , UP | 19 | Sanjay Nagar, , Ghaziabad, UP | 26 | Jahangirpuri, DL | 30 | Sector116, Noida, UP | 35 | National Stadium, DL |
| 8 | Palwal, HR | 20 | Knowledge Park III, Greater Noida, U | 26 | Rohini, DL | 31 | Sector 16A, Faridabad, HR | 35 | Lodhi Road IMD, DL |
| 9 | Dharuhera, HR | 20 | Knowledge Park V, Greater Noida, U | 27 | Sonia Vihar, DL | 31 | New Industrial Town, Faridabad, HR | 35 | Lodhi Road IITM, DL |
| 9 | Bhiwadi, RJ | 21 | Ballabgarh, HR | 27 | Ashok Vihar, DL | 32 | Dr KS Shooting Range, DL | 36 | Okhla Phase 2, DL |
| 10 | Mandikhera, HR | 22 | Sector 30, , Faridabad, HR | 27 | Wazirpur, DL | 32 | Sri Aurobindo Marg, DL | 36 | CRRI Mathura Road, DL |
| 11 | Manesar, HR | 22 | Sector 11, , Faridabad, HR | 27 | North Campus DU, DL | 32 | RK Puram, DL | 36 | Sector 1, Noida, UP |
| 12 | Sector 51, Gurugram, HR | 23 | Aya Nagar, DL | 27 | Burari Crossing, DL | 33 | IGI Airport T3, DL | 36 | Sector 125, Noida, UP |
| 13 | Bahadurgarh, HR | 23 | Gwal Pahari, Gurugram, HR | 28 | East Arjun Nagar, DL | 34 | Punjabi Bagh, DL | | |
| 14 | Rohtak, HR | 23 | Vikas Sadan, Gurugram, HR | 28 | Anand Vihar, DL | 34 | Pusa DPCC, DL | | |

Note: Clustered are determined by spatial distance. A cluster can have single or multiple stations within it based on density of stations in the area. Color of cluster represents relative severity of ozone exceedance in that cluster compared to other clusters. Yellow represents median severity. Light green is marginally less than median, dark green is significantly less than the median. Similarly, orange is marginarly higher than the median and red is significantly higher than the median.

Source: CSE analysis of CPCB real-time data

## Ground-level ozone is a year-round problem

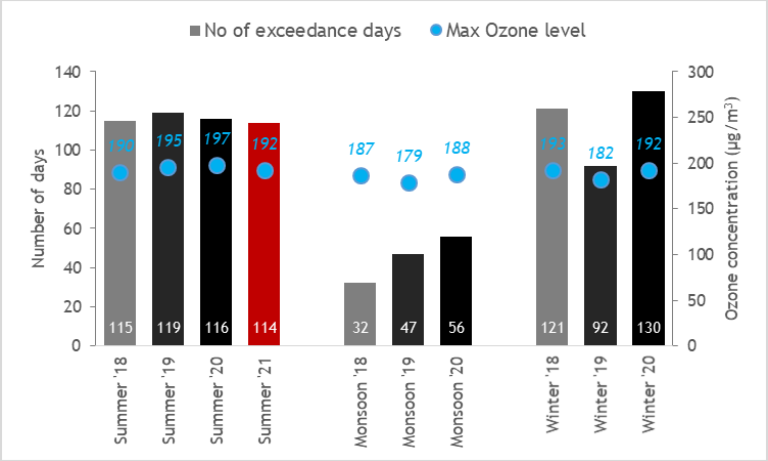
This analysis has also bust the myth that ozone is only a summer problem and is not a concern during colder months. It has come as a surprise how the number of days exceeding the standards across stations are well distributed across the months and seasons. Days breaching the 8-hr standard is happening throughout the year despite varying weather conditions. As the formation of ozone is highly dependent on the local atmospheric chemistry the levels vary widely across the city. It may be more helpful to understand the seasonal pattern of exceedance across monitoring locations. It has been found that there can be days when even with fewer stations exceeding the standards, the city average can be higher than days when more stations across the city exceed the standards. It is necessary to understand this daily spatial spread as the local health impacts can be higher.

This analysis has captured nature and level of exceedance in different parts of the city while also noting the city average level. Moreover, there is another limitation with regard to computing city average and peak levels. As mentioned earlier, currently, in the CPCB portal ozone levels above 200 µg/m$^3$ is not recorded. This capping does not allow estimation of peak levels and real world maximum averages for cities. When levels breach the standard in any monitoring location the levels reach nearly the same maximum 8-hr ozone levels. This is certainly a side-effect of capping of maximum value reported by CPCB. Thus, the capping stunts the reported peak level as 8-hr average cannot breach 200 µg/m$^3$.

## Ozone is a problem of all seasons – even winter and monsoon

The stunning aspect of the ozone phenomenon is that this problem of ozone that is normally treated as a sunny summer problem, is evidently a concern even during the winter. This has not been adequately tracked and studied to inform policy. This analysis has found unsafe ozone levels during winter and especially during smog episode making the smog more toxic. (See *Graph 5: Ozone pollution is growing in monsoon and winter*).

**Graph 5: Ozone pollution is growing in monsoon and winter**




Source: CSE analysis of CPCB real-time data

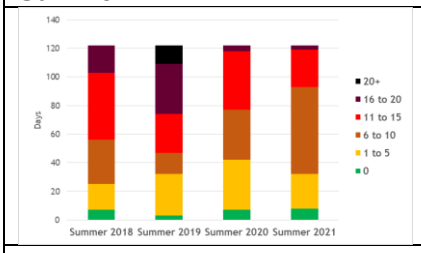
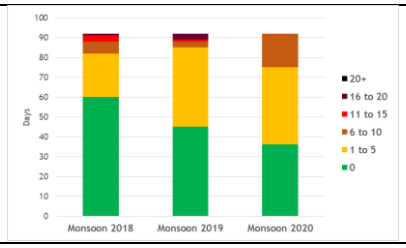
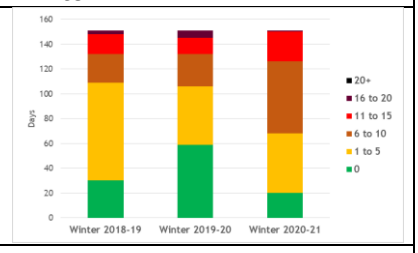
Most of the shift in annual number are due to uncharacteristic increase in ozone during monsoon and winter. Winter of 2020-21 shows a dramatic 84 per cent increase in number of days with six or more stations exceeding the standard. In fact, there is a 32 per cent increase in number of days when more than 10 stations exceeded the standard during 2020-21 winter compared to previous two winters (See *Graph 6: Seasonal break-up of annual exceedance by number of stations: a) Summer, b) Monsoon, c) Winter*).
In comparison, summer data looks quite stable over years. 2021 summer has had 90 days with six or more stations exceeding the standard, which is identical to 2019 summer and 10 days more than 2020 summer. This is despite the fact 2021 summer was one of the mildest in recent years with no severe heat waves reported.

This shift in seasonal pattern is worrying given the fact that monsoon and the foggy-smoggy winters of Delhi that are characterized by low sunshine are not expected to be conducive for ozone formation. This means

the strategy for combating ozone in the city would have to be reworked and start looking beyond summer action plan.

Monsoon data is another shocker. 2020 monsoon saw 140 per cent more days with six or more stations exceeding the standard compared to 2019 monsoon. If looked from the perspective from days when no exceedance was recorded in the city, 2020 monsoon had only 36 such days, while the number for 2019 monsoon was 45 days and for 2018 monsoon 60 days.

**Graph 6: Seasonal break-up of annual exceedance by number of stations:**

| Summer | Monsoon | Winter |
|---|---|---|
|  |  |  |



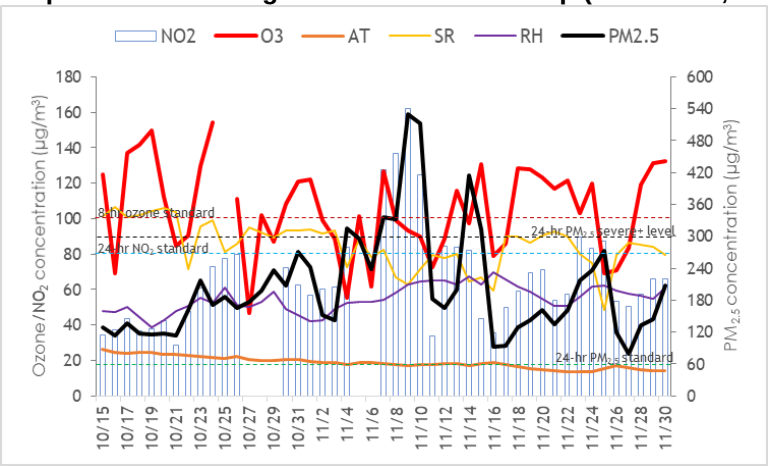
Note: Break-up of city level exceedance is based on number of stations in the city exceeding the 8-hr ozone standard on a particular day. Summer is considered from March to June, monsoon from July to September, and winter from October to February.
Source: CSE analysis of CPCB real-time data

## Ozone during winter smog episodes

How ozone behaves during the winter smog episode is still the least understood phenomenon. To understand this, data on Ozone, $PM_{2.5}$ and $NO_2$ levels in RK Puram were analysed for the smog season of 2020. It is a matter of concern that ozone has remained high throughout the winter smog season. There is minor drop noted on the peak smog day when the solar radiation was considerably lower, but as soon as the wind improved and removed $PM_{2.5}$, ozone levels spiked up. During these few days, even high level of $NO_2$ in the air did not seem to have considerable impact on reducing ozone levels (See *Graph 7: Winter Smog and ozone relationship*).

This shows how dangerously elevated levels of ozone and $NO_2$ remain masked by the big build-up of $PM_{2.5}$ levels and fails to draw public and policy attention. This neglect can increase health risk. Elevated level of ozone and $NO_2$ makes the smog more toxic. Further, ozone builds up again after thinning of the smog episode means that the toxic treat persists during winter.

**Graph 7: Winter smog and ozone relationship (RK Puram, 15 Oct – 30 Nov 2020)**




Source: CSE analysis of CPCB real-time data

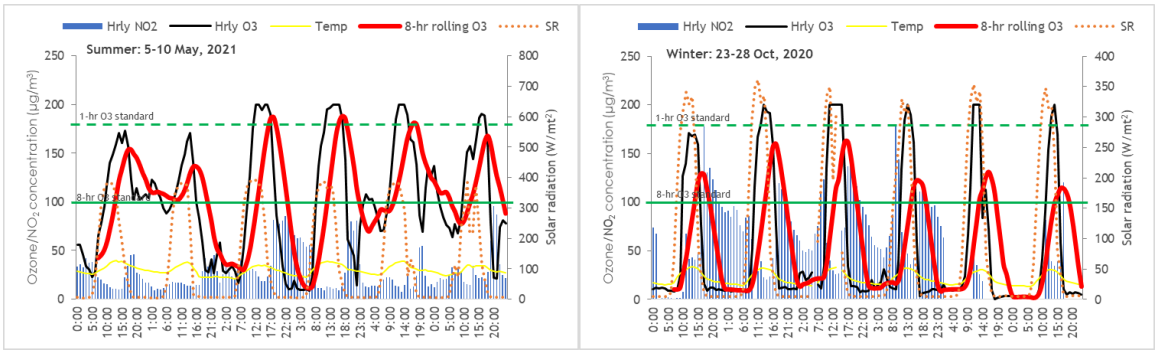
## Meteorology aids in ozone formation both during summer and winter

It is now well understood that sunshine plays a critical role in triggering photochemical reaction between gases to form ozone and it is typically expected that ozone is a bigger problem in summer. But the problem seems to be quite uniformly spread across seasons. To understand this phenomenon, ozone data from two stations RK Puram and Sirifort were correlated with solar radiation, temperature, and $NO_2$ to understand spatial differences and difference between summer and winter. It was noted that hourly peak ozone level in the day perfectly corresponds with the peak solar radiation but it is not proportional. Quantum of ozone generated at 600-700 W/mt$^2$ of solar radiation during summer was identical to ozone generated at 100-300 W/mt$^2$ of solar radiation during winter. However, temperature does not seem to have as much impact on increasing the concentration. But night time ozone seems to have some relationship with higher night-time temperature. This needs to be further investigated. Similarly, $NO_2$ and ozone that has a very strong negative relationship during summer somewhat weakens during winter. Winter ozone has a much defined diurnal cycle compared to summer. This can also be further investigated.

In RK Puram, the rolling 8hr average remained above the standard for significant 31 hours between 5$^{th}$ and 6$^{th}$ of May, 2021 (See *Graph 8: Trend in hourly ozone pollution at RK Puram*). Drop in ozone level during evening rush hours was noted but levels rapidly build-up post 10-11 PM indicating presence of low level inversion in the neighbourhood. Similar summer trend was noted at Sirifort (See *Graph 9: Trend in hourly ozone pollution at Sirifort*).

**Graph 8: Trend in hourly ozone pollution at RK Puram**

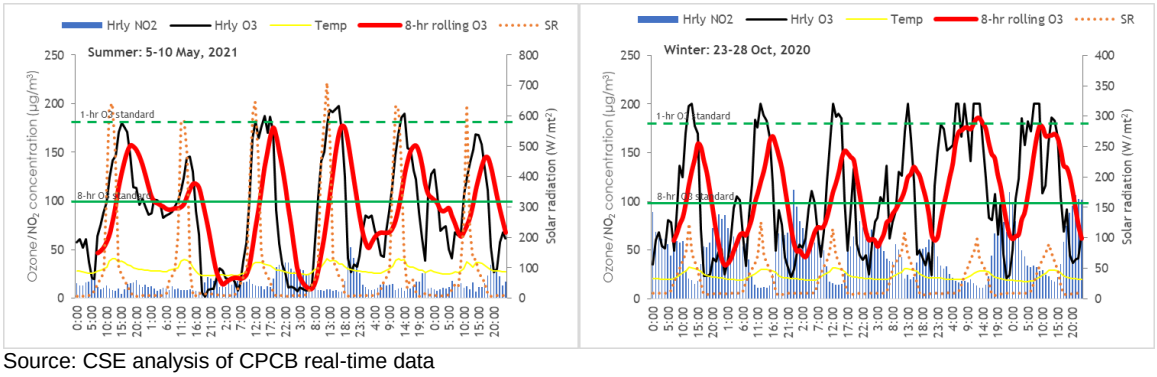
**i) Summer (5-10 May 2021)** **ii) Winter (23-29 Oct 2020)**




Source: CSE analysis of CPCB real-time data

**Graph 9: Trend in hourly ozone pollution at Sirifort**

**i) Summer (5-10 May 2021)** **ii) Winter (23-29 Oct 2020)**




Source: CSE analysis of CPCB real-time data

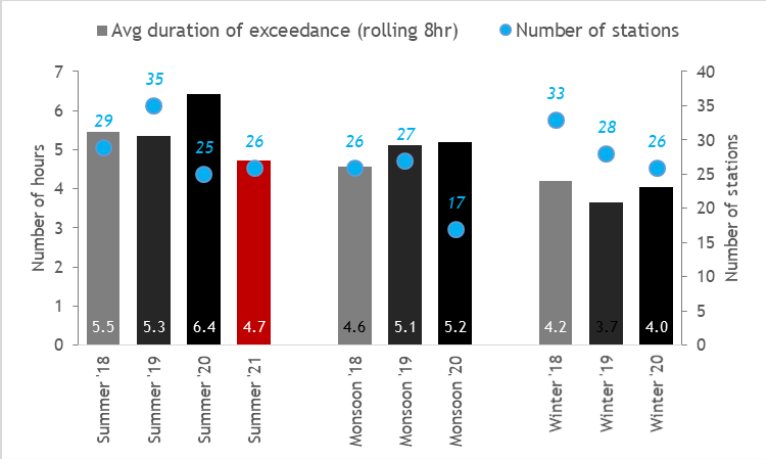
## Pandemic effect – ozone problem persisted and duration of ozone exceedance also increased

Ozone behaved very differently from other pollutants during the lockdown phases. While particulate and NOx levels dropped quite significantly and predictably, ozone levels recorded high levels in several locations. During the pandemic year of 2020, days recording exceedance was also noted during monsoon months.

Also the duration of high elevated levels for number of hours increased during the lockdown phases. For instance, the stations noting exceedance of the 8-hr ozone standard during the summer of 2019 recorded continuous elevation for about 5.3 hours during the day. But this duration jumped by 20 per cent during the 2020 summer lockdown due to the pandemic. This increase in duration of elevated levels was also noted during monsoon and winter that followed in 2020 (See *Graph 10: Average duration (in hours) of ozone standard exceedance in a day*).

This needs to be studied further in terms of how the ratio between NOx and VOC level behaved during these phases to understand the deeper pattern that contributed to ozone formation. It is also quite possible that with lower day time and night time NOx during this period (largely owing to reduced traffic) ozone had less chance of further reacting to get mopped up. This might have slowed down the breaking process of ozone leading to longer duration and elevation of heightened levels.

**Graph 10: Average duration (in hours) of ozone standard exceedance in a day**




Source: CSE analysis of CPCB real-time data

It is also notable that even though the regular ozone hotspots in the city registered prolonged duration of elevated levels, several locations that otherwise recorded sporadic instances of exceedance before the pandemic, did not experience any exceedance during the pandemic. For example, DU North Campus, Aya Nagar, and Patparganj which had registered a 6-10 days of exceedance in summer of 2019 have not registered a single day with exceedance during the summer of 2020 and 2021.

But there are also places that were not noted as ozone hotspots before the pandemic but registered significant number of days with exceedances during the pandemic. Ananda Vihar is most striking among such places. It had less than 5 days of exceedances during previous two summers (2018 and 2019) but during the pandemic summer it registered 49 days of exceedances. It highlights the volatile nature of ozone formation and build-up which is aided by calm environmental conditions which was made available by lockdowns.

## Night time ozone higher during pandemic lockdown and night curfews

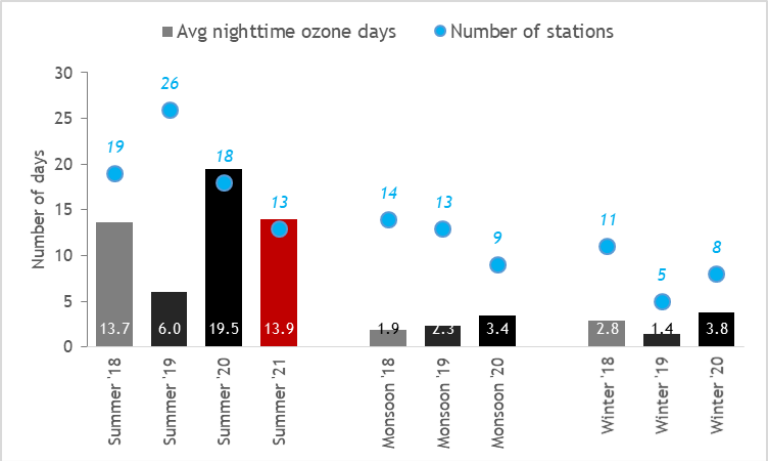
Ozone generally disintegrates in the atmosphere after sunset as in the absence of sunlight NOx in the air attacks and neutralizes it. But as evident from the data, elevated ozone level has been noticed during night time. International scientific literature has also noted this phenomenon in other countries stating that this is connected with persisting low level inversions, under which the photochemically generated ozone is trapped during the day. With the gradual setting in of inversion towards the evening and reduced traffic, ozone levels

rise, remaining above standard even after midnight. This uncommon phenomena seems to have become common-place in Delhi during the pandemic when number of day with high night time levels have breached 100µg/m$^3$ after 10PM (See *Graph 11: Night time ozone in Delhi*).

Hourly ozone level were found to be in excess of 100 µg/m$^3$ beyond 10PM at 18 Delhi stations during the Pandemic summer of 2020. These stations on an average registered this unusually high levels on 19-20 nights during the summer. Dr Karni Singh Shooting Range with 54 nights was the most affected with nighttime ozone, followed by Sirifort (44 nights) and Nehru Nagar (34 nights). Numbers are relatively lower this summer.

**Graph 11: Night time ozone pollution in Delhi**

*Average number of days with high night time ozone (>100µg/m$^3$ after 10PM) in Delhi*




Source: CSE analysis of CPCB real-time data

## Ozone pollution in major NCR cities

Ozone is also an emerging problem in the NCR. After Delhi, Faridabad is next on the list with the station at Sector 16A recording 152 days of exceedance during 2020. There is considerable spatial variation among Faridabad stations. Station at New Industrial Town recorded just three instances of exceedance in 2020, two of which happened during winter. Stations at Gurugram and Ghaziabad also have very high number of days exceeding the standard. There are more exceedances recorded during summer than winter among Ghaziabad stations.

All stations in Ghaziabad have very high exceedances while Gurugram is more like neighbouring Faridabad with considerable spatial variation among its stations. Vikas Sadan with 139 days of exceedance was the most polluted part of the city while Terigram recorded just 35 days of exceedances (mostly during winter). Noida has shown the least number of days with exceedance among the big four cities in NCR, with three of its four of its stations recording less than 20 days of exceedance in 2020. Neighbouring Greater Noida has considerably higher number of exceedances, with majority happening during winters. (See *Annexure 1: Number of days that exceeded the 8-hourly ozone standard in different locations of Delhi and NCR*).

## Top twenty locations in Delhi and NCR with higher number of days with exceedance shows ozone is also a small town problem

When cities and towns in Delhi and NCR are ranked in terms of number of days exceeding the standards, even smaller towns of NCR including Bulandshahr in Uttar Pradesh and Bhiwani in Haryana are next on the list of ozone afflicted towns and cities. Dr Karni Singh Shooting Range, Bulandshahr, and Nehru Nagar were the most polluted spots in Delhi-NCR in 2020. Bulandshahr at second spot is shockingly as smaller cities are usually not seen as ozone hotspots. Bhiwani, HR is another small town that makes the list at 11$^{th}$ spot, and its 2021 data so far is indicating it might move up the list this year. Stations from Gurugram, Ghaziabad and Faridabad also feature among the top 10 (See *Table 1: Top 20 locations with highest ozone pollution in NCR*).

However, the small towns have only one monitoring station which is not adequate to capture the spatial variation and its location may also not be optimum for capturing ozone pollution as it is highly localized. Inadequate data reaffirms the fact that there is no room for complacency.

**Table 1: Top 20 locations with highest ozone pollution in NCR**

| Rank | Station name | 2020 exceedance days | 2021 exceedance days so far |
|---|---|---|---|
| **1** | Dr KS Shooting Range, DL | 233 | 135 |
| **2** | Bulandshahr, UP | 214 | 119 |
| **3** | Nehru Nagar, DL | 174 | 120 |
| **4** | Sector 16A, Faridabad, HR | 152 | 94 |
| **5** | Sirifort, DL | 150 | 119 |
| **6** | Sonia Vihar, DL | 142 | 57 |
| **7** | Vikas Sadan, Gurugram, HR | 139 | 19 |
| **8** | Indirapuram, Ghaziabad, UP | 129 | 83 |
| **9** | Sri Aurobindo Marg, DL | 126 | 134 |
| **10** | DTU, DL | 122 | 17 |
| **11** | Bhiwani, HR | 120 | 93 |
| **12** | JLN Stadium, DL | 116 | 33 |
| **13** | Sector 51, Gurugram, HR | 110 | 9 |
| **14** | Jai Bhim Nagar, Meerut, UP | 106 | 44 |
| **15** | Knowledge Park III, Greater Noida, UP | 104 | 38 |
| **16** | Sector 1, Noida, UP | 103 | 9 |
| **17** | Dwarka Sector 8, DL | 102 | 4 |
| **18** | Bawana, DL | 100 | 2 |
| **19** | Knowledge Park V, Greater Noida, UP | 89 | 50 |
| **20** | RK Puram, DL | 87 | 90 |

Note: Ranks are based on number of exceedance days recorded in 2020. Data for 2021 is up till 18 July, and is meant to provide information about current year but has not been used for ranking calculation. Many locations lower in this list have recorded exceptionally high rate of exceedances in 2021 compared to 2020 and are thus highlighted in yellow.

Source: CSE analysis of CPCB real-time data

## Daily trend and Air Quality Index bulletin must capture the intensity and spread of ozone pollution across locations

The analysis has shown that the current method of spatial averaging of ozone for city-wide averages for computing city-wide trend and AQI may not effectively capture the most polluted part of the day and therefore the magnitude of the danger. Nature of ozone pollution is such that at any given day only a fraction of city's monitoring stations would exceed the standard. By averaging all stations for daily AQI bulletin severity of the localized impact of zone pollution gets masked.

Further, the CPCB AQI bulletin considers only an 8 AM-4 PM concentration average of ozone to compute and compare with the eight-hour standard. But this analysis shows that this approach is not correct as it may fail to include the hours with higher elevation. Ozone concentration generally peaks in the late afternoon in Delhi and the usual peak hour is either 4-5 PM or 5-6 PM during summer. Therefore, exclusively using 8 AM-4 PM averages leaves out the most polluted hours from the calculations. For instance, on July 16, 2021, the eight-hour average for RK Puram for 8 AM-4 PM stood at 96 µg/m$^3$, just below the standard. But the eight-hour average for 10 AM-7 PM rose to 103 µg/m$^3$, above the standard. In fact, data shows that even the 4 PM-midnight average can exceed the standard, something CPCB's AQI bulletin currently fails to inform.

This approach has to change. For instance, the USEPA uses maximum 8-hr value recorded in a day to report daily AQI. The AQI is also station based. They do not do spatial averaging. Additionally, they also do real time AQI release under their AirNow program which is updated every hour for ozone.[1] Moreover, USEPA's AQI related health warnings are different ozone and particulate matter. If ozone is the lead pollutant of the day the warning will be more explicit as ozone is sensitive for more vulnerable groups.

[1] USEPA 2018, Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI).

## Need urgent response

**Address health risk from ozone in national clean air programme and in comprehensive clean air action plan for Delhi NCR:** This analysis has exposed that ground level ozone is emerging as a serious health risk in the region. This highly reactive gas has serious health consequences for those suffering from respiratory conditions and asthma. This needs refined action to reduce the risk.

**Refine the comprehensive clean air action plan to include ozone mitigation strategies:** The comprehensive clean air action plan as well as graded response action plan that are being currently implemented in Delhi and NCR need to be recalibrated to reduce the key precursor gases – particularly NOx and VOCs that come entirely from the combustion sources. Their changing ratio and local atmospheric conditions need to be assessed to control and prevent ozone risk. Specific action is needed to control gases from combustion sources. If action plan focuses only on controlling particulate pollution, ozone can grow as a bigger threat that will be difficult to undo. Over emphasis on dust control to reduce particulate matter and other particulate related action may increase the ozone problem. This demands integrated reduction strategy for both the pollutants.

**Take strong action on high emitters of NOx and VOCs – vehicles and industry**: The recent source inventory studies in Delhi have shown that the transport sector is the highest contributor of NOx and VOCs in Delhi followed by industry and other sources. The SAFAR emission inventory of 2018 shows that transport is responsible for 62.5 per cent of NOx load and industry 24 per cent. In the case of VOCs transport is responsible for as much as 90.4 per cent followed by industry at 9 per cent. Similarly, the ARAI-TERI inventory that has considered more pollution sources indicate that transport is responsible for 81.4 per cent of NOx load followed by power plant at 7.2 per cent. For VOCs transport is responsible for 80.1 per cent followed by solvents at 13.4 per cent. Other contributors are waste burning. This demands immediate refinement of measures to target vehicles, transport and industrial sources in Delhi. Over emphasis on dust control for particulate pollution can detract attention from the more toxic sources.

While scaling up public transport and vehicle electrification, also restrain vehicle numbers with parking policy and pricing, congestion pricing and road design to promote walking cycling and use of public transport. Industrial sector will require massive scaling up of clean fuels and control of dirty fuels especially small scale units and strong controls on stack emissions. Also strengthen municipal systems for decentralised systems for waste segregation, material recovery and reuse and move towards zero landfill target.

**Include ozone in winter smog mitigation plan:** It is deeply worrying that the ozone levels have been found to be exceeding the mark of 100 µg/m$^3$ during both summer and winter and is highly sensitive to solar radiation. In fact, not only the number of days exceeding the standard in different locations during winter is high, it also spikes after the dimming effect of particulate matter is reduced after dissipation of the smog episodes. Both NOx and VOCs will have to be effectively reduced to tame ozone. Also, the other benefit of reducing gases includes reduction of particulate concentration as these gases also form secondary particulate and contribute towards increase in particulate concentration. The IIT Kanpur source apportionment study has shown that secondary particulate can be as high as 25 per cent of the particulate concentration during the winter in Delhi.

**Refine the approach to ozone trend analysis and AQI reporting to provide ozone appropriate advisory on days when ozone is the lead pollutant:** As ozone is a very harmful gas it is important to calibrate AQI to report the most polluted 8 hr average of the day, ideally making it an hourly alert. Also the current practice of only city averaging needs to change to include alerts based on the worst affected area as is the global good practice. Moreover, any capping of data needs to be avoided for real time reporting to enable assessment of peak levels and health risk in the city. Capping can hamper assessment of both hourly trend and 8 hourly trend, as ozone standards are set for one hour (180 µg/m$^3$) average and 8 hour average (100 µg/m$^3$). Such short term standards are needed to reduce the health risk from this extremely reactive and harmful gas.

**Annexure 1: Number of days that exceeded the 8-hourly ozone standard in different locations of Delhi and NCR (2020 and 2021)**

| | Station name | 2020 exceedance days | Seasonal exceedance days* | | | |
|---|---|---|---|---|---|---|
| | | | 2021 summer | 2020-21 winter | 2020 monsoon | 2020 summer |
| | **Delhi** | | | | | |
| | Dr KS Shooting Range, DL | **233** | 103 | 87 | 43 | 105 |
| | Sirifort, DL | **150** | 84 | 96 | 16 | 70 |
| | Nehru Nagar, DL | **174** | 94 | 69 | 26 | 87 |
| | Sri Aurobindo Marg, DL | **126** | 100 | 54 | 0 | 72 |
| | RK Puram, DL | **87** | 83 | 56 | 14 | 20 |
| | Punjabi Bagh, DL | **19** | 88 | 44 | 0 | 0 |
| | Sonia Vihar, DL | **142** | 52 | 59 | 16 | 46 |
| | Ashok Vihar, DL | **43** | 67 | 40 | 0 | 8 |
| | Najafgarh, DL | **74** | 13 | 82 | 0 | 6 |
| | Narela, DL | **87** | 49 | 39 | 0 | 43 |
| | Alipur, DL | **58** | 45 | 32 | 0 | 27 |
| | JLN Stadium, DL | **116** | 25 | 33 | 15 | 61 |
| | National Stadium, DL | **82** | 3 | 34 | 26 | 26 |
| | Mundka, DL | **78** | 23 | 28 | 0 | 39 |
| | Dwarka Sector 8, DL | **102** | 2 | 36 | 10 | 56 |
| | DTU, DL | **122** | 17 | 15 | 15 | 85 |
| | Jahangirpuri, DL | **27** | 22 | 25 | 0 | 2 |
| | Okhla Phase 2, DL | **18** | 27 | 9 | 7 | 1 |
| | East Arjun Nagar, DL | **19** | 1 | 38 | 0 | 0 |
| | Bawana, DL | **100** | 2 | 16 | 4 | 70 |
| | Anand Vihar, DL | **64** | 6 | 2 | 13 | 49 |
| | Pusa DPCC, DL | **35** | 11 | 0 | 4 | 29 |
| | IGI Airport T3, DL | **5** | 0 | 3 | 2 | 0 |
| | Pusa IMD, DL | **4** | 0 | 3 | 1 | 0 |
| | Shadipur, DL | **22** | 3 | 0 | 0 | 22 |
| | Rohini, DL | **0** | 3 | 0 | 0 | 0 |
| | Wazirpur, DL | **3** | 0 | 3 | 0 | 2 |
| | CRRI Mathura Road, DL | **1** | 1 | 0 | 1 | 0 |
| | NSIT Dwarka, DL | **34** | 1 | 1 | 0 | 33 |
| | Lodhi Road IMD, DL | **2** | 0 | 0 | 2 | 0 |
| | Mandir Marg, DL | **2** | 0 | 1 | 0 | 0 |
| | IHBAS Dilshad Garden, DL | **0** | 0 | 0 | 0 | 0 |
| | ITO, DL | **13** | 0 | 0 | 0 | 13 |
| | North Campus DU, DL | **0** | 0 | 0 | 0 | 0 |
| | Aya Nagar, DL | **0** | 0 | 0 | 0 | 0 |
| | Burari Crossing, DL | **0** | 0 | 0 | 0 | 0 |
| | Chandni Chowk IITM, DL | **0** | 0 | 0 | 0 | 0 |
| | Lodhi Road IITM, DL | **0** | 0 | 0 | 0 | 0 |
| | Patparganj, DL | **0** | 0 | 0 | 0 | 0 |
| | Vivek Vihar, DL | **1** | 0 | 0 | 0 | 1 |
| | **Haryana** | | | | | |
| | **Faridabad** | | | | | |
| | Sector 16A, Faridabad, HR | **152** | 82 | 32 | 24 | 77 |
| | New Industrial Town, Faridabad, HR | **3** | 32 | 0 | 0 | 3 |
| | Sector 30, , Faridabad, HR | **5** | 12 | 4 | 0 | 1 |
| | Sector 11, , Faridabad, HR | **6** | 1 | 2 | 0 | 4 |
| | **Gurugram** | | | | | |
| | Gwal Pahari, Gurugram, HR | **79** | 31 | 63 | 12 | 6 |
| | Vikas Sadan, Gurugram, HR | **139** | 19 | 26 | 10 | 84 |
| | Sector 51, Gurugram, HR | **110** | 9 | 8 | 9 | 93 |
| | TeriGram, Gurugram, HR | **35** | 0 | 4 | 0 | 31 |
| | **Other Haryana cities** | | | | | |
| | Bhiwani, HR | **120** | 77 | 82 | 14 | 23 |
| | Charkhi Dadri, HR | **69** | 0 | 32 | 10 | 27 |
| | Bahadurgarh, HR | **29** | 19 | 21 | 0 | 8 |
| | Manesar, HR | **32** | 6 | 30 | 0 | 2 |
| | Ballabgarh, HR | **37** | 1 | 0 | 31 | 6 |
| | Rohtak, HR | **14** | 18 | 14 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Panipat, HR | **46** | 0 | 28 | 0 | 17 |
| | Jind, HR | **50** | 9 | 0 | 7 | 40 |
| | Karnal, HR | **5** | 13 | 0 | 0 | 5 |
| | Dharuhera, HR | **13** | 1 | 6 | 0 | 6 |
| | Mandikhera, HR | **32** | 0 | 0 | 0 | 25 |
| | Narnaul, HR | **0** | 0 | 0 | 0 | 0 |
| | Palwal, HR | **0** | 0 | 0 | 0 | 0 |
| | Sonipat, HR | **0** | 0 | 0 | 0 | 0 |
| **Uttar Pradesh** | | | | | | |
| **Ghaziabad** | | | | | | |
| | Indirapuram, Ghaziabad, UP | **129** | 66 | 55 | 32 | 57 |
| | Vasundhara, Ghaziabad, UP | **82** | 64 | 22 | 28 | 26 |
| | Sanjay Nagar, , Ghaziabad, UP | **43** | 67 | 23 | 7 | 13 |
| | Loni, , Ghaziabad, UP | **68** | 60 | 27 | 2 | 49 |
| **Greater Noida** | | | | | | |
| | Knowledge Park III, Greater Noida, UP | **104** | 30 | 62 | 7 | 37 |
| | Knowledge Park V, Greater Noida, UP | **89** | 42 | 41 | 5 | 41 |
| **Meerut** | | | | | | |
| | Jaibhimnagar, Meerut, UP | **106** | 36 | 63 | 9 | 26 |
| | Ganganagar, Meerut, UP | **5** | 18 | 10 | 0 | 0 |
| | Pallavpuram, Meerut, UP | **0** | 5 | 0 | 0 | 0 |
| **Noida** | | | | | | |
| | Sector 62, Noida, UP | **19** | 24 | 2 | 0 | 16 |
| | Sector116, Noida, UP | **6** | 18 | 7 | 1 | 1 |
| | Sector 1, Noida, UP | **103** | 2 | 4 | 13 | 68 |
| | Sector 125, Noida, UP | **1** | 0 | 1 | 0 | 0 |
| **Other UP cities** | | | | | | |
| | Bulandshahr , UP | **214** | 92 | 80 | 16 | 93 |
| | Bagpat, UP | **76** | 4 | 55 | 14 | 9 |
| | Hapur, UP | **18** | 44 | 18 | 0 | 0 |
| | Muzaffarnagar, UP | **0** | 0 | 0 | 0 | 0 |
| **Rajasthan** | | | | | | |
| | Bhiwadi, RJ | **7** | 4 | 4 | 0 | 2 |
| | Alwar, RJ | **12** | 0 | 6 | 0 | 3 |

Note: Stations are arranged based geography and on any kind of ranking in this table.
* Seasonal data provided in the table will not add up to 2020 figure as 2020-21 winter includes data of Jan-Feb of 2021. Summer is considered from March to June, monsoon from July to September, and winter from October to February.
Source: CSE analysis of CPCB real-time data