

Seasonal Variation in Air Quality Index across Rural and Urban Bihar: A Comparative Study of Gaya City and Kusdihra Village

Navneet Kumar^{1,*}, Nidhi Sinha²

Abstract

Air Quality Index (AQI) is a composite indicator used to communicate ambient air-quality conditions and their potential health implications. This study examines spatial and seasonal variation in AQI between Gaya city and Kusdihra village, representing urban and rural settings in Gaya district, Bihar. Secondary AQI observations were obtained from the Central Pollution Control Board (CPCB) National Air Quality Index portal at eight fixed time-slots per day during two 20-day observation windows: 1–20 May 2024 (pre-monsoon) and 1–20 November 2024 (post-monsoon). Study-specific daily means were calculated from the eight observations and used for comparative analysis. The results show that mean AQI at Gaya increased from 132.11 in the pre-monsoon period to 181.77 in the post-monsoon period, while Kusdihra increased from 84.25 to 89.21. Gaya therefore recorded substantially poorer air quality in both periods and a much stronger post-monsoon deterioration. Day-wise observations also reveal marked short-term variability and episodic high-AQI conditions. The observed pattern is interpreted in relation to local anthropogenic activities, seasonal atmospheric dispersion and regional pollution influences, while recognising that the AQI dataset does not permit direct source attribution. The study highlights the value of settlement-sensitive monitoring in the eastern Indo-Gangetic Plain and the need to include rural and peri-urban areas in air-quality planning.

Keywords: Air quality index (AQI), rural-urban variation, seasonal variation, pre-monsoon, post-monsoon, Gaya, Kusdihra, Bihar, particulate pollution.

INTRODUCTION

Air pollution is a major environmental and public-health concern because exposure to particulate matter and gaseous pollutants is associated with adverse respiratory and cardiovascular outcomes. The World Health Organization identifies particulate matter (PM_{2.5} and PM₁₀), ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂) and carbon monoxide (CO) among the principal pollutants for which health-based guidelines have been established. In India, the Air Quality Index converts pollutant concentrations into a single index and associated category, making it a practical tool for communicating spatial and temporal changes in ambient air quality [1].

*Author for Correspondence

Navneet Kumar
E-mail: navneetku95084@gmail.com

¹UG Scholar, Department of Geography, Ram Krishna Dwarika Mahavidyalaya, Patliputra University, Patna, Bihar, India

²Assistant Professor, Department of Geography, Ram Krishna Dwarika Mahavidyalaya, Patliputra University, Patna, Bihar, India

Received Date: September 08, 2026
Acceptance Date: September 23, 2026
Published Date: September 24, 2026

Citation: Navneet Kumar , Nidhi Sinha. Seasonal Variation in Air Quality Index across Rural and Urban Bihar: A Comparative Study of Gaya City and Kusdihra Village. International Journal of Climate Conditions. 2026; 3(2): 33–41p.

Air-quality conditions vary with emission intensity, settlement structure, land use, traffic, topography, atmospheric circulation, and seasonal weather. Consequently, air pollution cannot be understood solely through metropolitan comparisons. Rural and peri-urban environments may also experience substantial particulate exposure from biomass burning, dust, agricultural activities and regional transport. Recent studies show that rural particulate pollution across India, particularly in

the Indo-Gangetic Plain (IGP), is substantial and displays strong seasonal variation [2].

Bihar forms part of the eastern IGP, where high aerosol loading reflects the interaction of local emissions with regional atmospheric processes. Gaya provides a useful setting for a paired rural-urban comparison because the city and nearby Kusdihra village share broadly similar regional seasonal influences while differing in built-up intensity, population concentration, traffic and land use. Examining the two locations during contrasting seasonal windows can therefore reveal how settlement characteristics and seasonal conditions are reflected in observed AQI [3].

The present study compares time-resolved AQI observations for 1–20 May 2024 and 1–20 November 2024. May represents the pre-monsoon hot-dry period, whereas November follows monsoon withdrawal and is commonly associated across the IGP with weaker atmospheric dispersion and enhanced regional particulate loading. By combining rural-urban and seasonal comparison, the study addresses a local-scale evidence gap for Bihar [4].

Objectives of the Study

- To examine and compare the air-quality conditions of Gaya city and Kusdihra village, representing urban and rural settings respectively, in Gaya district, Bihar.
- To analyse the temporal and seasonal variation in AQI during the pre-monsoon period (1–20 May 2024) and post-monsoon period (1–20 November 2024), and to identify the major differences between the two study areas.
- To interpret and discuss the observed rural-urban and seasonal variations in AQI in relation to local anthropogenic activities, seasonal conditions, atmospheric dispersion, and regional pollution influences.

LITERATURE REVIEW

India's air-pollution literature has historically concentrated on major metropolitan areas, where rapid urbanisation, traffic growth, industrial activity and construction have generated high concentrations of particulate matter. Recent research, however, increasingly demonstrates that pollution is spatially heterogeneous and extends across urban, peri-urban and rural landscapes. Using satellite and reanalysis datasets for 2000–2019, reported a gradual increase in particulate pollution in rural India and identified the IGP as the most affected rural region. Rural IGP concentrations were particularly high during winter and post-monsoon periods, indicating that seasonal atmospheric stagnation and regional emission processes remain important away from large cities [2].

The rural-urban distinction is therefore becoming less straightforward using a high-resolution urban-rural sensor network in Lucknow, found PM_{2.5} hotspots in both urban and rural environments and demonstrated that local sources, regional transport and boundary-layer conditions can produce substantial short-distance variation. These findings are relevant to Gaya and Kusdihra because the two locations are geographically close but differ in population density, built-up form, transport intensity and land use [5].

Evidence from the eastern IGP further shows that semi-urban and non-metropolitan locations may experience severe particulate pollution. Documented strong seasonal variability in PM_{2.5} at a semi-urban eastern-IGP site, with high-pollution episodes associated with unfavourable dispersion, aerosol chemistry and regional or long-range transport. Such evidence supports extension of air-quality assessment beyond established metropolitan monitoring networks [6].

The spatial distribution of emissions across the IGP also helps explain persistent regional pollution. Developed a district-level inventory of primary anthropogenic PM_{2.5} emissions and identified contributions from industry, domestic fuel use, open burning, road dust and other sectors, with Gaya among important regional emission hotspots [3]. This is important for interpreting the present results because higher AQI in Gaya is unlikely to reflect a single source; it is more plausibly understood as the combined outcome of multiple local sources superimposed on regional

background pollution (Table 1).

Meteorological conditions determine whether emitted pollutants disperse or accumulate near the surface. Demonstrated that meteorological controls on PM_{2.5} and ozone vary between urban and rural environments in India. Seasonal changes in atmospheric stability, wind and boundary-layer characteristics are particularly relevant during post-monsoon and winter conditions [4]. AQI variation should therefore be interpreted as the outcome of interacting emissions, atmospheric transport and meteorology rather than emissions alone (Table 2).

Despite this expanding literature, relatively few studies directly compare an urban centre and a nearby rural settlement using the same short seasonal windows and time-resolved AQI observations. This represents a local-scale research gap in Bihar. The present study addresses that gap by comparing Gaya city and Kusdihra village during pre-monsoon and post-monsoon periods in 2024 [7].

Study Area

Two contrasting study areas have been selected for the study.

Gaya City

Gaya city represents the urban study area in the Magadh region of southern Bihar. The source dataset describes an urban agglomeration population of 475,987. The city has a dense built environment and substantial traffic, commercial and construction activity. Its semi-enclosed topographic setting, with hills around parts of the city, may also influence local ventilation and pollutant dispersion.

Kusdihra Village

Kusdihra village represents the rural study area in Gaya district. The source dataset reports a population of 3,851. Its lower settlement density and predominantly rural land-use setting contrast with Gaya's more intensive built environment. Because both locations lie within the same district, they experience broadly comparable regional seasonal influences, although local emissions and land-use characteristics differ [8].

DATABASE AND METHODOLOGY

Data Source and AQI Framework

The study uses secondary AQI observations obtained from the CPCB (<https://cpcb.gov.in/>). AQI is treated as the principal indicator rather than being reconstructed from pollutant concentrations. Under the CPCB framework, pollutant-specific sub-indices are calculated, and the relevant maximum sub-index determines the reported AQI [1]. The present analysis therefore uses the reported composite AQI values available for the selected observations.

Data Processing and Computation

AQI observations for Gaya and Kusdihra were compiled at eight fixed time-slots per day (00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00 and 21:00 hours) for each of the 20 days in both observation windows. For each location and date, the eight observations were averaged to obtain a study-specific daily mean AQI (Table 3). The 20 daily means were then averaged to obtain the seasonal mean. This analytical daily mean should not be interpreted as the official CPCB daily AQI, which is calculated from pollutant sub-indices under the CPCB methodology [1].

Observation Period and Analytical Approach

Two 20-day windows were selected: 1–20 May 2024 for the pre-monsoon period and 1–20 November 2024 for the post-monsoon period. The analysis is descriptive and comparative, focusing on day-wise variability, seasonal change and rural-urban differences (Table 4). Interpretations concerning local sources, atmospheric dispersion and regional transport are evaluated against the

literature; because meteorological variables and source-apportionment data were not independently measured, causal contributions are not quantified [9].

RESULTS AND ANALYSIS

Raw AQI Data

Tables 1–4 present the complete day-wise AQI observations recorded at eight times of day for Kusdihra and Gaya during the pre-monsoon and post-monsoon windows, together with the study-specific daily mean. The tables provide the empirical basis for the comparative analysis.

The raw series show substantial day-to-day and within-day variability. Kusdihra's 20-day mean changes only modestly between May (84.25) and November (89.21), whereas Gaya rises from 132.11 to 181.77. High-AQI episodes occur in both locations, but the magnitude and persistence of elevated values are greater in Gaya, particularly in November (Figure 1). These differences are visualised in further sections.

Temporal and Comparative Patterns

Figures 1 and 2 retain the full temporal sequence for each settlement; Figures 3 and 4 summarise the seasonal and rural-urban contrasts.

Interpretation

Seasonal Pattern

Both settlements record higher mean AQI in the post-monsoon observation period, but the scale of change differs sharply. Kusdihra increases by 4.96 AQI units (about 5.9%), whereas Gaya increases by 49.66 units (about 37.6%). The central seasonal finding is therefore the much stronger post-monsoon deterioration in the urban setting (Figure 2).

Table 1. AQI of Kusdihra (Rural) - Pre-Monsoon, May 2024.

Date	24:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00	Avg AQI
1	93	93	95	96	99	101	104	105	98.25
2	105	105	104	104	91	91	91	91	97.75
3	105	98	103	111	117	120	116	118	111
4	113	110	107	102	104	104	103	108	106.37
5	113	121	135	143	148	153	153	151	139.62
6	153	149	135	119	104	103	101	107	121.37
7	103	94	91	88	87	86	84	79	89
8	70	60	56	52	48	61	83	78	63.5
9	58	57	62	68	70	64	62	61	62.7
10	57	54	49	47	46	50	68	67	57.75
11	60	62	53	54	56	56	59	63	56.62
12	59	58	70	72	69	70	72	49	64.87
13	47	44	44	47	51	53	54	55	49.37
14	93	55	58	56	57	56	59	64	62.25
15	67	69	74	80	88	90	84	105	82.12
16	82	86	89	92	91	90	106	97	91.62
17	102	100	97	95	97	111	108	111	101.62
18	111	106	105	100	90	81	76	73	92.75
19	71	69	70	72	69	70	72	70	70.37

20	70	68	65	64	64	66	66	66	66.12
----	----	----	----	----	----	----	----	----	-------

Source: CPCB, <https://cpcb.gov.in/>

Table 2. AQI of Kusdihra (Rural) - Post-Monsoon, November 2024.

Date	24:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00	Avg AQI
1	66	71	73	74	75	76	78	79	74
2	76	73	72	72	78	78	93	83	78.12
3	72	72	71	70	69	80	95	72	75.12
4	73	74	76	79	82	83	85	87	79.87
5	89	89	87	87	87	88	91	92	88.75
6	94	96	100	102	105	105	99	97	99.75
7	96	98	97	99	98	99	106	99	99
8	84	82	82	82	81	79	75	86	81.37
9	70	67	65	61	57	77	85	56	67.25
10	57	58	57	59	59	59	58	67	59.25
11	72	77	80	82	84	266	117	113	111.37
12	104	104	104	104	106	105	110	114	106.37
13	113	114	116	116	114	109	100	94	109.5
14	90	90	88	86	85	82	79	76	84.5
15	73	68	64	62	63	66	69	70	66.87
16	70	69	70	70	66	85	98	94	77.75
17	81	70	66	66	71	84	85	74	74.62
18	78	80	83	84	88	104	121	136	96.75
19	149	155	159	163	164	151	136	119	149.5
20	107	100	95	92	91	107	122	122	104.5

Source: CPCB, <https://cpcb.gov.in/>

Table 3. AQI of Gaya (Urban) - Pre-Monsoon, May 2024.

Date	24:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00	Avg AQI
1	94	84	88	84	83	81	83	85	85.25
2	84	86	94	120	128	127	126	125	111.25
3	133	137	133	128	102	123	125	129	128.75
4	151	159	166	171	186	188	193	196	176.25
5	197	207	225	229	230	229	230	237	223
6	235	221	190	163	157	169	171	163	183.62
7	170	141	131	161	173	191	169	174	163.75
8	170	89	89	81	80	84	65	69	90.87
9	69	69	67	71	75	78	78	77	73
10	73	75	77	75	76	76	81	86	77.37
11	92	145	144	144	140	128	131	129	131.62
12	102	103	98	93	100	103	112	116	103.37
13	118	114	114	115	104	113	115	116	114.37
14	122	119	123	121	120	122	124	123	121.75
15	130	142	143	151	158	160	157	158	148.87
16	164	155	168	173	181	184	185	182	174.5
17	173	180	108	108	127	136	159	162	144.12
18	161	150	137	123	140	117	92	91	126.37
19	89	88	114	131	132	131	130	128	117.87

20	129	130	130	121	137	160	172	191	146.25
----	-----	-----	-----	-----	-----	-----	-----	-----	--------

Source: CPCB, <https://cpcb.gov.in/>

Table 4. AQI of Gaya (Urban) - Post-Monsoon, November 2024.

Date	24:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00	Avg AQI
1	154	226	192	212	218	228	236	233	212.37
2	203	173	158	147	143	135	117	110	148.25
3	98	97	93	93	92	94	97	96	95
4	192	200	189	199	199	197	197	199	196.5
5	200	203	205	198	206	211	213	217	206.62
6	162	160	149	150	149	149	147	155	157.62
7	161	166	172	172	174	171	163	156	166.87
8	148	142	140	140	134	132	129	125	136.25
9	118	114	109	103	100	103	107	104	107.25
10	278	280	294	306	306	304	303	304	296.87
11	162	219	203	203	205	205	206	206	201.87
12	205	205	205	208	191	218	226	225	210.37
13	224	225	220	213	210	200	186	187	208.12
14	184	178	176	171	165	158	157	162	168.87
15	157	161	160	163	170	173	169	147	162.5
16	133	120	118	116	101	101	101	114	113
17	133	145	147	145	146	150	153	157	147
18	166	166	171	174	192	217	242	250	197.25
19	254	268	282	294	295	215	252	246	270.75
20	240	227	220	220	221	241	261	268	237.25

Source: CPCB, <https://cpcb.gov.in/>

This pattern is consistent with research showing that weaker atmospheric mixing, reduced wet scavenging after monsoon withdrawal, and enhanced seasonal regional emissions can increase particulate accumulation across the IGP [2, 5, 6]. These mechanisms are interpretive rather than directly measured in the present study.

Rural-Urban Pattern

Gaya records higher mean AQI than Kusdihra in both observation periods. The urban mean is approximately 1.57 times the rural mean in May and 2.04 times the rural mean in November (Figure 3). The widening post-monsoon gap suggests that urban emission intensity and seasonal atmospheric conditions may reinforce one another. District-level emission evidence identifies industry, domestic combustion, open burning, road dust, and vehicular sources as important PM_{2.5} contributors across the IGP, with Gaya among identified emission hotspots [3].

The lower mean at Kusdihra should not be interpreted as an absence of pollution. Rural environments may be affected by biomass use, dust, agricultural activity, and regional transport similarly show that rural particulate pollution is a substantial concern across the IGP [2].

Short-Term Variability and High-AQI Episodes

Seasonal means conceal important short-term fluctuations. Gaya's post-monsoon daily mean reaches 296.87 on day 10 and 270.75 on day 19, while Kusdihra's post-monsoon maximum is 149.50 on day 19. Such episodes indicate that exposure conditions can deteriorate sharply even when a

seasonal mean is lower. The dataset cannot determine whether individual peaks arise from a particular local source, meteorological event or transported pollution (Figure 4).

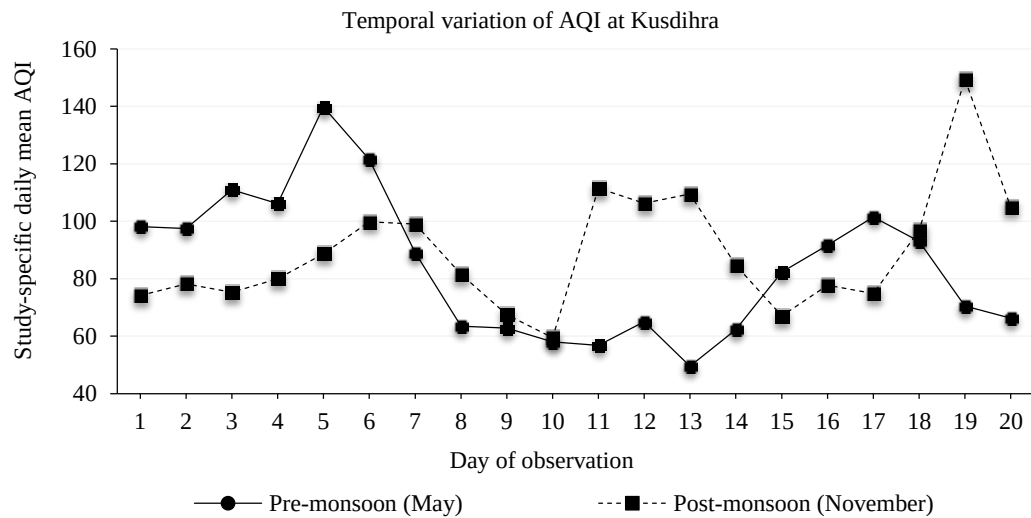


Figure 1. Temporal variation in study-specific daily mean AQI at Kusdihra.

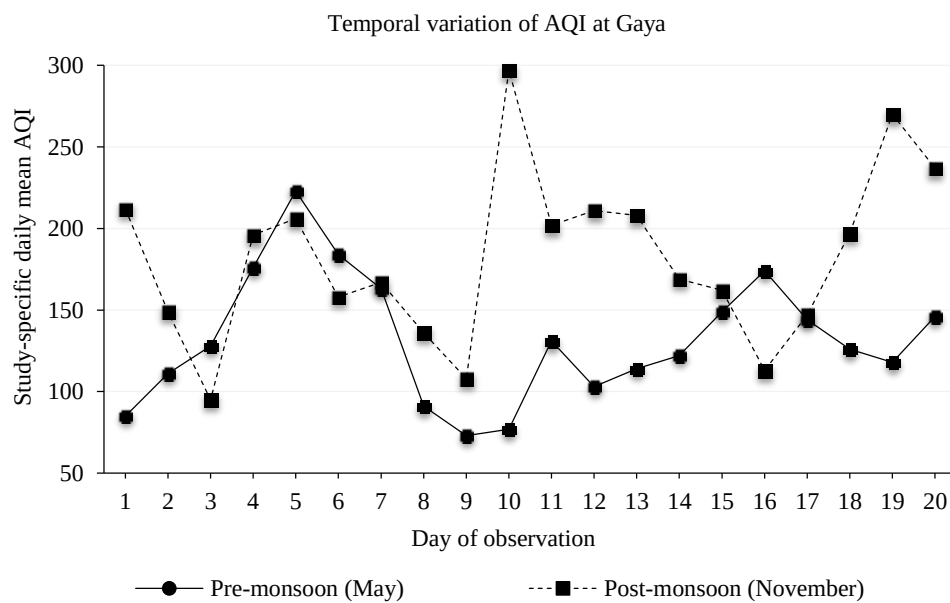


Figure 2. Temporal variation in study-specific daily mean AQI at Gaya.

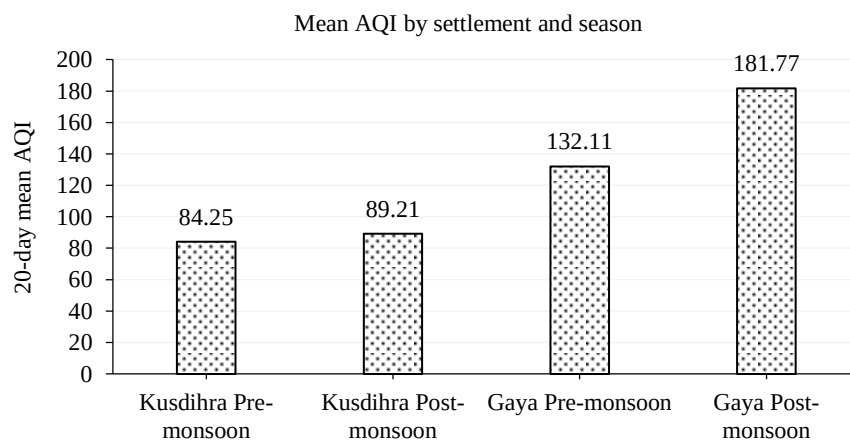
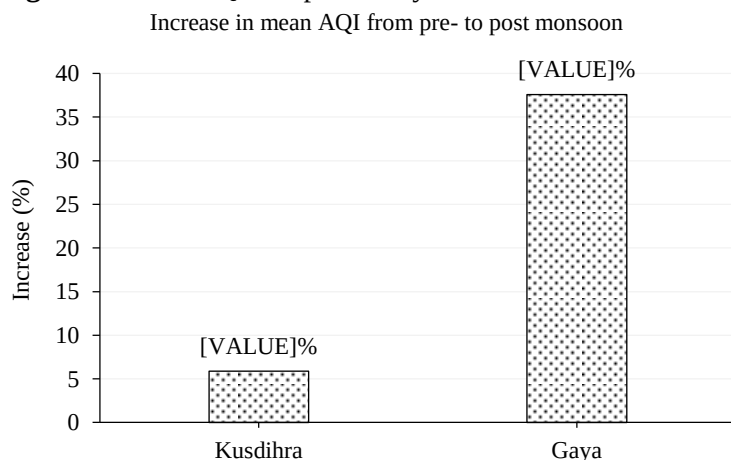


Figure 3. Mean AQI comparison by settlement and season.**Figure 4.** Percentage increase in mean AQI from pre-monsoon to post-monsoon.**Table 5.** Summary of seasonal and rural-urban AQI differences.

Study area	Setting	Pre-monsoon mean	Post-monsoon mean	Absolute change	Change (%)
Kusdihra	Rural	84.25	89.21	4.96	5.9
Gaya	Urban	132.11	181.77	49.66	37.6

Seasonal Dispersion and Wet Deposition

Rainfall can remove airborne particles through wet deposition, while post-monsoon atmospheric conditions may become less favourable for dispersion. Studies from the IGP consistently report strong seasonal differences in particulate concentrations associated with meteorology, emissions and transport [2, 6]. The higher November AQI is therefore best interpreted as the combined outcome of seasonal atmospheric conditions and emission processes rather than rainfall wash-out alone [10].

Discussion

The findings address the study objectives in a coherent sequence. First, Gaya exhibits consistently poorer air-quality conditions than Kusdihra. Second, both locations show temporal variability and higher mean AQI in the post-monsoon window, but the deterioration is far stronger in Gaya. Third, the observed rural-urban and seasonal contrasts are consistent with the combined influence of settlement characteristics, local anthropogenic activity, atmospheric dispersion, and regional pollution processes (Table 5).

The results align with recent IGP research showing that rural areas can experience substantial particulate pollution while urban locations continue to display strong local emission effects [2, 3, 5]. The comparison therefore avoids a simple polluted-city/clean-village interpretation: Kusdihra remains part of the same regional airshed, but Gaya's denser anthropogenic activity is associated with a markedly higher observed AQI burden.

From a policy perspective, the findings support settlement-sensitive air-quality management. Urban interventions should prioritise traffic emissions, road and construction dust, waste burning and relevant industrial or brick-kiln sources, while rural and peri-urban planning should also address biomass burning and regional transport. Continuous monitoring outside major urban centres would improve understanding of how pollution moves across the rural-urban continuum.

Limitations

The analysis covers two 20-day windows in a single year and therefore does not establish a long-term trend. It relies on reported AQI values rather than pollutant-specific concentration series and does not include source-apportionment modelling. Meteorological variables such as wind speed,

temperature, relative humidity, rainfall and boundary-layer height were not statistically modelled. The results should therefore be interpreted as descriptive comparative evidence rather than causal attribution. Future research should use longer time series, pollutant-specific data and simultaneous meteorological observations.

CONCLUSION AND RECOMMENDATIONS

The comparative assessment demonstrates a clear rural-urban difference and a marked seasonal contrast in AQI. Gaya recorded mean AQI values of 132.11 in the pre-monsoon period and 181.77 in the post-monsoon period, compared with 84.25 and 89.21 at Kusdihra. The post-monsoon increase was therefore substantially stronger in Gaya. Day-wise analysis further shows that both settlements experience episodic deterioration, although the highest and most persistent values occur in the urban series.

The study recommends strengthening continuous air-quality monitoring in both urban and rural settings; improving control of road and construction dust, waste burning and relevant industrial emissions; promoting cleaner household fuels; and incorporating rural and peri-urban areas into regional air-quality planning. Preventive measures and intensified monitoring should receive particular attention before and during the post-monsoon period. Future studies should extend the observation period and integrate pollutant-specific, meteorological, and source-apportionment data.

REFERENCES

1. Central Pollution Control Board. National air quality index: final report. New Delhi: Ministry of Environment, Forests and Climate Change, Government of India; 2014. <https://www.pib.gov.in/newsite/printrelease.aspx?relid=110654®=48&lang=2>
2. Pathak M, Kuttippurath J. Elucidating the changing particulate matter pollution and associated health effects in rural India during 2000–2019. *Environmental Pollution*. 2024 May 1;348(7):123830. <https://doi.org/10.1016/j.envpol.2024.123830>
3. Ghosh A, Nagar PK, Maddhesia J, Sharma M, Azmi S, Singh B, Dutta M. A district-level emission inventory of anthropogenic PM_{2.5} from the primary sources over the Indian Indo Gangetic Plain: identification of the emission hotspots. *Science of The Total Environment*. 2024 Mar 1; 914(8):169865. [10.1016/j.scitotenv.2023.169865](https://doi.org/10.1016/j.scitotenv.2023.169865)
4. Krishnaveni AS, Madhavan BL, Jain CD, Ratnam MV. Spatial, temporal features and influence of meteorology on PM_{2.5} and O₃ association across urban and rural environments of India. *Atmospheric Environment: X*. 2024 Apr 1;22(1):100265. <https://doi.org/10.1016/j.aeaoa.2024.100265>
5. Madhwal S, Tripathi SN, Bergin MH, Bhawe P, de Foy B, Reddy TR, Chaudhry SK, Jain V, Garg N, Lalwani P. Evaluation of PM_{2.5} spatio-temporal variability and hotspot formation using low-cost sensors across urban-rural landscape in lucknow, India. *Atmospheric Environment*. 2024 Feb 15;319(11):120302. <https://doi.org/10.1016/j.atmosenv.2023.120302>
6. Mukherjee S, Singh GK, Dutta M, Srivastava V, Qadri AM, Gupta T, Chatterjee A. PM_{2.5} pollution exceeding Indian standard over a semi-urban region at eastern IGP: Chemistry, meteorological impact, and long-range transport. *Science of the Total Environment*. 2023 Nov 10;898:165415. <https://doi.org/10.1016/j.scitotenv.2023.165415>
7. World Health Organization. WHO global air quality guidelines: particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021. <https://www.who.int/publications/i/item/9789240034228>
8. Kumar N, Rafi S, Prasad G, Tahir M. Assessing the trend and status of air quality in NCT Delhi. *International Journal of Environmental Sciences*. 2021;10(4):84-94.
9. Ghosh B, De A, Seth M, Ghosh K, Sarkar O, Das S, Mondal S, Ali D, De M, Sultana R, Das D. Evaluating the national burden of PM_{2.5} in India: a comprehensive study of spatiotemporal distribution at state and city levels, non-carcinogenic health hazards, and premature mortality. *Environmental Monitoring and Assessment*. 2025 Dec 12;198(1):43.
10. Shukla U, Manjunath N. Studies on air quality status at selected pockets of Indian Capital Delhi.

Int Res J Eng Technol. 2018 Aug;5(8):416-20.