

Seasonal Comparative study of Air Quality Index between Residential and Commercial Zones of Jhansi City

Angita^{1*}, Vinit Kumar², Ekta Panday³

¹Department of Regional & Environmental Studies, Bundelkhand University, Jhansi, Uttar Pradesh, India

²Department of Regional & Environmental Studies, Bundelkhand University, Jhansi, Uttar Pradesh, India

³Applied Science Department, Bundelkhand Institute of Engineering & Technology, Jhansi, Uttar Pradesh, India

* Corresponding author: angita9506@gmail.com

Abstract:

Smaller Indian cities such as Jhansi have few published comparisons of air quality between city zones and across seasons. We compared a residential site (Site 1, BIET campus area) with a commercial site (Site 2, Bus Stand) using monthly mean PM₁₀, SO₂ and NO₂ for every month of 2023 and 2024. Sampling and analysis followed CPCB guidelines, and the sub-indices and overall Air Quality Index (AQI) were calculated by the CPCB method and checked against the National Ambient Air Quality Standards (NAAQS). PM₁₀ was higher at the commercial site in 22 of 24 paired months, but the mean gap was only 2.64 µg/m³ (2.4%). PM₁₀ decided the AQI in every month at both sites. Seasonal AQI ran from 82 to 163; of 48 site-months, 27 were Moderate, 20 Satisfactory and one Good. Post-monsoon was the most polluted season in both years, and monthly PM₁₀ passed the 24-hour limit of 100 µg/m³ in 28 of 48 site-months, while SO₂ and NO₂ never reached theirs. Concentrations were lower in 2024, mainly after the monsoon (about 39%). The difference between zones is consistent but small, and without traffic or weather records it cannot be tied to particular sources.

Keywords: Air Quality Index; PM₁₀; SO₂; NO₂; seasonal variation; CPCB; NAAQS, air pollution

1. Introduction

Air pollution is a major health burden in Indian cities. The Global Burden of Disease study for 2019 attributed about 1.7 million deaths in India to air pollution, with wide gaps between states (Pandey et al., 2021). Because raw concentrations are hard to interpret, they are converted into an Air Quality Index (AQI), which gives a single value and a class. India's National AQI, developed by the CPCB, covers eight pollutants and takes the highest sub-index among those with valid data as the overall value (CPCB, 2014). Measured levels are also checked against the legal limits in the National Ambient Air Quality Standards (CPCB, 2009). Pollution is not even across a city. Bus stands and commercial streets are expected to be dirtier because of exhaust, idling engines, congestion and road dust, while residential areas depend more on distance from busy roads and on nearby greenery. Reviews of Indian cities report that

particulate matter often exceeds the standards while SO₂ and NO₂ usually stay within them, and that winter is generally the worst season (Chauhan et al., 2017; Nasir et al., 2016; Verma et al., 2018). Studies from other cities show why land use alone is not enough to predict this. In Jodhpur, AQI values in March 2016 were 194–273 at residential sites near a busy commercial district but only 118–129 at a site farther from main roads (Rai, 2016). In Lucknow and Kanpur, PM_{2.5} and PM₁₀ exceeded national standards at all six sites, yet the Lucknow PM_{2.5} averages did not follow land use neatly (Mumtaz et al., 2017). In Warangal, respirable particulate matter at a busy junction was several times higher than at a residential site (Shashidhar et al., 2011), and in Jakarta, PM_{2.5} fell during the Eid holiday when inner-city traffic eased (Kusumaningtyas et al., 2018). Data quality is a further concern: Tataavarti (2021) reports that many continuous monitoring stations in India during early 2020 had gaps of several days and did not all record every pollutant needed for an AQI.

2. Study Sites and Methods

2.1 Sites and seasons

Site 1 (residential) is located within the Bundelkhand Institute of Engineering and Technology (BIET) campus on Kanpur Road (NH-25), Jhansi 284128. Since the campus fronts a national highway, the difference from the commercial site may be smaller than the zone labels imply. Site 2 (commercial) is the Jhansi Bus Station (UPSRTC) at Talpura, Jhansi 284002, a transport hub surrounded by busy market streets. Seasons followed the standard Indian classification: pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and winter (December–February). Each calendar year was treated separately, so “winter” for a given year covers January, February and December of that year, and a seasonal value is the mean of its monthly means.

2.2 Sampling and measurement

PM₁₀, SO₂ and NO₂ were measured at both sites following the CPCB measurement guidelines (CPCB, 2013) and the NAAQS sampling design of 24-hour samples taken twice a week, at least 104 a year (CPCB, 2009). The equipment at both sites was installed by BIET. PM₁₀ was collected on pre-weighed glass-fibre filters with an Envirotech APM 460 respirable dust sampler, whose cyclone removes particles coarser than 10 µm before the air reaches the filter (CPCB, 2003). Filters were conditioned in a desiccator for 24 hours before and after a 24-hour run at 1.1–1.7 m³/min. Concentration was calculated as $C = (W_2 - W_1) \times 10^6 / V$, where W_1 and W_2 are the filter weights before and after sampling (g) and V is the air volume (m³). The monthly value is the mean of that month's 24-hour samples. SO₂ was measured by UV fluorescence and NO₂ by chemiluminescence, as described in CPCB (2013), with NO₂ taken as the difference between total NO_x and NO. Inlets were kept at least 1 m from the instrument enclosure, enclosure temperature was held within ± 5 °C, and zero and span checks were done at least weekly, with multipoint calibration after installation and repairs.

2.3 Standards and AQI calculation

Measured values were compared with the NAAQS limits (CPCB, 2009), which are identical for residential and commercial areas, and converted to sub-indices (0–500) using the CPCB breakpoints in Table 1 (CPCB, 2014). Sub-indices were obtained by linear interpolation, $I = [(I_{HI} - I_{LO}) / (B_{HI} - B_{LO})] \times (C - B_{LO}) + I_{LO}$, with values between classes interpolated across the gaps in the published breakpoints and rounded to the nearest whole number. The highest sub-index is the overall AQI, and its pollu-

tant is the determining pollutant. Because the CPCB sub-indices are defined for 24-hour averages, AQI values from monthly or seasonal means are indicative only.

Table 1. NAAQS limits and the upper breakpoint of each AQI class ($\mu\text{g}/\text{m}^3$)

Pollutant	NAAQS annual	NAAQS 24-h	Good ($\leq$)	Satisfactory ($\leq$)	Moderate ($\leq$)
PM ₁₀	60	100	50	100	250
SO ₂	50	80	40	80	380
NO ₂	40	80	40	80	180

3. Results & Discussion

3.1 Concentrations and AQI by season

Post-monsoon 2023 was by far the worst period (Table 2, Fig. 1). Seasonal PM₁₀ reached 190.63 $\mu\text{g}/\text{m}^3$ at Site 1 and 193.72 $\mu\text{g}/\text{m}^3$ at Site 2, SO₂ reached 51.52 and 52.36, and NO₂ 56.06 and 56.97 $\mu\text{g}/\text{m}^3$ (Table 3). Pre-monsoon was the cleanest season (PM₁₀ 82.67 and 81.58 $\mu\text{g}/\text{m}^3$). The seasons were much closer together in 2024, when PM₁₀ ranged from 94.39 to 119.13 $\mu\text{g}/\text{m}^3$, with post-monsoon again highest and monsoon lowest. November had the highest monthly PM₁₀ in both years (222.06 and 226.26 $\mu\text{g}/\text{m}^3$ in 2023; 118.41 and 121.65 in 2024). The lowest months were March 2023 (55.26 and 49.65) and August 2024 (88.47 and 88.92).

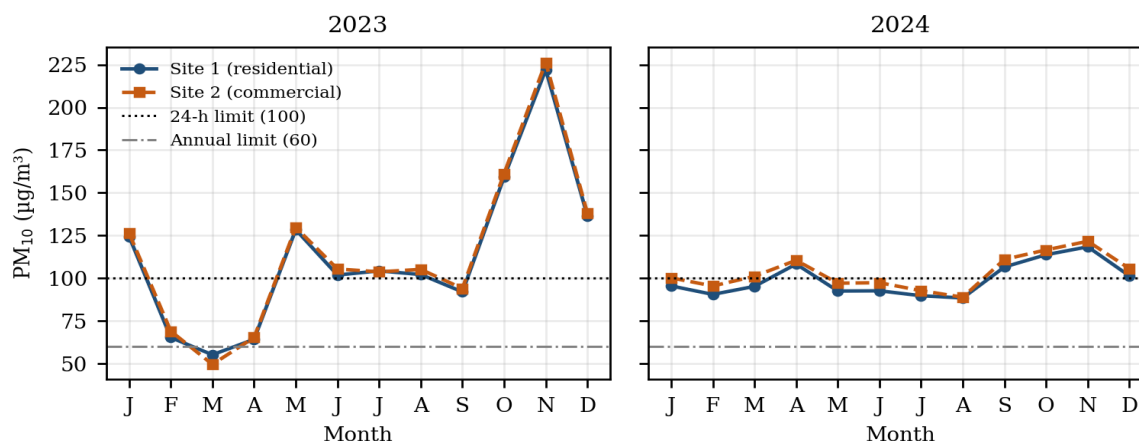


Figure 1. Monthly mean PM₁₀ at the residential (Site 1) and commercial (Site 2) sites, 2023 and 2024. Dotted lines show the NAAQS 24-hour (100) and annual (60) limits.

Table 2. Seasonal mean PM₁₀ (µg/m³) and overall AQI at the residential (Site 1) and commercial (Site 2) sites

Season	Year	PM ₁₀ Site 1	PM ₁₀ Site 2	AQI Site 1	AQI Site 2
Pre-monsoon	2023	82.67	81.58	83	82
Monsoon	2023	100.12	102.13	100	102
Post-monsoon	2023	190.63	193.72	161	163
Winter	2023	108.75	111.12	106	108
Pre-monsoon	2024	98.70	102.94	99	102
Monsoon	2024	94.39	97.54	94	98
Post-monsoon	2024	116.10	119.13	111	113
Winter	2024	95.82	100.46	96	100

AQI classes: Good 0–50, Satisfactory 51–100, Moderate 101–200. PM₁₀ was the determining pollutant in every case.

Seasonal AQI ran from 82 (pre-monsoon 2023, Site 2) to 163 (post-monsoon 2023, Site 2). PM₁₀ set the AQI in every season and in all 48 site-months; the SO₂ and NO₂ sub-indices were far lower (64 and 70 against 161 for PM₁₀ at Site 1 in post-monsoon 2023). Of the 48 site-months, 27 were Moderate, 20 Satisfactory and one Good (Bus Stand, March 2023, index 50), and none was Poor. The highest monthly AQI was 181 at Site 1 and 184 at Site 2 in November 2023 (Fig. 2). A seasonal mean can also hide quick changes: in pre-monsoon 2023 the AQI climbed from 55 and 50 in March to 119 and 120 in May. Many seasonal values (94 to 108) sit close to the 100 boundary, so the category can flip on a few index points. Site 2 in January 2024 is one case: its PM₁₀ of 100.26 µg/m³ is just over the 24-hour limit, yet the AQI rounds to 100 (Satisfactory), which is why 28 site-months exceeded the limit while 27 were Moderate.

Table 3. Seasonal mean SO₂ and NO₂ (µg/m³) at the residential (Site 1) and commercial (Site 2) sites

Season	Year	SO ₂ Site 1	SO ₂ Site 2	NO ₂ Site 1	NO ₂ Site 2
Pre-monsoon	2023	22.34	22.04	25.98	23.99
Monsoon	2023	27.06	27.60	29.44	30.04
Post-monsoon	2023	51.52	52.36	56.06	56.97
Winter	2023	29.22	30.03	34.99	32.68
Pre-monsoon	2024	26.67	27.82	29.03	30.27
Monsoon	2024	25.50	26.36	27.76	28.68
Post-monsoon	2024	31.38	32.19	34.14	35.03
Winter	2024	25.89	27.14	28.04	29.54

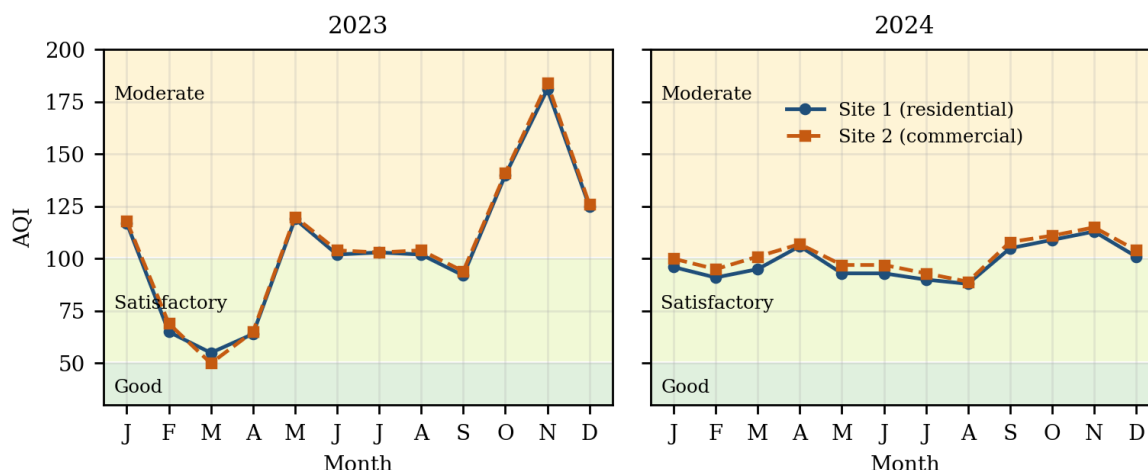


Figure 2. Monthly overall AQI at both sites, 2023 and 2024, with the CPCB Good, Satisfactory and Moderate bands shaded. PM_{10} was the determining pollutant in every month.

3.2 Differences between the zones

The commercial site was higher in most months (Table 4). PM_{10} was higher at Site 2 in 22 of 24 paired months by a mean of $2.64 \mu\text{g}/\text{m}^3$ (2.4%), SO_2 in 22 and NO_2 in 20. The overall AQI was higher at Site 2 in 22 months, equal in July 2023 and lower in March 2023. The exceptions were few and small: in March and July 2023 the residential site was slightly higher for all three pollutants. The largest monthly PM_{10} gap was $5.91 \mu\text{g}/\text{m}^3$ (6.2%) in March 2024, and the mean PM_{10} gap was $1.50 \mu\text{g}/\text{m}^3$ in 2023 and $3.78 \mu\text{g}/\text{m}^3$ in 2024. These gaps are tiny beside the seasonal swing; at Site 1 in 2023 seasonal PM_{10} differed by about $108 \mu\text{g}/\text{m}^3$ between post-monsoon and pre-monsoon.

Table 4. Commercial (Site 2) minus residential (Site 1) over 24 paired months, 2023–2024

Pollutant	Months Site 2 higher	Mean diff. ($\mu\text{g}/\text{m}^3$)	Mean diff. (%)	Range (%)	Sign test p
PM_{10}	22 of 24	+2.64	+2.4	−10.2 to +6.2	< 0.001
SO_2	22 of 24	+0.73	+2.5	−10.2 to +6.2	< 0.001
NO_2	20 of 24	+0.21	+0.1	−28.7 to +6.2	0.002

3.3 Comparison with the standards

PM_{10} was the pollutant that failed (Table 5). Its annual mean was 99.44 to $114.50 \mu\text{g}/\text{m}^3$ at both sites in both years, well above the NAAQS annual limit of $60 \mu\text{g}/\text{m}^3$, and the monthly mean passed $100 \mu\text{g}/\text{m}^3$ in 28 of 48 site-months. SO_2 and NO_2 never went over their 24-hour limits, and their annual means (SO_2 26.87 – $30.94 \mu\text{g}/\text{m}^3$; NO_2 29.21 – $34.40 \mu\text{g}/\text{m}^3$) were below the annual limits of 50 and 40. Every monthly PM_{10} mean was above the WHO (2021) 24-hour guideline of $45 \mu\text{g}/\text{m}^3$; the lowest was $49.65 \mu\text{g}/\text{m}^3$. Setting monthly means against limits defined for other averaging periods is only a rough guide.

Table 5. Annual mean of monthly means ($\mu\text{g}/\text{m}^3$) and months above the 24-hour limit

Pollutant (NAAQS annual / 24-h)	2023 Site 1	2023 Site 2	2024 Site 1	2024 Site 2
PM ₁₀ (60 / 100)	113.00; 8 of 12	114.50; 8 of 12	99.44; 5 of 12	103.22; 7 of 12
SO ₂ (50 / 80)	30.49; 0 of 12	30.94; 0 of 12	26.87; 0 of 12	27.89; 0 of 12
NO ₂ (40 / 80)	34.40; 0 of 12	33.67; 0 of 12	29.21; 0 of 12	30.35; 0 of 12

3.4 Change from 2023 to 2024

Air quality was better in 2024 at both sites. Annual mean PM₁₀ fell from 113.00 to 99.44 $\mu\text{g}/\text{m}^3$ at Site 1 (−12.0%) and from 114.50 to 103.22 $\mu\text{g}/\text{m}^3$ at Site 2 (−9.9%); SO₂ fell by 11.9% and 9.9%, and NO₂ by 15.1% and 9.9%. The change depended on the season: post-monsoon dropped about 39% at both sites, winter PM₁₀ by 10 to 12%, and monsoon PM₁₀ by roughly 5%. Pre-monsoon went the other way, rising 19 to 26%, partly because March 2023 was so low. The commercial site was higher for PM₁₀ and SO₂ in nearly every month and for NO₂ in most. That fits a transport hub: buses, idling, congestion and road dust are all reasonable suspects, and the Jakarta result shows that thinner traffic can lower particle levels (Kusumaningtyas et al., 2018). Studies in Jodhpur, Lucknow and Warangal likewise tie higher particle levels near commercial areas to traffic, road dust and construction (Rai, 2016; Mumtaz et al., 2017; Shashidhar et al., 2011). We had no traffic counts or source data, so these remain possibilities. Three things restrict what we can say. The gaps are small, about 2 to 3% for PM₁₀ and SO₂ and close to zero for NO₂, and may be within instrument error, so the steady direction tells us more than the size. The residential site stands on NH-25, which probably narrows the contrast. And the two sites rise and fall almost together, which suggests that city-wide or regional influences and weather drive most of the variation. The wider gap in 2024 could reflect local activity, but equally instrument or data-handling differences between years. Compared with the sharp contrasts reported from Jodhpur and Warangal (Rai, 2016; Shashidhar et al., 2011).

Seasons. Post-monsoon concentrations were highest in both years, with November the worst month. Calmer, cooler weather after the monsoon and regional sources active in northern India at that time of year are both possible explanations, but we had no weather or emission data to test either. Winter 2023 was also high, in line with reports of higher winter levels elsewhere in India (Nasir et al., 2016; Verma et al., 2018), though winter was close to the other seasons in 2024. The monsoon was the cleanest season in 2024, as expected from rain washing particles out of the air, but not in 2023, when March and April were lower than every monsoon month. May 2023 was high (128.46 and 129.75 $\mu\text{g}/\text{m}^3$), possibly from pre-monsoon dust. The very low March 2023 values and the large pre-monsoon rise in 2024 are not explained by our data and could be real weather effects or data problems. Topography and weather are known to shape differences between places (Chauhan et al., 2017).

5. Conclusion

The commercial site in Jhansi had higher PM₁₀ than the residential site in 22 of 24 paired months (mean +2.64 $\mu\text{g}/\text{m}^3$, 2.4%), with SO₂ higher in 22 and NO₂ in 20. The difference is consistent but small, and much smaller than the change between seasons. Post-monsoon was the most polluted season in both years (seasonal AQI 161–163 in 2023 and 111–113 in 2024). PM₁₀ set the AQI in every month,

exceeded the 24-hour limit in 28 of 48 site-months and the annual limit in every site-year, whereas SO₂ and NO₂ stayed within their limits. Pollution fell in 2024, most strongly after the monsoon (about 39%). Over the two years, the air at both sites sat in the Satisfactory to Moderate range. SO₂ stayed low, which fits with Jhansi having no heavy industrial belt, and NO₂ never reached its limits either, so traffic exhaust at these two locations does not seem to have been a major source. PM₁₀ is the pollutant that held the index up, and it is the one that most needs attention, particularly from road dust and vehicles in the months before and after the monsoon.

REFERENCES:

1. Central Pollution Control Board. (2003). *Guidelines for ambient air quality monitoring* (National Ambient Air Quality Monitoring Series). Ministry of Environment and Forests, Government of India.
2. Central Pollution Control Board. (2009). *National Ambient Air Quality Standards* (Notification, 18 November 2009). Ministry of Environment and Forests, Government of India.
3. Central Pollution Control Board. (2013). *Guidelines for the measurement of ambient air pollutants, Volume II: Guidelines for real time sampling and analyses* (NAAQMS/37/2012-13). Central Pollution Control Board, Delhi.
4. Central Pollution Control Board. (2014). *National Air Quality Index*. Ministry of Environment, Forest and Climate Change, Government of India. https://app.cpcbcr.com/ccr_docs/FINAL-REPORT_AQI_.pdf
5. Chauhan, P., Gauba, P., Aggarwal, S., & Chaudhary, S. R. (2017). Status of ambient air quality of topographical different cities. *Indo Global Journal of Pharmaceutical Sciences*, 7(1), 46.
6. Kusumaningtyas, S. D. A., Aldrian, E., Wati, T., Atmoko, D., & Sunaryo. (2018). The recent state of ambient air quality in Jakarta. *Aerosol and Air Quality Research*, 18, 2343–2354. <https://doi.org/10.4209/aaqr.2017.10.0391>
7. Mumtaz, N., Yadav, A., & Izhar, T. (2017). Comparative assessment of air quality of major cities of Uttar Pradesh, India. *International Journal of Scientific Research in Science and Technology*, 3(4), 220–225.
8. Nasir, H., Goyal, K., & Prabhakar, D. (2016). Review of air quality monitoring: Case study of India. *Indian Journal of Science and Technology*, 9(44). <https://doi.org/10.17485/ijst/2016/v9i44/105255>
9. Pandey, A., Brauer, M., Cropper, M. L., Balakrishnan, K., Mathur, P., Dey, S., et al. (2021). Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019. *The Lancet Planetary Health*, 5(1), e25–e38.
10. Rai, N. K. (2016). Comparative study of ambient air quality using air quality index in residential areas of Jodhpur city. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 10(12, Ver. II), 93–98. <https://doi.org/10.9790/2402-1012029398>
11. Shashidhar, Kanth, K., Reddy, N., Singh, V. K., & Mahapatra, S. K. (2011). Ambient air quality monitoring for Warangal city. *Indian Journal of Air Pollution Control*, 11(1), 31–40.
12. Tatavarti, R. (2021). Ambient air quality monitoring: Impetus, complexities, challenges and solutions. *Global Journal of Science Frontier Research: H Environment & Earth Science*, 21(4), 41–58.

13. Verma, A. K., Shukla, N. K., & Rai, A. K. (2018). Urban air quality of million populated cities of India. *International Journal of Science Technology & Engineering*, 5(4), 69–77.
14. World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. WHO.