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Micro-Spatial and Seasonal Variability of the National Air Quality Index at Sixteen CPCB-Monitored Stations in Delhi, Mumbai, Nashik and Patna During the 2026 Monsoon–Post-Monsoon Transition

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***Abstract*—A single city-wide Air Quality Index (AQI) can hide the neighbourhoods where people are most exposed. This study examines how India's National AQI varies between stations and between months in four contrasting urban airsheds—Delhi, Mumbai, Nashik and Patna—from 1 July to 31 October 2026, a window that covers the south-west monsoon and the first month after its withdrawal. Four continuous ambient air quality monitoring stations (CAAQMS) were retained per city (16 in all), and station-month mean AQI values were derived with the Central Pollution Control Board (CPCB) sub-index method. Spatial dispersion was summarised by the inter-station standard deviation and coefficient of variation (CV), and seasonal change was tested with Wilcoxon signed-rank, Friedman and Kruskal–Wallis tests. The station-mean AQI rose from 77.8 in July–September to 118.4 in October (+52 %); 14 of 16 stations were higher in October (exact Wilcoxon $p < 0.001$). The relative rise was largest in Nashik (+139 %) and the absolute level highest in Delhi (October mean 157.9). In Patna the inter-station CV exceeded 60 % from July to September, because Samanpura stayed at 164–174 while Rajbansi Nagar remained near 43–50, and fell to 27 % in October as the whole city shifted upward. Persistent hotspots (Samanpura, Anand Vihar, Worli, MIDC Ambad) were identified, and city-level values agreed with independent CPCB-derived benchmarks. The results support station-level reporting and targeted civil-engineering controls on traffic corridors, construction dust and industrial margins.**

***Index Terms*—air quality index, CAAQMS, CPCB, monsoon scavenging, post-monsoon stagnation, spatial variability, pollution hotspots, urban civil engineering.**

I. INTRODUCTION

Air pollution is among the leading environmental health risks in India. Global Burden of Disease estimates attribute about 1.24 million deaths in 2017 and 1.67 million deaths in 2019 to air pollution, equal to 12.5 % and 17.8 % of all deaths, with ambient particulate matter responsible for the larger share of the later figure [1], [2]. In 2017 roughly 77 % of the population lived where the annual-mean $PM_{2.5}$ exceeded the national standard of 40 µg/m³ [1]. Urban growth, expanding vehicle fleets, construction and industry keep loading city airsheds, and the resulting exposure is unevenly distributed in both space and time.

India's regulatory framework rests on the Air (Prevention and Control of Pollution) Act of 1981, the National Ambient Air Quality Standards (NAAQS) revised in 2009 [3], and the National Air Quality Index (AQI) introduced in 2014 [4]. The AQI converts concentrations of up to eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3 and Pb) into a single number on a 0–500 scale with six colour-coded categories, and the reported value is that of the worst pollutant [4]. Data from continuous ambient air quality monitoring stations (CAAQMS) operated by the CPCB and the State Pollution Control Boards are published through the CPCB Central Control Room (CCR) portal [5].

How high a given AQI is depends heavily on the season. Wet removal during the south-west monsoon lowers particle concentrations, while after the monsoon withdraws, weaker winds, shallower night-time mixing layers and, in northern India, crop-residue burning allow emissions to accumulate [6], [7]. The switch from one regime to the other takes place within a few weeks, which makes it a demanding test of how an urban monitoring network behaves.

A second difficulty is spatial. City bulletins usually give one number per city, which can mask neighbourhoods exposed to traffic hubs, industrial estates or dust-generating sites. Civil engineers shape many of the relevant sources and controls—junction and corridor design, construction-site dust management, pavement stabilisation and green buffers—so station-level evidence is more actionable for them than a city mean.

This paper analyses station-level AQI at 16 CAAQMS in four cities between 1 July and 31 October 2026. Its contributions are: (i) a station-by-month AQI dataset spanning the monsoon and the first post-monsoon month; (ii) quantification of seasonal change with nonparametric tests suited to small samples; (iii) dispersion metrics showing where city averages are unrepresentative; (iv) cross-checks against independently published CPCB-derived benchmarks; and (v) an engineering-oriented reading of persistent hotspots. Section II reviews the literature, Sections III and IV state the problem and objectives, Sections V and VI describe the method and the work carried out, Section VII presents results and discussion, and Sections VIII–X give limitations, future scope and conclusions.

II. LITERATURE REVIEW

A. Standards and Index Design

India's AQI follows the sub-index approach: each pollutant's concentration is mapped linearly within concentration bands to a sub-index, and the largest sub-index sets the AQI. At least three pollutants, one of them $PM_{2.5}$ or PM_{10}, must be available, and at least 16 hours of data are needed for a daily sub-index [4]. The U.S. EPA index uses the same worst-pollutant principle with different breakpoints [8]. The Indian category limits are less stringent than the 2021 WHO guideline values: the WHO 24-hour $PM_{2.5}$ guideline is 15 μg/m³, whereas the Indian 'Satisfactory' band extends to 60 μg/m³ [4], [9]. An 'acceptable' AQI category therefore does not imply compliance with health-based guidelines.

B. Monsoon Removal and Its Limits

Precipitation removes particles by in-cloud and below-cloud scavenging. The below-cloud rate is usually written as a first-order process whose coefficient depends on rain intensity and the particle size spectrum [6]. Observations in Delhi agree with this picture: monsoon PM_{10} was lower than pre-monsoon levels by roughly 25–80 μg/m³ and $PM_{2.5}$ by roughly 10–15 μg/m³ in 2007–08 [10]. A 2026 analysis of CPCB data found that Delhi's mean $PM_{2.5}$ fell from 60.2 μg/m³ in April–May to 40.2 μg/m³ in June–August (−33.2 %), yet relief during individual rain spells was short-lived, only one 'Good' air day occurred in the monsoon, and once particles had been scavenged, gaseous pollutants such as ozone led the daily AQI on a number of days [11]. Washout therefore lowers, but does not remove, the baseline set by local emissions, and an AQI built from the worst sub-index need not track particulate matter alone.

C. Post-Monsoon Build-Up in the Indo-Gangetic Plain

Across the Indo-Gangetic Plain (IGP), $PM_{2.5}$ is lower in the pre-monsoon and monsoon seasons than in the post-monsoon and winter seasons, biomass burning has its largest effect after the monsoon, and seasonal means exceed recommended levels in every season [7]. Measurements at seven sites in Patna during 2015 gave seasonal $PM_{2.5}$ of about 38 μg/m³ in the monsoon and 40 μg/m³ in the post-monsoon, against roughly 65 and 69 μg/m³ in the pre-monsoon and winter, and pointed to brick kilns as a significant contributor [12]. These figures indicate that the post-monsoon rise is gradual and peaks later in winter, so a window ending on 31 October captures only its beginning.

D. Intra-Urban Differences and Hotspots

Hama et al. analysed daily data from 12 stations across Delhi–NCR for 2014–2017 and found the highest concentrations of most pollutants at Anand Vihar; $PM_{2.5}$ was homogeneous among Delhi sites but diverged between Delhi and the wider NCR, which they read as evidence of dominant local sources [13]. A CEEW hotspot analysis of CAAQMS data likewise lists Anand Vihar among Delhi's 'legacy' hotspots [14]. At national scale, source-attribution work estimates that emissions

from outside city boundaries account for 82–89 % of urban $PM_{2.5}$ across 143 cities [15] and that secondary aerosol makes up about 62 % of annual ambient $PM_{2.5}$ in regional airsheds [16]. Differences between stations in a city should accordingly be read as local increments on top of a shared regional background.

E. Research Gap

Most station-level analyses cover full years or the winter peak. Studies that follow the same stations through the monsoon-to-post-monsoon transition, across cities with different geography (inland IGP, west coast, Deccan plateau), and that report intra-city dispersion explicitly, are less common in the literature we reviewed. Station-level CAAQMS assessments for mid-sized cities such as Nashik appear especially sparse.

III. PROBLEM STATEMENT

Three problems motivate this work. First, averaging over stations hides hotspots. In July 2026 the four Patna stations averaged an AQI of 89.1, in the 'Satisfactory' band, yet Samanpura recorded 171.5 ('Moderate') while Rajbansi Nagar recorded 43.5 ('Good'). Second, the transition from rain-scrubbed to stagnant conditions is documented less thoroughly at station level than the winter peak. Third, raw CAAQMS streams contain gaps, duplicates and sensor faults, so validation has to precede any use for planning.

Formally, let $A_{s,m}$ be the mean AQI at station s in month m (s = 1,…,16; m = July,…,October). The task is to (a) test whether October values differ systematically from the monsoon-month values, (b) quantify the dispersion of $A_{s,m}$ among stations of the same city, and (c) identify stations that remain consistently above their city mean.

IV. OBJECTIVES

The objectives are: (O1) to compile validated station-month AQI values for 16 CAAQMS in Delhi, Mumbai, Nashik and Patna for July–October 2026; (O2) to quantify the change between the monsoon months and October at station and city level and test its significance; (O3) to quantify intra-city dispersion (standard deviation, CV, max/min ratio) and its seasonal evolution; (O4) to identify persistent hotspots and examine, as an exploratory contrast, source-proximate versus background stations; (O5) to cross-check results against independent CPCB-derived city-level benchmarks; and (O6) to relate the findings to civil-engineering mitigation priorities.

Three working hypotheses are tested: H1, October AQI exceeds the July–September AQI; H2, inter-station dispersion differs between cities and between months; H3, stations adjacent to traffic hubs, freight terminals or industrial estates exceed background stations in the same city.

V. METHODOLOGY

The analysis followed the workflow in Fig. 1: data retrieval, validation, station shortlisting, AQI computation, aggregation, statistical testing and interpretation.

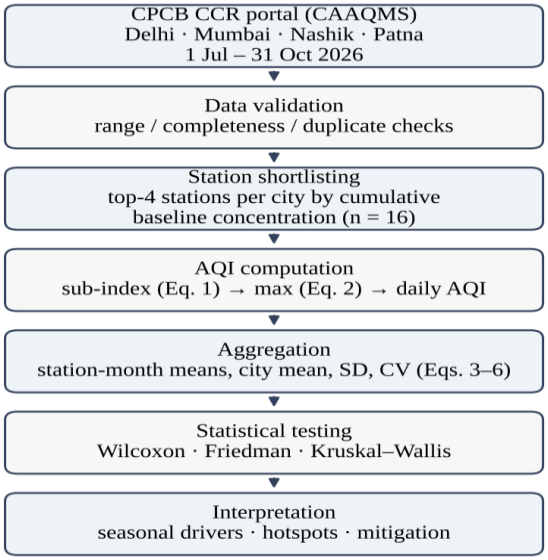


Fig. 1. Analytical workflow adopted in this study.

A. Study Area and Stations

The four cities differ in geography. Delhi and Patna lie in the Indo-Gangetic Plain; Mumbai is a west-coast city with a sea-breeze circulation; Nashik is an inland city on the Deccan plateau in western Maharashtra with a large industrial estate. The stations (Table II) report through the Delhi Pollution Control Committee (DPCC), the Maharashtra Pollution Control Board (MPCB) and the Bihar State Pollution Control Board (BSPCB). Land-use descriptions in Table II are the authors' site characterisations.

TABLE II MONITORING STATIONS ANALYSED

City	Station	Setting	Grp.
Delhi	Alipur	Semi-urban, agricultural fringe (north)	B
	Anand Vihar	Inter-state bus terminal, transport interchange	S
	Ashok Vihar	Dense commercial–residential	B
	Aya Nagar	Semi-rural, south Delhi	B
Mumbai	Borivali East	Suburban residential, near national park	B
	Ghatkopar	Dense commercial–industrial, east suburbs	S
	Shivaji Nagar	Dense residential, adjacent to Deonar landfill	B
	Worli	Arterial roads, infrastructure construction	S

City	Station	Setting	Grp.
Nashik	Gangapur Road	Residential and educational	B
	Hirawadi	Residential, urban fringe	B
	MIDC Ambad	Primary industrial estate	S
	Pandav Nagari	Semi-urban residential	B
Patna	Samanpura	Residential–commercial; dusty roads, local waste burning	S
	Muradpur	Institutional and hospital zone	B
	DRM Office Danapur	Railway station and freight terminal	S
	Rajbansi Nagar	Central residential and office zone	B

Grp.: S = source-proximate (traffic hub, freight/transport terminal, industrial or construction activity); B = background/residential. The grouping is used only in the exploratory analysis of Section VII-F.

B. Data Source and Period

Hourly CAAQMS records for 1 July–31 October 2026 (123 days) were obtained from data published by the CPCB CCR portal and the DPCC, MPCB and BSPCB networks [5]. The window covers the last three months of the south-west monsoon, which withdrew from Delhi on 23 September 2026, two days before its normal date [11], and the first post-monsoon month. The India Meteorological Department convention places the monsoon in June–September and the post-monsoon in October–December [7]; October is therefore treated as the post-monsoon month and July–September as the monsoon baseline.

C. Station Selection

Candidate cities and stations were first screened on baseline concentration. The most polluted city in each author's screening set was retained (Delhi, Mumbai, Nashik, Patna), and within each city the four CAAQMS with the highest cumulative baseline concentration were selected, giving 16 stations. Because selection favours high-concentration sites, the results describe the upper end of each city's monitoring network, not a city-wide mean (Section VIII).

D. AQI Computation

Daily AQI was computed by the CPCB procedure [4]. For pollutant p with 24-hour mean concentration C_p (8-hour for CO and O_3), the sub-index is obtained by linear interpolation within the band that contains C_p:

$$I_p = \frac{I_{HI} - I_{LO}}{B_{HI} - B_{LO}} \times (C_p - B_{LO}) + I_{LO} \qquad (1)$$

where B_{HI} and B_{LO} are the breakpoint concentrations bounding C_p, and I_{HI} and I_{LO} are the corresponding index values. Table I lists the breakpoints for the three pollutants used in the worked

example of Section VI. The daily AQI is the largest sub-index, provided at least three pollutants (one of them a particulate) are available:

$$\mathrm{AQI_d} = \max_p(\mathrm{I_p}) \quad (2)$$

TABLE I CPCB AQI CATEGORIES AND 24-H BREAKPOINTS (μG/M³)

AQI category	PM_{10}	$PM_{2.5}$	NO_2
Good (0–50)	0–50	0–30	0–40
Satisfactory (51–100)	51–100	31–60	41–80
Moderate (101–200)	101–250	61–90	81–180
Poor (201–300)	251–350	91–120	181–280
Very poor (301–400)	351–430	121–250	281–400
Severe (401–500)	>430	>250	>400

Source: CPCB [4].

E. Aggregation and Dispersion Metrics

The monthly mean AQI at station s is the average of the $N_{s,m}$ valid daily values:

$$\mathrm{A_{s,m}} = \frac{1}{\mathrm{N_{s,m}}}\sum_{d=1}^{\mathrm{N_{s,m}}} \mathrm{AQI_{s,m,d}} \quad (3)$$

For city c with four stations, the spatial mean, sample standard deviation and coefficient of variation are:

$$\mu_{c,m} = \frac{1}{4}\sum_{s\in c} \mathrm{A_{s,m}} \quad (4)$$

$$\sigma_{c,m} = \sqrt{\frac{1}{3}\sum_{s\in c}\left(\mathrm{A_{s,m}} - \mu_{c,m}\right)^2} \quad (5)$$

$$\mathrm{CV_{c,m}} = \frac{\sigma_{c,m}}{\mu_{c,m}} \times 100\ \% \quad (6)$$

The seasonal change at station s is the percentage difference between October and the July–September baseline:

$$\Delta_s = \frac{\mathrm{A_{s,Oct}} - \mathrm{A_{s,JAS}}}{\mathrm{A_{s,JAS}}} \times 100\ \% \quad (7)$$

where $A_{s,JAS}$ is the mean of the July, August and September values. The three-month baseline is used instead of a single month because the month with the lowest AQI differs between stations (Section VII-B).

F. Statistical Analysis

With 16 stations, skewed values and unequal variances, nonparametric methods were chosen [17]. The Wilcoxon signed-rank test [18] compared October with the July–September baseline across the 16 stations, with the Hodges–Lehmann estimate as the shift and the rank-biserial correlation, $r_{rb} = (W^+ - W^-)/(W^+ + W^-)$, as effect size. The Friedman test [19] compared the four months, with Kendall's $W = \chi^2_F/[n(k-1)]$ as effect size, where

$$\chi^2_F = \frac{12}{nk(k+1)}\sum_{j=1}^{k} R_j^2 - 3n(k+1) \quad (8)$$

with n = 16 stations, k = 4 months and R_j the rank sum of month j. Differences among cities were tested with the Kruskal–Wallis test [20], and the exploratory source-proximate versus background contrast with the Mann–Whitney U test on city-normalised values (station mean divided by its city mean). Exact two-sided p-values were used, with $\alpha = 0.05$. Computations used Python 3 with pandas and SciPy [21].

G. Interpretive Framework

The data contain no meteorological variables, so physical explanations rest on established theory and independent observations. Below-cloud wet removal follows first-order decay, $C(t) = C_0 \exp(-\Lambda t)$, with scavenging coefficient Λ obtained by integrating the collision efficiency E, raindrop fall speed V_t and drop number density N over drop radius r [6]:

$$\Lambda(d_p) = \int_0^\infty \pi r^2 \, E(d_p, r) V_t(r) \, N(r) \, dr \qquad (9)$$

Accumulation under a shallow mixing layer can be illustrated with a one-box model, in which the concentration increment above the regional background C_b scales with the emission flux q, the along-wind fetch L, the mean wind speed $\bar{u}$ and the mixing height H [6]:

$$C = C_b + \frac{q\,L}{\bar{u}\,H} \qquad (10)$$

The product $\bar{u}H$ is the ventilation coefficient. Near-source gradients along roads and stacks are conventionally modelled with Gaussian plume and line-source formulations [22], [23]; these were not run here but frame the recommendations of Section IX.

VI. ACTUAL WORK

The work was carried out in six steps. Step 1, compilation: hourly CAAQMS records for each station were compiled into spreadsheet workbooks for the four city portfolios. Step 2, validation: the protocol followed the CPCB completeness rule (at least 16 hours of valid data for a daily value [4]) and screened for out-of-range values, duplicated time stamps and sensor faults. Step 3, AQI computation: sub-indices and daily AQI were calculated with Eqs. (1) and (2). Step 4, aggregation: daily AQI values were averaged to station-month means (Eq. 3), and city statistics were obtained from Eqs. (4)–(6). Step 5, testing: the tests of Section V-F were applied to the 16 × 4 table of station-month means, which was loaded into Python and all statistics recomputed from it. Step 6, interpretation: results were compared with published benchmarks and with the site descriptions of Table II.

To confirm that the AQI procedure was implemented correctly, a hand calculation was carried out for a test station with $PM_{2.5}$ = 145 µg/m³, PM_{10} = 280 µg/m³ and NO_2 = 95 µg/m³ (Table III). For $PM_{2.5}$, which lies in the 'Very poor' band (121–250 µg/m³), Eq. (1) gives $I = [(400 - 301)/(250 - 121)] \times (145 - 121) + 301 = 319.42$. The PM_{10} and NO_2 values follow in the same way. The overall AQI is the maximum, 319 ('Very poor'), with $PM_{2.5}$ as the dominant pollutant.

TABLE III WORKED EXAMPLE OF THE AQI CALCULATION

Pollutant	C_p (µg/m³)	Band (µg/m³)	Sub-index I_p
$PM_{2.5}$	145.0	Very poor, 121–250	319.42
PM_{10}	280.0	Poor, 251–350	230.00
NO_2	95.0	Moderate, 81–180	115.00
Overall AQI = max(I_p) = 319, 'Very poor'; dominant pollutant $PM_{2.5}$			

VII. RESULTS AND DISCUSSION

A. City-Level Seasonal Pattern

Table IV and Fig. 2 give the city-level statistics. Delhi had the highest city mean in every month (143.0, 129.5, 97.3 and 157.9). Nashik stayed in the 'Good' band and Mumbai and Patna in the 'Satisfactory' band through September, while Delhi was 'Moderate' in July and August. October was the highest month for all four cities. Relative to the July–September baseline, the city mean rose by 28 % in Delhi, 66 % in Mumbai, 139 % in Nashik and 37 % in Patna, and by 52 % over all 16 stations (77.8 to 118.4). The absolute increments were more similar than the percentages suggest—+34.6 in Delhi, +37.9 in Mumbai, +33.4 in Patna and +56.2 in Nashik—so Nashik's large relative rise mostly reflects its low monsoon baseline (40.5).

TABLE IV CITY-LEVEL MONTHLY SPATIAL STATISTICS OF AQI

City	Stat.	Jul	Aug	Sep	Oct
Delhi	µ	143.0	129.5	97.3	157.9
	σ	46.8	67.9	14.4	23.5
	CV (%)	32.7	52.5	14.8	14.9
Mumbai	µ	56.2	63.1	54.1	95.7
	σ	14.4	18.8	7.5	8.4
	CV (%)	25.6	29.9	13.9	8.8
Nashik	µ	38.5	35.4	47.6	96.7
	σ	4.6	5.9	8.6	6.4
	CV (%)	12.0	16.5	18.1	6.6
Patna	µ	89.1	92.5	87.4	123.1
	σ	57.5	55.5	56.1	33.7
	CV (%)	64.5	60.0	64.2	27.4
All 16	µ	81.7	80.1	71.6	118.4
	σ	53.2	54.0	34.3	32.3

µ: mean of four station-month means (Eq. 4); σ: sample SD (Eq. 5); CV: Eq. (6). "All 16" pools all stations.

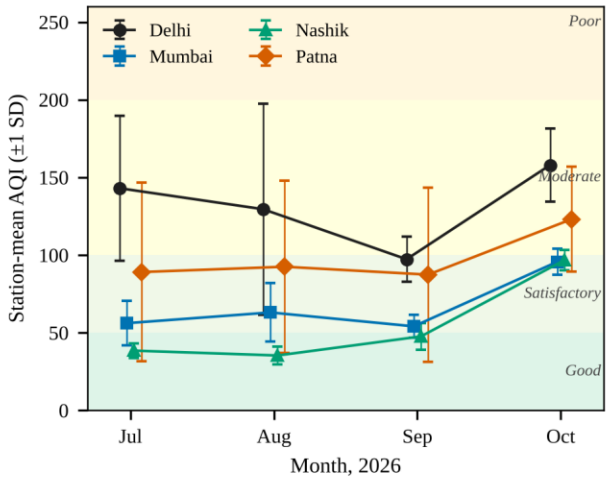


Fig. 2. Monthly station-mean AQI (±1 SD) for the four cities. Shading shows CPCB categories.

The lowest city mean occurred in September for Delhi (97.3), Mumbai (54.1) and Patna (87.4), and in August for Nashik (35.4). The common explanation that July and August are the cleanest months is therefore not borne out uniformly: at 10 of the 16 stations the minimum fell in July or August, at five in September and at one (Samanpura) in October. A more accurate summary is that AQI stayed low and fairly flat through the monsoon months and rose in October, after the monsoon withdrew. The Delhi pattern is consistent with the withdrawal date of 23 September [11].

B. Station-Level Values and Categories

Fig. 3 and Table V show the 16 station-month means with their CPCB categories. The monthly means include 6, 5, 5 and 0 stations in the 'Good' band in July, August, September and October, respectively; the corresponding counts for 'Moderate' are 3, 3, 3 and 9. In October no station was 'Good', nine were 'Moderate' and seven 'Satisfactory'. 'Poor' occurred only at Anand Vihar in July (208.0) and August (229.7). No monthly mean reached 'Very poor', although daily values may have, since a monthly mean conceals daily extremes.

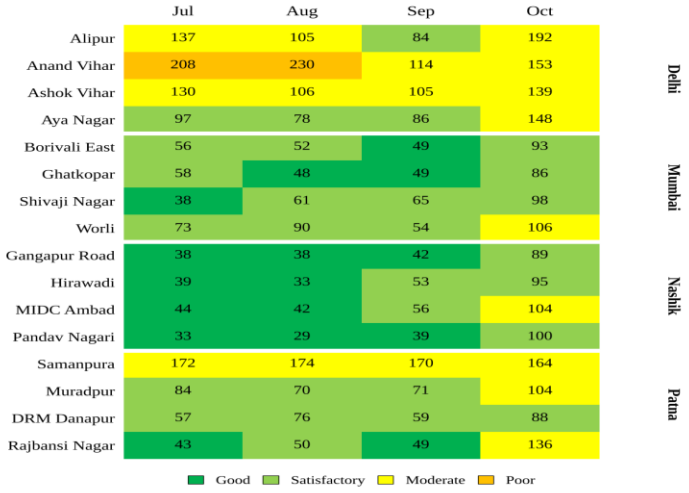


Fig. 3. Station-month mean AQI at 16 CAAQMS, coloured by CPCB category.

TABLE V STATION-MONTH MEAN AQI, JULY–OCTOBER 2026

Station	Jul	Aug	Sep	Oct
Delhi				
Alipur	137.3	104.6	84.3	192.2
Anand Vihar	208.0	229.7	113.9	152.7
Ashok Vihar	130.2	105.5	104.8	139.2
Aya Nagar	96.6	78.3	86.3	147.6
Mumbai				
Borivali East	56.3	52.3	49.2	93.4
Ghatkopar	57.8	48.5	48.7	85.7
Shivaji Nagar	37.7	61.4	64.8	97.9
Worli	72.8	90.2	53.8	105.8
Nashik				
Gangapur Road	38.0	37.7	41.7	88.8
Hirawadi	39.3	32.8	53.5	94.7
MIDC Ambad	43.9	42.3	56.5	103.8
Pandav Nagari	32.7	28.8	39.0	99.5
Patna				
Samanpura	171.5	174.1	170.5	164.1
Muradpur	84.0	69.6	71.0	104.3
DRM Danapur	57.4	76.2	58.9	88.2
Rajbansi Nagar	43.5	50.3	49.3	135.7

Cell shading follows the CPCB category colours of Table I.

C. Seasonal Change: Inferential Tests

October exceeded the July–September baseline at 14 of 16 stations (Fig. 4). The exceptions were Anand Vihar (−16.9 %) and Samanpura (−4.6 %), both of which were already high during the monsoon. The paired Wilcoxon test gave $W = 6$, exact $p = 4.3 \times 10^{-4}$, with a Hodges–Lehmann shift of +42.2 AQI points and $r_{rb} = 0.91$ (Table VI), supporting H1. The Friedman test rejected equality of the four months ($\chi^2(3) = 18.7$, $p = 3.2 \times 10^{-4}$), with moderate agreement in ranks (Kendall's $W = 0.39$). The largest relative increases were at Pandav Nagari (+197 %) and Rajbansi Nagar (+185 %), both residential stations that had been in the 'Good' band in most monsoon months.

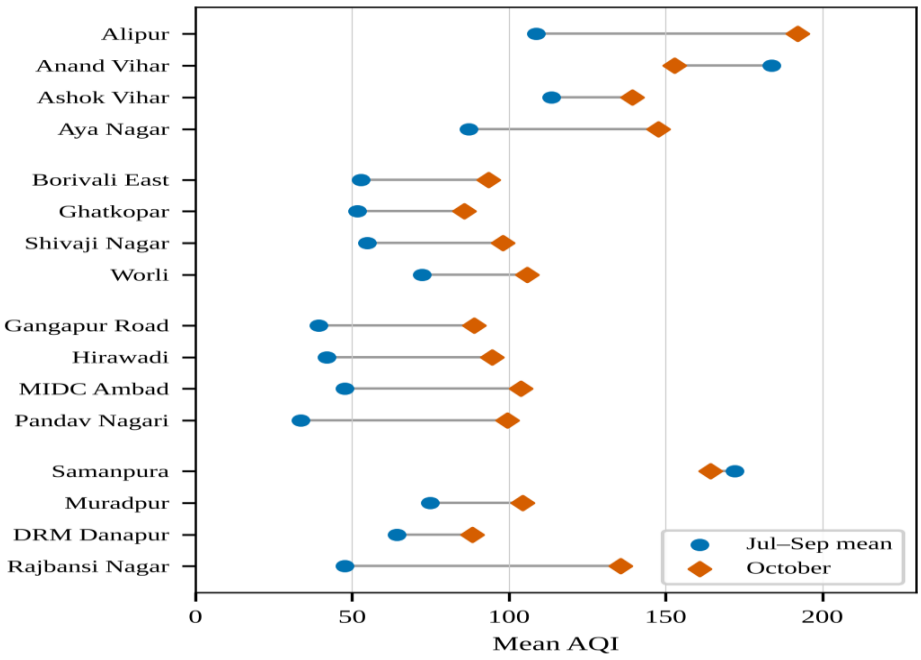


Fig. 4. Mean AQI in July–September (circles) and October (diamonds) at each station, grouped by city.

TABLE VI SUMMARY OF NONPARAMETRIC TESTS (N = 16 STATIONS)

Test	Comparison	Result	p
Wilcoxon	Oct vs Jul–Sep mean	W = 6; HL = +42.2; r_{rb} = 0.91	4.3×10^{-4}
Wilcoxon	Aug vs Oct	W = 15	0.0042
Wilcoxon	Sep vs Oct	W = 1	6.1×10^{-5}
Friedman	Jul, Aug, Sep, Oct	$\chi^2(3) = 18.68$; W = 0.39	3.2×10^{-4}
Kruskal–Wallis	Four-month station means, 4 cities	H(3) = 12.13	0.0069
Kruskal–Wallis	October values, 4 cities	H(3) = 8.16	0.043
Mann–Whitney	S vs B, city-normalised	U = 44	0.147

HL: Hodges–Lehmann shift in AQI points; r_{rb}: rank-biserial correlation. Exact two-sided p from SciPy [21]. Seven comparisons are listed. After Bonferroni correction ($\alpha/7 = 0.0071$) the first five remain significant; the October Kruskal–Wallis test and the Mann–Whitney test do not. The Aug–Oct and Sep–Oct comparisons are post hoc and not independent of the primary test.

D. Intra-City Spatial Heterogeneity

Dispersion differed markedly between cities (Table IV, Fig. 5), supporting H2. Patna had the widest spread from July to September (CV 60–65 %; max/min ratio 3.5–3.9), caused by the contrast between Samanpura (164–174) and Rajbansi Nagar (43–50). In Delhi the CV peaked in August (52.5 %) because Anand Vihar (229.7) was 2.9 times Aya Nagar (78.3). Nashik was the most homogeneous (CV 12–18 % in July–September). In every city the CV was lowest in October (Delhi 14.9 %, Mumbai 8.8 %, Nashik 6.6 %, Patna 27.4 %). The picture is that of a regional

loading that raises all stations together once the monsoon retreats and compresses local differences, a pattern in line with the homogeneity of Delhi sites reported by Hama et al. [13] and with the dominant role of out-of-city emissions [15]. Local hotspots therefore tend to stand out when the regional background is lower, as in July–August in Delhi and Patna, although Delhi's September spread was already narrow (CV 14.8 %).

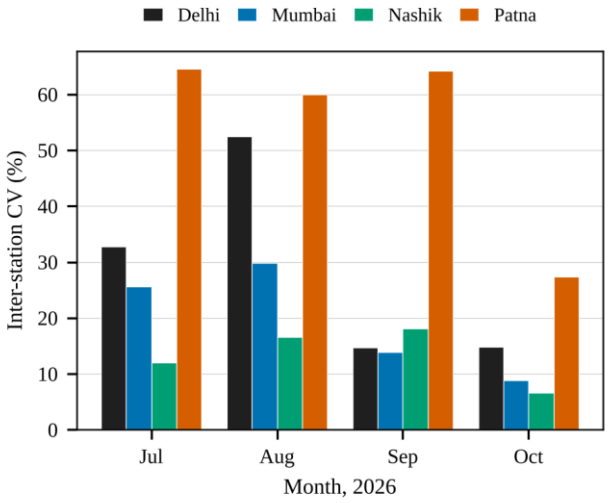


Fig. 5. Inter-station coefficient of variation of AQI by city and month.

E. Persistent Hotspots

Four stations ranked first in their city in three or four of the four months: Samanpura (Patna, four months), MIDC Ambad (Nashik, four), Anand Vihar (Delhi, July–September) and Worli (Mumbai, July, August and October). Samanpura is the most striking. Its monthly mean stayed between 164 and 174 even in the rainiest months, and it was the only station whose minimum fell in October. A level that does not respond to the season points to a strong local source, such as road dust, commercial activity or waste burning (the authors' site notes), or to a persistent measurement offset; the monthly AQI alone cannot separate the two, and pollutant-level and instrument-audit data are needed.

Anand Vihar's July and August means (208.0 and 229.7) are about twice the 105 city-wide Delhi mean AQI reported for July–September 2026 [24]. A monthly mean above 200 implies many days at or above the 'Poor' threshold unless a few extreme days dominate, which is notable in the monsoon. Anand Vihar is a known legacy hotspot [13], [14], and because a 2026 analysis found that gases, especially ozone, led the daily AQI on many monsoon days [11], its monsoon AQI may be driven by a non-particulate sub-index. This needs the dominant-pollutant records to confirm. The fall of its AQI from August to October (−33 %) is another reminder that the post-monsoon rise is not universal: the stations with the highest monsoon baseline have the least room to rise.

F. Source-Proximate versus Background Stations (Exploratory)

Six stations whose surroundings are dominated by a transport hub, freight terminal, industrial estate or construction activity (Table II, 'S') had a four-month mean AQI of 103.1, against 78.9 for the ten background stations, a difference of +31 %. Within cities the gaps were +50 % (Delhi),

+58 % (Patna), +18 % (Nashik) and +10 % (Mumbai). After normalising by each city's mean, the difference was not significant (Mann–Whitney U = 44, p = 0.147; Table VI). Reasonable alternative groupings gave differences between +22 % and +45 % and p-values between 0.02 and 0.20, so the result depends on how borderline stations (e.g., the landfill-adjacent Shivaji Nagar) are classified. The data are consistent with H3 in direction but do not confirm it. We therefore do not claim a fixed percentage excess for source-proximate sites. The grouping rests on the authors' site descriptions, not on CPCB station-type metadata, and should be re-run with the latter.

G. Cross-Check with Independent CPCB-Derived Benchmarks

City-level benchmarks derived from CPCB data by other organisations allow a plausibility check (Table VII). The September Delhi mean from the four stations (97.3) is close to the 102 reported for the whole city [25]. The July–September mean (123.3) is higher than the city-wide 105 [24], as expected when high-concentration stations are selected. In October, Delhi's monthly $PM_{2.5}$ placed it in the 'Moderate' band, and 33 of 36 Maharashtra cities were in the 'Satisfactory' band [26]; both match the station results in Table V (Delhi 157.9, 'Moderate'; Mumbai 95.7 and Nashik 96.7, 'Satisfactory'). These benchmarks use different averaging and, in the October case, a $PM_{2.5}$-only classification, so the agreement is qualitative.

TABLE VII COMPARISON WITH CPCB-DERIVED CITY-LEVEL BENCHMARKS

Quantity	This study	Benchmark	Ref.
Delhi, Sep mean AQI	97.3 (4 stations)	102 (city-wide)	[25]
Delhi, Jul–Sep mean AQI	123.3 (4 stations)	105 (city-wide)	[24]
Delhi, Oct	AQI 157.9, Moderate	Monthly $PM_{2.5}$ in Moderate band (61–90 μg/m³)	[26]
Mumbai, Nashik, Oct	AQI 95.7 and 96.7, Satisfactory	33 of 36 Maharashtra cities Satisfactory ($PM_{2.5}$)	[26]

H. Implications for Civil Engineering Practice

The station-level contrasts suggest where engineering effort is likely to pay off, with the caveat that the data do not identify sources. (1) Traffic hubs and freight terminals (Anand Vihar, Worli, Samanpura, DRM Office Danapur): coordinated signal timing to reduce idling, grade-separated bypasses for through freight, terminal layouts that limit queuing, and paving, mechanised sweeping and dust stabilisation of road shoulders. (2) Construction activity: perimeter enclosures and wind-breaks, water misting, stabilised haul roads and covered transport of spoil, with monitoring-based compliance. (3) Industrial margins and landfill edges (MIDC Ambad, Shivaji Nagar): multi-tier vegetative buffers combined with process and fugitive-emission control. Because out-of-city emissions dominate urban $PM_{2.5}$ [15], such local measures complement but cannot replace airshed-level action.

The one-box model of Eq. (10) shows why the post-monsoon months matter for design and operation of controls: with emissions and wind fixed, halving the mixing height doubles the

increment above background, and a fall from 1000 m to 250 m would quadruple it. The observed rise of 1.3–2.4 times in station-mean AQI is smaller than that idealised scaling, because wind speed, emissions and the background also change, and because the AQI is a piecewise-linear, worst-pollutant function of concentration rather than a proportional one.

VIII. LIMITATIONS

(1) The record covers four months of one year, so it cannot represent the winter peak or inter-annual variability. (2) The AQI is the maximum sub-index; without dominant-pollutant data, changes cannot be attributed to particulate scavenging or to any single pollutant, and gaseous sub-indices may govern in the monsoon [11]. (3) No meteorological observations (rainfall, wind, mixing height) were analysed; the explanations in Sections VII-A and VII-D rest on theory and independent studies, not on a fitted model. (4) Stations were chosen for high baseline concentration, so the 16 stations are not representative of city-wide exposure, as Section VII-G illustrates. (5) Monthly means of daily AQI conceal daily extremes, and the number of valid days per station-month was not tabulated, so completeness could not be assessed station by station. (6) With four stations per city, intra-city statistics are descriptive and city-wise tests have little power. (7) The source-proximate grouping is subjective and untested against CPCB station metadata. (8) The data come from three state networks whose calibration and quality-assurance practices may differ.

IX. FUTURE SCOPE

The study can be extended in six directions. (1) Extend the record to a full year or several years, including November–February. (2) Analyse pollutant-level data to establish the dominant pollutant, the $PM_{2.5}/PM_{10}$ ratio and the role of gases in the monsoon. (3) Merge rainfall, wind and boundary-layer height from the India Meteorological Department or reanalysis data into regression or generalised additive models, and add satellite fire counts for the post-monsoon biomass-burning signal. (4) Use GIS-based interpolation (e.g., kriging) and land-use regression with road density, industrial area and green cover to estimate AQI at unmonitored locations. (5) Apply line-source and Gaussian plume models [22], [23] to corridors identified as hotspots, and evaluate interventions with before-and-after or difference-in-differences designs. (6) Densify monitoring with calibrated low-cost sensors near hotspots and publish station-level AQI dashboards alongside city averages.

X. CONCLUSION

Station-level AQI at 16 CPCB-network stations in Delhi, Mumbai, Nashik and Patna showed a clear seasonal break. The mean AQI was 77.8 during July–September and rose to 118.4 in October (+52 %), with 14 of 16 stations higher (exact Wilcoxon $p < 0.001$). Delhi was highest in absolute

terms (157.9 in October) and Nashik rose most in relative terms (+139 %). Inter-station dispersion was large during the monsoon, especially in Patna (CV above 60 %), and shrank in October as regional loading raised all stations. Persistent hotspots (Samanpura, Anand Vihar, Worli, MIDC Ambad) were identified, and city-level results agreed qualitatively with independent CPCB-derived benchmarks. The excess of source-proximate stations over background stations (+31 %) was directionally consistent but not statistically established. The findings argue for station-level reporting and for targeting traffic corridors, construction dust and industrial margins with civil-engineering controls, within an airshed-wide strategy.

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Data availability: Station-month values analysed here are given in Table V; the underlying CAAQMS records are publicly available through the CPCB CCR portal [5].

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