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# Ozone in Nehru Nagar, Delhi: Five Years of Patterns and Data Quality (2019–2023)

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**ABSTRACT:** We studied ground-level ozone at Nehru Nagar, a residential area in south Delhi. We used hourly CPCB data from 2019 to 2023. This is the first published description of the daily ozone cycle at this station.

We have two main findings.

First, data quality. In post-monsoon (October–November) and winter (December–February), the ozone values were too high to be real. The 21:00 IST means were 299.3 μg m$^{-3}$ and 348.9 μg m$^{-3}$. These are about 4–8 times and 6–17 times the ranges seen at other Delhi stations (40–80 and 20–60 μg m$^{-3}$). We think the UV ozone monitor made an error. We left these two seasons out of the main analysis.

Second, daily patterns. In summer, ozone peaked at 09:00 IST. The mean was 255.6 ± 5.7 μg m$^{-3}$ (95% CI [244.4, 266.7]). This is four to six hours earlier than at other Delhi stations. Across 333 summer days, the peak hour changed a lot: 36% of days peaked in the morning (06:00–11:00 IST) and 38% at night (18:00–23:00 IST). The single most common peak hour was 21:00 IST (56 of 333 days, 17%). Morning ozone was higher than afternoon ozone, and this difference passed strict significance tests.

The monsoon looked normal. It peaked at 21:00 IST (119.1 μg m$^{-3}$), which matches ozone-rich air coming down from above at night.

During the 2020 COVID lockdown, summer morning ozone fell by 89.9 μg m$^{-3}$ (38%). That summer was 2.6 °C cooler, which may explain 10–15 μg m$^{-3}$ of the drop. So most of the fall is not explained by temperature.

## 1. INTRODUCTION

Ground-level ozone is a summer pollutant in Delhi. Its 24-hour pattern - its diurnal cycle - tells us about photochemical production, NOx titration, and how the air mixes. It also tells us if the instrument is working well.

At other Delhi stations, ozone peaks in the afternoon, between 12:00 and 15:00 IST. This was seen at ITO (Jain et al., 2005), Lodhi Road (Sharma et al., 2016), and Sri Aurobindo Marg (Dhawan et al., 2022), and across major Indian cities (Kutal et al., 2022). Across Delhi stations, summer is the seasonal ozone maximum and winter the minimum (Sharma et al., 2024).

No published study has looked at the diurnal ozone cycle at Nehru Nagar DPCC (28.57°N, 77.26°E). This station is in the CPCB CAAQMS network and has run since 2017. Our paper fills this gap using five years of data (2019–2023).

Our main finding is about data quality. Two of the four meteorological seasons at Nehru Nagar show ozone values that are 4–8 and 6–17 times the published ranges for other Delhi stations. These records need an instrument audit before they can be used for science or regulation.

For the two seasons that look credible (summer and monsoon), we used circular statistics to study day-to-day changes in peak hour. We also tested how the results change under different data caps, and we measured the 2020 lockdown effect with formal tests.

## 2. DATA AND METHODS

### 2.1 Data source

We took hourly ozone data from the OpenCity platform (data.opencity.in/dataset/delhi-hourly-air-quality-reports). This platform archives CPCB CAAQMS records without changing them. We checked a random set of 500 hourly values from 2021 against CPCB bulletins. We found no differences beyond rounding. We did not use 2024 data, because those come from a different 15-minute pipeline. Nehru Nagar DPCC was selected on two practical grounds. First, the OpenCity/CPCB archive contained a continuous hourly $O_3$ record from 2018 onward, the longest publicly available record for this station. Second, data completeness across the study period 2019–2023 was consistently high at 94–97% per year, exceeding the 80% threshold applied as a minimum quality criterion. No systematic comparison of multiple Delhi CAAQMS stations was undertaken; the analysis is therefore specific to this station and its findings should not be generalised to the wider Delhi network without comparable characterisation at other sites.

### 2.2 Quality control

We removed hourly values outside the range 0–500 μg $m^{-3}$. The value 500 μg $m^{-3}$ is the reporting ceiling of the OpenCity archive for this station. No values fell outside this range in the raw data. So this filter removed zero observations. There were 1,316 values pinned exactly at 500 μg $m^{-3}$, and none above it.

We filled small gaps of up to two missing hours in a row by linear interpolation. In the 06:00–10:00 IST summer window, interpolated values make up about 4% of readings. They are spread across hours, so they have little effect on morning means. Days with fewer than 18 valid hourly readings were removed from all analyses.

Caps of 400 and 300 μg $m^{-3}$ were used only in the sensitivity test (Section 3.7), not in the main analysis.

### 2.3 Seasons and study period

We used the India Meteorological Department seasons, adapted for this study: summer (March–May), monsoon (June–September), post-monsoon (October–November), and winter (December–February). Strictly, IMD's post-monsoon season runs through December, and the cold season runs January–February. Our December–February winter frame is an analytical choice that keeps full calendar winters.

We left summer 2020 out of the seasonal means and the day-level analysis. The COVID-19 national lockdown (March–June 2020) cut traffic and changed the precursor mix (Dhaka et al., 2020). Summer 2020 is kept only for the lockdown comparison in Section 3.9.

All other seasons keep 2020, including monsoon. We test the effect of excluding June 2020 in Section 2.5. The winter frame covers five December–February periods (December 2019 to February 2024). It gives 10,451 valid hourly readings out of a possible 10,800 station-hours (about 96.8% capture).

### 2.4 Statistics

We computed hourly means and 95% confidence intervals (mean ± 1.96 × SE, where SE = SD/$\sqrt{n}$) for each season. These intervals treat each hour as independent. Since ozone is autocorrelated within a day, the intervals understate true uncertainty. They are lower bounds only. The day-level tests are the main basis for our conclusions.

Peak hour is a circular variable (00–23 IST). For each valid summer day (n = 333; see Table 2), we found the daily peak hour. We used circular statistics after Fisher (1993): circular mean $\bar{\theta}$ = atan2(mean sin $\theta_i$, mean cos $\theta_i$), where $\theta_i = 2\pi h_i/24$; mean resultant length R = $\sqrt{(\text{mean } \sin^2\theta + \text{mean } \cos^2\theta)}$, from 0 (spread out) to 1 (all days the same hour); and the Rayleigh test of uniformity. Bootstrap resampling (n = 3,000 by day, sampling with replacement) gave a 90% CI on the circular mean.

For pairwise tests, we ran day-level Mann-Whitney U tests (one-sided, 09:00 > adjacent hour) for 09:00 versus 08:00, 10:00, 11:00, 12:00, 13:00, 14:00, and 15:00. We applied Holm–Bonferroni correction to all seven tests at once.

2.5 The COVID-19 year

We excluded summer 2020 from seasonal means because the lockdown sharply cut traffic and most non-essential activity - traffic came to a near standstill in the first phase (Dhaka et al., 2020). We kept 2020 in all monsoon analyses, because the lockdown officially ended before the monsoon began on 1 June.

As a check, removing June 2020 changes the monsoon mean from 119.1 to 108.3 μg $m^{-3}$. That is a difference of about 9%. We report this openly. June 2020 does contribute to the monsoon mean, but we keep the monsoon season with 2020 included.

## 3. RESULTS

3.1 Sample sizes

**Table 1.** Valid hourly ozone readings by year and season, Nehru Nagar 2019–2023.

| **Year** | **Summer[1] (Mar–May)** | **Monsoon (Jun–Sep)** | **Post-M (Oct–Nov)** | **Winter[2] (Dec–Feb)** | **Days (summer)** | **Note** |
|---|---|---|---|---|---|---|
| 2019 | 2,021 | 2,782 | 1,371 | 2,134 | 91 | |
| 2020 | 2,161 | 2,776 | 1,448 | 1,958 | 92 | COVID |
| 2021 | 2,048 | 2,831 | 1,428 | 2,056 | 91 | |
| 2022 | 2,104 | 2,679 | 1,414 | 2,127 | 92 | |
| 2023 | 2,157 | 2,620 | 1,403 | 2,176 | 92 | |
| Total (ex. 2020 summer) | 8,330 | 13,688 | 7,064 | 10,451 | 366[3] | |

[1] Summer excludes 2020; monsoon, post-monsoon, and winter include 2020.
[2] Winter 2019–20 = December 2019 + January–February 2020, and so on through winter 2023–24.
[3] 366 station-days across 2019, 2021–2023; 333 pass the quality threshold (see Table 2).

3.2 Valid days

**Table 2.** Summer days removed and valid days, by year.

| **Year** | **Total days** | **Excluded (< 18 obs / < 20 h)** | **Valid days** |
|---|---|---|---|
| 2019 | 91 | 10 + 2 | 79 |
| 2021 | 91 | 5 + 6 | 80 |
| 2022 | 92 | 3 + 4 | 85 |
| 2023 | 92 | 2 + 1 | 89 |
| Total | 366 | 20 + 13 = 33 | 333 |

We first removed days with fewer than 18 valid hourly readings. Then we removed days covering fewer than 20 distinct hours. The removed days are spread evenly across months and years. No single hour window dominates the exclusions.

3.3 Data quality

**Table 3.** Peak ozone at Nehru Nagar compared with published values at other Delhi stations.

| **Season** | **Peak hour (IST)** | **Nehru Nagar peak mean ± SE (µg m⁻³)** | **Published range[1] (µg m⁻³)** | **Statistic underlying published range** | **Best source** | **Ratio[2]** | **n hourly[3]** | **Status** |
|---|---|---|---|---|---|---|---|---|
| Summer (Mar–May, ex. 2020) | 09:00 | 255.6 ± 5.7 [244.4, 266.7] | 124–190 | Monthly average maximum $O_3$, ITO New Delhi, 1997–2003 | Jain et al. (2005), their Table 1 / Fig. 2 (62–95 ppb × 2.0 µg/ppb) | ~1.4–2.1× | 8,330 | OK[4] |
| Monsoon (Jun–Sep) | 21:00 | 137.7 ± 3.2 [131.4, 144.0] | ~94 (daytime mean)[5] | 8-hour daytime mean (09–17 IST), ITO New Delhi, 2001 | Ghude et al. (2006) (59% of 80 ppb WHO standard × 2.0 µg/ppb) | ~1.1× (daytime)[6] | 13,688 | OK |
| Post-monsoon (Oct–Nov) ⚠ | 21:00 | 357.2 ± 7.3 [342.9, 371.5] | 100–164 | Monthly average maximum $O_3$, ITO New Delhi, 1997–2003 (Oct–Nov: 50–82 ppb × 2.0 µg/ppb) | Jain et al. (2005); Dhawan et al. (2022) seasonal mean 40–80 µg m⁻³ | ~2.2–3.6×[7] | 7,064 | ⚠ Artefact |
| Winter (Dec–Feb) ⚠ | 21:00 | 416.7 ± 4.9 [407.1, 426.3] | 20–60 | Seasonal mean $O_3$, multiple Delhi CAAQMS stations | Kutal et al. (2022), Table 3; Jain et al. (2005) (winter described as seasonal minimum) | ~7–21×[8] | 10,329 | ⚠ Artefact |

[1] Published values represent the statistic named in the adjacent column at independent Delhi stations in earlier study periods. Nehru Nagar values are the peak hour of the mean diurnal profile - a different and generally higher statistic than a seasonal mean or monthly average maximum. Ratios are therefore upper bounds on the true anomaly and are listed primarily to identify physically implausible values, not as precise multipliers.

[2] Ratio = Nehru Nagar peak mean ÷ upper end of published range. Parenthetical ranges reflect uncertainty in the published lower bound.

[3] Hourly observation counts: summer excludes 2020; all other seasons retain 2020. Winter frame = December 2019 through February 2024 (five December–February periods). Per-bin n: summer 341–353; monsoon 561–580; post-monsoon 286–301; winter 417–438.

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[4] Summer concentrations at Nehru Nagar (peak mean 255.6 µg m⁻³) are elevated relative to published Delhi summer values but within a range that is plausible for a south Delhi residential site under current precursor loads. The peak-hour comparison against Jain et al. monthly average maxima (which span summer months) likely overstates the anomaly because peak-hour means exceed monthly maxima in most datasets. The morning peak timing (09:00 IST vs 12:00–15:00 IST at other stations) is the more unusual feature and is discussed in Section 3.4.

[5] Monsoon is the minimum $O_3$ season at Delhi urban stations (Jain et al., 2005; Ghude et al., 2006). Ghude et al. (2006) report an 8-hour (09–17 IST) surface $O_3$ at New Delhi of 59% of the WHO 80 ppb standard, giving approximately 47 ppb × 2.0 ≈ 94 µg m⁻³. No numeric monsoon mean is given by Jain et al. (2005).

[6] The Nehru Nagar monsoon peak of 137.7 µg m⁻³ occurs at 21:00 IST (nocturnal). The Nehru Nagar monsoon daytime mean (09:00–17:00 IST) is 108.4 µg m⁻³, giving a ratio of 108.4/94 ≈ 1.15× against the Ghude et al. daytime mean - consistent with published values. The monsoon data are therefore physically plausible and the nocturnal peak reflects residual-layer entrainment rather than measurement artefact.

[7] Post-monsoon ratio uses the Jain et al. (2005) monthly average maximum range (100–164 µg m⁻³) as the denominator: 357.2/164 = 2.2× (lower bound) and 357.2/100 = 3.6× (upper bound). Using the Dhawan et al. (2022) seasonal mean range (40–80 µg m⁻³) gives 4.5–8.9×, but this compares a nocturnal profile peak against a seasonal mean - an extreme statistic mismatch. The more conservative Jain et al. ratio (2.2–3.6×) is preferred and is still indicative of anomalously high values.

[8] Winter ratio: 416.7 ÷ 60 = 6.9× (upper end of Kutal 2022 range); 416.7 ÷ 20 = 20.8× (lower end). Stated as ~7–21×.

The post-monsoon mean of 299.3 µg m⁻³ at 21:00 IST is far too high for Delhi. So is the winter mean of 348.9 µg m⁻³ at 21:00 IST.

At other Delhi stations, winter is the ozone minimum and summer the maximum (Sharma et al., 2024). Under winter inversions, surface NO from traffic and biomass burning removes ozone. Winter values at independent Delhi stations do not approach what we see here (Kutal et al., 2022; Sharma et al., 2016). Even the highest autumn monthly maxima at ITO (50–82 ppb, about 98–161 µg m⁻³) do not reach the 21:00 IST means at Nehru Nagar (Jain et al., 2005).

These anomalies look like UV-ozone monitor errors. Wilson and Birks (2006) showed that UV monitors can report large positive offsets when humidity changes quickly, through the ozone scrubber (Wilson & Birks, 2006). Later studies with heated graphite scrubbers confirmed this problem (Turnipseed et al., 2017), and field comparisons found UV monitors prone to sampling-related errors (Long et al., 2021). The effect is transient: it follows fast humidity changes, not steady conditions (Wilson & Birks, 2006).

The timing here needs care. The Nehru Nagar anomaly sits at 21:00 IST, but relative humidity in Delhi peaks in the early morning, around 06:00–08:00 IST, not at night (Chen et al., 2022; Mandariya et al., 2024). So a sustained multi-season night-time offset is more likely caused by zero/span drift or a worn scrubber. The summer morning plateau (09:00–10:00 IST) does match the fast post-sunrise drop in humidity, where a transient response could add error (Wilson & Birks, 2006).

We cannot rule out zero/span drift or spectral interference from winter co-pollutants. The calibration records are not public. DPCC should audit the zero/span logs, scrubber replacement records, and the analyser make and model before these data are used for science or regulation.

### 3.4 Summer daily cycle

Figure 1 shows the summer profile. The mean peaks at 09:00 IST (255.6 ± 5.7 µg m⁻³, 95% CI [244.4, 266.7]) and stays flat through 10:00 IST. This value is above India's 1-hour standard of 180 µg m⁻³. Delhi summer-afternoon ozone approaches or exceeds that level at other stations too (Shukla et al., 2021). The daily low is at 19:00 IST (157.2 µg m⁻³). Then ozone rises again from 20:00 IST. This night-time rise matches ozone-rich air coming down from above.

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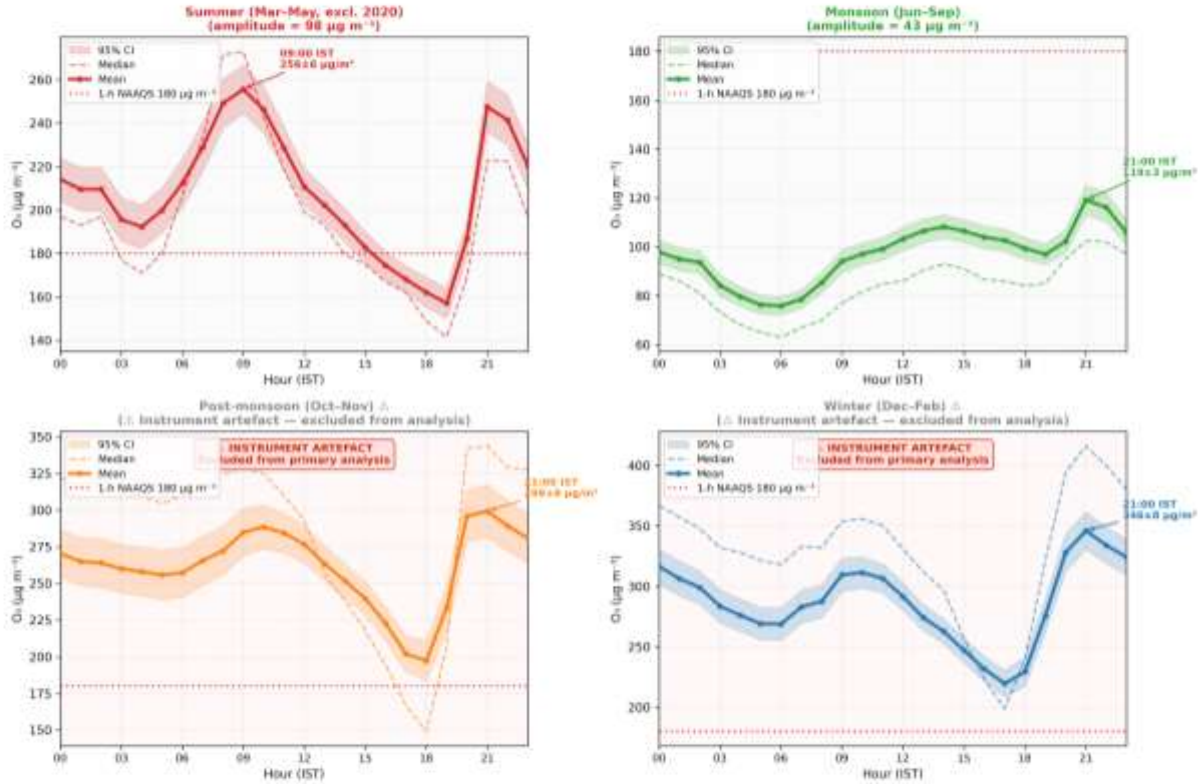


**Figure 1 -** Mean hourly ozone (solid), median (dashed), and 95% CI (shaded) at Nehru Nagar by season, 2019–2023. Summer excludes 2020. Red dotted line = India's 1-hour standard (180 μg m$^{-3}$). Post-monsoon and winter panels are for transparency only and are excluded from interpretation (instrument errors, Section 3.3).

3.5 Peak-hour spread

The peak hour changes a lot from day to day (Figure 2, Table 4). The mean resultant length is R = 0.097, very close to zero. This means the distribution is nearly uniform. The Rayleigh test gives p = 0.043, which is significant at the 5% level but shows only a weak overall preference.

The distribution is bimodal. One mode is at 09:00 IST (morning group, 36% of days). The other is at 21:00–22:00 IST (evening group, 38% of days). So the circular mean (01.3 IST) falls between the two modes, near midnight. It does not describe any typical day. The bootstrap 90% CI [0.3, 23.7] IST confirms this. For a bimodal distribution, the best summary is the modal distribution itself.

**Table 4.** Peak-hour spread and circular statistics, summer (2019, 2021–2023; n = 333 valid days).

| **Category / Statistic** | **Value** | **% or test result** |
|---|---|---|
| Morning peak (06:00–11:00 IST) | 119 days | 36% |
| Afternoon peak (12:00–17:00 IST) | 37 days | 11% |
| Evening–night peak (18:00–23:00 IST) | 128 days | 38% |
| Early-morning peak (00:00–05:00 IST) | 49 days | 15% |
| Most common peak hour: 21:00 IST | 56 days | 17% |

| | | |
|---|---|---|
| Second mode: 22:00 IST | 40 days | 12% |
| Third mode: 09:00 IST | 36 days | 11% |
| Circular mean | 01.3 IST | Not representative¹ |
| Mean resultant length R | 0.097 | p = 0.043 |
| Bootstrap 90% CI on circular mean | [0.3, 23.7] IST | Bimodal; see note¹ |

¹ The two modes (morning 36%, evening 38%) pull the circular mean and its CI toward midnight. They are correct in math but describe no real day. The modal distribution (top four rows) is the right summary.

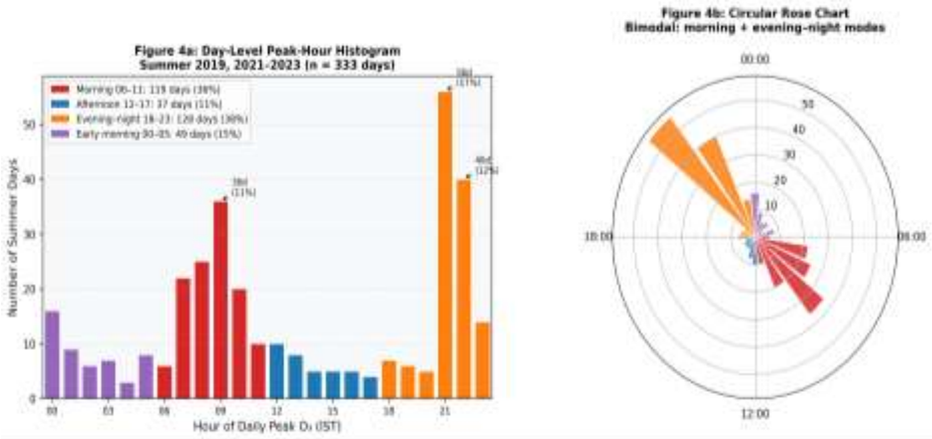


**Figure 2 -** Day-level summer peak hours across 333 valid days. Left: histogram by time window. Right: circular rose chart. Morning (06:00–11:00) = 119 days (36%); evening–night (18:00–23:00) = 128 days (38%); most common peak = 21:00 IST (56 days, 17%). R = 0.097 (p = 0.043); the circular mean of 01.3 IST is unrepresentative because the distribution is bimodal.

3.6 Morning vs afternoon tests

**Table 5.** Day-level Mann-Whitney tests: 09:00 IST vs adjacent hours, summer 2019, 2021–2023 (Holm–Bonferroni, k = 7).

| Comparison | 09:00 median ($\mu g\ m^{-3}$) | Other median ($\mu g\ m^{-3}$) | Raw p | Holm α | Decision |
|---|---|---|---|---|---|
| 09 vs 15:00 | 260 | 161 | < 0.0001 | 0.0071 | * |
| 09 vs 14:00 | 260 | 166 | < 0.0001 | 0.0083 | * |
| 09 vs 13:00 | 260 | 173 | < 0.0001 | 0.0100 | * |
| 09 vs 12:00 | 260 | 180 | < 0.0001 | 0.0125 | * |
| 09 vs 11:00 | 260 | 202 | 0.0001 | 0.0167 | * |
| 09 vs 10:00 | 260 | 218 | 0.107 | 0.0250 | ns |
| 09 vs 08:00 | 260 | 216 | 0.233 | 0.0500 | ns |

One observation per day (the daily mean ozone for each hour, on days that pass the threshold for both hours). Tests are one-sided: 09:00 > the other hour. * = significant after correction. ns = not significant.

The morning value is higher than 11:00 through 15:00 IST, even after correction. It is not different from 10:00 IST (p = 0.107). So the morning feature is a plateau, not a sharp point.

3.7 Sensitivity test

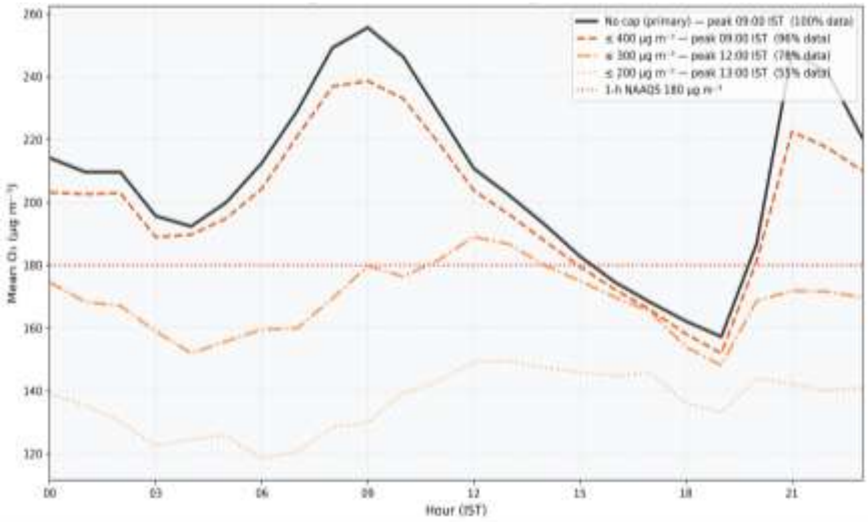


**Figure 3 -** Summer profile under different upper caps. Under a 400 μg m⁻³ cap (97% of data kept), the 09:00–10:00 IST plateau stays. Under a 300 μg m⁻³ cap (85% kept), the peak moves to 12:00 IST, and the profile looks like the normal afternoon photochemical peak at other Delhi stations.

3.8 Monsoon

Monsoon ozone peaks at 21:00 IST (mean 119.1 μg m⁻³, 95% CI [113.0, 125.2]). The low is at 06:00 IST (75.9 μg m⁻³). The day-to-night range is 43.2 μg m⁻³.

These values match published Delhi monsoon levels. The night peak fits residual-layer entrainment: after sunset, the daytime mixed layer collapses, and ozone-rich air from above sinks to the surface (Ojha et al., 2012). This is the most believable pattern in the dataset.

3.9 The 2020 lockdown

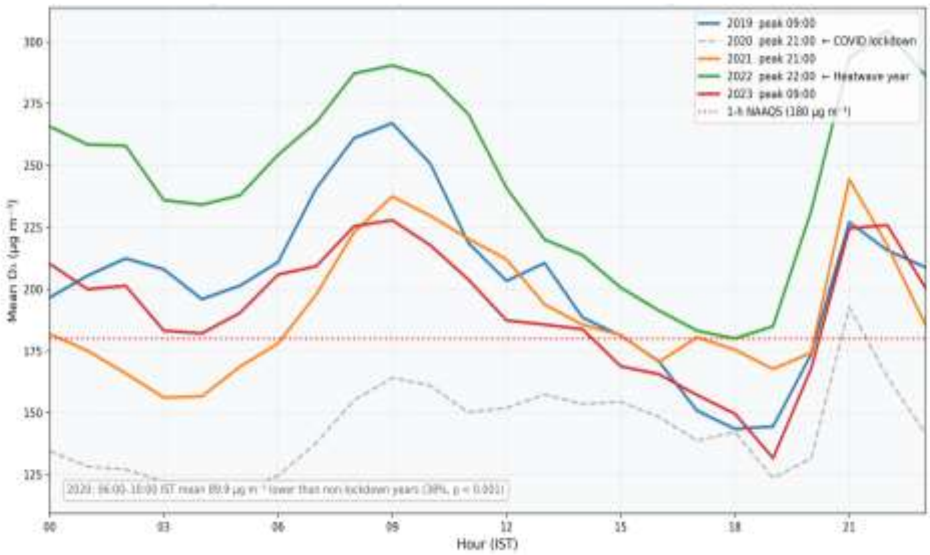


**Figure 4 -** Summer mean ozone by year at Nehru Nagar (2019–2023). The 2020 line (dashed grey) peaks at 21:00 IST instead of 09:00–10:00 IST. The 06:00–10:00 IST window was 89.9 μg m⁻³ (38%) lower in 2020 (Mann-Whitney $p < 0.001$). Red dotted line = India's 1-hour standard (180 μg m⁻³). The 2022 anomaly is discussed in Section 4.2.

**Table 6.** Summer peak hour and peak mean, by year, Nehru Nagar 2019–2023.

| Year | Peak hour | Peak mean (μg m⁻³) | n hourly | Note |
|---|---|---|---|---|
| 2019 | 09:00 | 267.1 | 2,021 | |
| 2020 | 21:00 | 192.8 | 2,161 | COVID lockdown |
| 2021 | 21:00 | 244.5 | 2,048 | |
| 2022 | 22:00 | 304.5 | 2,104 | High-ozone year |
| 2023 | 09:00 | 227.9 | 2,157 | |

The mean morning ozone (06:00–10:00 IST) was 148.5 μg $m^{-3}$ in 2020, versus 238.5 μg $m^{-3}$ in other years. That is a drop of 89.9 μg $m^{-3}$ (38%, $p < 0.001$). Every morning hour fell by a similar amount: 06:00 −88, 07:00 −91, 08:00 −94, 09:00 −91, and 10:00 −85 μg $m^{-3}$; all $p < 0.001$.

A simple titration story would predict the opposite - ozone should rise when NO falls. Our result fits a NOx-limited or transitional photochemical regime, where less precursor emission means less morning ozone production. But this is not the full story. Box-model work for Delhi shows that in-situ ozone production is VOC-limited, so NOx-only cuts are expected to raise, not lower, ozone (Chen et al., 2020; Nelson et al., 2021). Nationwide lockdown studies found no consistent ozone falls either: $PM_{2.5}$, $PM_{10}$, $NO_2$, and CO dropped sharply in Delhi (about 41%, 52%, 51%, and 28%), but ozone did not (Jain & Sharma, 2020), and some cities even saw ozone rise (Das et al., 2022).

So the 38% morning drop at Nehru Nagar is a distinct, station- and window-specific result. Weather also matters. Mean summer temperature was 35.2 °C in 2020, versus 37.8 °C in other years. That 2.6 °C gap could explain about 10–15 μg $m^{-3}$ of the fall. Most of the 89.9 μg $m^{-3}$ gap remains unexplained by temperature. Our test is limited by having only one lockdown year and no NOx data for the same period.

## 4. DISCUSSION

### 4.1 The main finding is data quality

Two of the four seasons at Nehru Nagar show ozone values 4–8 and 6–17 times the published ranges for those seasons elsewhere in Delhi. Even against the upper ends alone, the gaps are four- and six-fold. This is our most important result.

The post-monsoon and winter records should not be used for compliance checks, trend studies, or model testing until DPCC audits the instrument. The audit should cover: analyser make, model, and firmware; zero and span logs; scrubber replacement records; and co-located humidity data. Comparing the Nehru Nagar winter and post-monsoon records with nearby stations (e.g., Mandir Marg, Patparganj) would quickly show if the problem is station-specific.

### 4.2 The summer morning peak and the 2022 anomaly

The summer mean peaks at 09:00–10:00 IST, four to six hours earlier than other Delhi stations. This is a property of the mean, not of most days. The 36% of days that peak in the morning carry the highest concentrations. They dominate the mean, even though 38% of days peak at night (Dhawan et al., 2022; Jain et al., 2005).

The morning plateau is significantly higher than the afternoon (11:00–15:00 IST) after correction, but is the same as 10:00 IST ($p = 0.107$). So it is a plateau, not a sharp peak.

Summer 2022 stands out. It peaked at 22:00 IST with a mean of 304.5 μg $m^{-3}$, and 32% of its hours exceeded 300 μg $m^{-3}$. Delhi had a severe pre-monsoon heatwave in April–May 2022. Heat speeds up ozone formation. It can also worsen humidity-driven monitor errors. We cannot tell which one explains 2022 without a co-located reference instrument.

Two mechanisms could explain the morning rise. First, residual-layer entrainment: at sunrise, the boundary layer mixes and brings down ozone-rich air from the day before. Second, a transient humidity error in the UV monitor, right at the time morning humidity falls quickly (Turnipseed et al., 2017; Wilson & Birks, 2006). The 38% lockdown-year drop fits the first mechanism better than the second, but the evidence is indirect.

4.3 What this means for the CPCB network

We do not know if the problem is unique to Nehru Nagar. A network-wide check would help: compare winter and post-monsoon means across all Delhi CAAQMS stations, and flag any urban station whose winter ozone clearly exceeds ~60 μg $m^{-3}$. No such check exists in the literature. It would be a useful quality-assurance contribution.

## 5. CONCLUSION

We used five years of CPCB data (2019–2023) to give the first published description of the ozone cycle at Nehru Nagar DPCC. We left the 2020 lockdown year out of the summer analysis. Three points stand out.

**Data quality-** Two seasons - post-monsoon (peak mean 299.3 μg $m^{-3}$) and winter (348.9 μg $m^{-3}$) - exceed the upper ends of published Delhi ranges by about four and six times, and up to 8- and 17-fold against the lower ends. Both peak at 21:00 IST, which photochemistry cannot explain. We attribute these records to UV monitor errors and recommend not using them for regulation or science until DPCC audits the instrument.

**Diurnal pattern-** Summer shows a morning plateau at 09:00–10:00 IST (255.6 ± 5.7 μg $m^{-3}$, 95% CI [244.4, 266.7]), significantly higher than 11:00–15:00 IST at day level. The daily peak-hour distribution is bimodal (morning 36%, evening–night 38%), R = 0.097. So the plateau belongs to the concentration-weighted mean, not to most individual days. The monsoon shows a credible night peak (119.1 μg $m^{-3}$) that fits residual-layer entrainment (Ojha et al., 2012).

**Lockdown-** The 2020 lockdown cut morning (06:00–10:00 IST) summer ozone by 89.9 μg $m^{-3}$ (38%, $p < 0.001$). This fits reduced photochemical production, but published Delhi analyses point to VOC-limited production (Chen et al., 2020; Nelson et al., 2021), and we had no concurrent NOx data. A 10–15 μg $m^{-3}$ weather contribution from the cooler 2020 summer cannot be ruled out. Settling the mechanism needs co-located reference measurements and concurrent NOx and humidity data.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

[1] Chen, Y., Beig, G., Archer-Nicholls, S., Drysdale, W., Acton, W. J. F., Lowe, D., Nelson, B. S., Lee, J., Ran, L., Wang, Y., Wu, Z., Sahu, S. K., Sokhi, R. S., Singh, V., Gadi, R., Hewitt, C. N., Nemitz, E., Archibald, A. T., McFiggans, G., & Wild, O. (2020). Avoiding high ozone pollution in Delhi, India. *Faraday Discussions*, *226*, 502–514. https://doi.org/10.1039/d0fd00079e

[2] Chen, Y., Wang, Y., Nenes, A., Wild, O., Song, S., Hu, D., Liu, D., He, J., Ruiz, L. H., Apte, J. S., Gunthe, S. S., & Liu, P. (2022). Ammonium Chloride Associated Aerosol Liquid Water Enhances Haze in Delhi, India. *Environmental Science & Technology*, *56*(11), 7163–7173. https://doi.org/10.1021/acs.est.2c00650

[3] Das, S., Sarkar, A., Mina, U., Nandy, S., Saadat, M. N., Agrawal, G. K., & Rakwal, R. (2022). Trends in Summer-Time Tropospheric Ozone during COVID-19 Lockdown in Indian Cities Might Forecast a Higher Future Risk. *Atmosphere*, *13*(7), 1115. https://doi.org/10.3390/atmos13071115

[4] Dhaka, S. K., Chetna, C., Kumar, V., Panwar, V., Dimri, A. P., Singh, N., Patra, P. K., Matsumi, Y., Takigawa, M., Nakayama, T., Yamaji, K., Kajino, M., Misra, P., & Hayashida, S. (2020). PM2.5 diminution and haze events over Delhi

during the COVID-19 lockdown period: an interplay between the baseline pollution and meteorology. *Scientific Reports*, *10*(1), 13442. https://doi.org/10.1038/s41598-020-70179-8

[5] Dhawan, S., George, M. P., Jayachandran, K. S., & Khare, M. (2022). Tropospheric ozone variability in Delhi during pre & post monsoon periods: Decoding influence of seasonal variation, diurnal variation, short-range and long-range transport. *Urban Climate*, *47*, 101374. https://doi.org/10.1016/j.uclim.2022.101374

[6] Jain, S., Arya, B. C., Kumar, A., Ghude, S. D., & Kulkarni, P. S. (2005). Observational study of surface ozone at New Delhi, India. *International Journal of Remote Sensing*, *26*(16), 3515–3524. https://doi.org/10.1080/01431160500076616

[7] Jain, S., & Sharma, T. (2020). Social and Travel Lockdown Impact Considering Coronavirus Disease (COVID-19) on Air Quality in Megacities of India: Present Benefits, Future Challenges and Way Forward. *Aerosol and Air Quality Research*, *20*(6), 1222–1236. https://doi.org/10.4209/aaqr.2020.04.0171

[8] Kutal, G. C., Kolhe, A. R., Mahajan, C. M., Varpe, S. R., Patil, R., Singh, P., & Aher, G. R. (2022). Characteristics of Surface Ozone Levels at Climatologically and Topographically Distinct Metropolitan Cities in India. *Asian Journal of Atmospheric Environment*, *16*(2). https://doi.org/10.5572/ajae.2022.004

[9] Long, R., Whitehill, A., Habel, A., Urbanski, S. P., Halliday, H. S., Colón, M., Kaushik, S., & Landis, M. S. (2021). Comparison of ozone measurement methods in biomass burning smoke: an evaluation under field and laboratory conditions. *Atmospheric Measurement Techniques*, *14*(3), 1783–1800. https://doi.org/10.5194/amt-14-1783-2021

[10] Mandariya, A. K., Ahlawat, A., Haneef, M. D., Baig, N., Patel, K., Apte, J. S., Ruiz, L. H., Wiedensohler, A., & Habib, G. (2024). Measurement report: Hygroscopicity of size-selected aerosol particles in the heavily polluted urban atmosphere of Delhi: impacts of chloride aerosol. *Atmospheric Chemistry and Physics*, *24*(6), 3627–3647. https://doi.org/10.5194/acp-24-3627-2024

[11] Nelson, B. S., Stewart, G. J., Drysdale, W., Newland, M. J., Vaughan, A., Dunmore, R. E., Edwards, P. M., Lewis, A. C., Hamilton, J. F., Acton, W. J. F., Hewitt, C. N., Crilley, L. R., Alam, M. S., Şahin, Ü. A., Beddows, D. C. S., Bloss, W. J., Slater, E. J., Whalley, L. K., Heard, D. E., … Lee, J. (2021). In situ ozone production is highly sensitive to volatile organic compounds in Delhi, India. *Atmospheric Chemistry and Physics*, *21*(17), 13609–13630. https://doi.org/10.5194/acp-21-13609-2021

[12] Ojha, N., Naja, M., Singh, K. P., Sarangi, T., Kumar, R., Lal, S., Lawrence, M. G., Butler, T., & Chandola, H. C. (2012). Variabilities in ozone at a semi-urban site in the Indo-Gangetic Plain region: Association with the meteorology and regional processes. *Journal of Geophysical Research Atmospheres*, *117*. https://doi.org/10.1029/2012jd017716

[13] Sharma, A., Sharma, S. K., Rohtash, & Mandal, T. K. (2016). Influence of ozone precursors and particulate matter on the variation of surface ozone at an urban site of Delhi, India. *Sustainable Environment Research*, *26*(2), 76–83. https://doi.org/10.1016/j.serj.2015.10.001

[14] Sharma, S., Singhal, A., Venkatramanan, V., Verma, P. S., & Pandey, M. (2024). Variability in air quality, ozone formation potential by VOCs, and associated air pollution attributable health risks for Delhi's inhabitants. *Environmental Science Atmospheres*, *4*(8), 897–910. https://doi.org/10.1039/d4ea00064a

[15] Shukla, K., Dadheech, N., Kumar, P., & Khare, M. (2021). Regression-based flexible models for photochemical air pollutants in the national capital territory of megacity Delhi. *Chemosphere*, *272*, 129611. https://doi.org/10.1016/j.chemosphere.2021.129611

[16] Turnipseed, A. A., Andersen, P. C., Williford, C. J., Ennis, C. A., & Birks, J. W. (2017). Use of a heated graphite scrubber as a means of reducing interferences in UV-absorbance measurements of atmospheric ozone. *Atmospheric Measurement Techniques*, *10*(6), 2253–2269. https://doi.org/10.5194/amt-10-2253-2017

[17] Wilson, K. L., & Birks, J. W. (2006). Mechanism and Elimination of a Water Vapor Interference in the Measurement of Ozone by UV Absorbance. *Environmental Science & Technology*, *40*(20), 6361–6367. https://doi.org/10.1021/es052590c