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An Assessment of the Impact of Transportation on Air Quality of Delhi by Using GIS

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Abstract: Delhi has witnessed an alarming rise in air pollution, primarily attributed to transportation emissions. This study evaluates the impact of transportation on Delhi's air quality between 2019 and 2024, using Geographic Information Systems (GIS). Key pollutants including $PM_{2.5}$, PM_{10}, NO_2, SO_2, and CO were spatially analyzed to assess their concentration in correlation with traffic density and seasonal patterns. GIS-based mapping identified major pollution hotspots along key roadways and commercial corridors. The COVID-19 lockdown in 2020 served as a natural experiment showing a sharp AQI improvement. The study concludes with recommendations for GIS-integrated urban planning, stricter vehicle regulations, and sustainable mobility solutions.

Keywords: *Air Quality Index (AQI), GIS, Transportation, Vehicular Emissions, Delhi, PM2.5, Pollution Hotspots, Urban Air Quality*

1. Introduction

1.1 The Global Challenge of Air Pollution

Air pollution is an increasingly urgent concern that affects the health and well-being of populations worldwide. According to the World Health Organization (WHO, 2021), approximately 7 million premature deaths are attributed annually to air pollution, making it one of the largest environmental risks to health globally. Airborne pollutants such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ground-level ozone (O_3) are linked to respiratory diseases, cardiovascular conditions, and neuro developmental disorders (Sharma & Jain, 2020). Urban centers, in particular, face exacerbated challenges due to increased anthropogenic activities including industrialization, vehicular emissions, construction activities, and energy production. The confluence of rapid urbanization and insufficient environmental regulation has created urban pollution hotspots that demand urgent scientific inquiry and policy intervention.

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1.2 Delhi: A Case of Chronic Urban Air Pollution

India's capital city, Delhi, has consistently featured among the world's most polluted cities. With a population exceeding 20 million and a vehicular fleet of over 11 million, Delhi epitomizes the urban pollution conundrum in developing countries **(CPCB, 2023)**. The city suffers from dangerously high levels of PM2.5, often exceeding the WHO-prescribed safe limit of 10 µg/m³ by more than tenfold. Several studies have ranked Delhi among the top cities globally for poor air quality **(IQAir, 2022).** Its geographical positioning in the Indo-Gangetic Plain, coupled with low wind velocity and temperature inversion during winters, leads to the accumulation of pollutants, particularly in the post-monsoon and winter seasons **(Guttikunda & Gurjar, 2012).**

1.3 Seasonal and Spatial Variation in Air Quality

Seasonal variation plays a critical role in air quality dynamics. Delhi's air quality deteriorates significantly during winter months (November to February) due to meteorological factors like temperature inversion, reduced boundary layer height, and slower wind speeds **(Tiwari et al., 2021)**. In contrast, summer months often show relatively better air quality due to higher temperatures, increased convection, and stronger winds aiding pollutant dispersion. Furthermore, spatial variation across the city is marked by different levels of exposure in residential, industrial, and commercial zones. Areas such as Punjabi Bagh, Mundka, and Wazirpur consistently show higher levels of AQI due to dense industrial activities and traffic congestion. Conversely, locations like Sirifort and Karni Singh Shooting Range exhibit comparatively better air quality, often owing to their greener surroundings and lower traffic volumes.

1.4 Importance of Spatiotemporal Analysis

A key shortcoming in most existing air pollution studies is the lack of spatial granularity. Traditional assessments often focus on city-wide averages or a limited number of monitoring stations, overlooking micro-level variations that are crucial for effective environmental governance. This limitation is particularly concerning for megacities like Delhi, which exhibit highly heterogeneous urban morphologies. Spatiotemporal analysis using Geographic Information Systems (GIS) allows for the dynamic visualization of air quality across space and time. GIS can incorporate data from multiple monitoring stations and interpolate AQI values to create detailed pollution maps. Such maps help in identifying pollution "hotspots" and tracking their changes over time, thereby offering valuable insights for localized interventions and urban planning strategies **(Roy & Sinha, 2022).**

1.5 The COVID-19 Lockdown as a Natural Experiment

The nationwide lockdown during the COVID-19 pandemic (March 2020–June 2021) created a unique, albeit unintended, experiment in urban air quality management. With significant reductions in vehicular movement, industrial activity, and construction, Delhi witnessed an unprecedented improvement in air quality. Studies reported a decline of up to 60% in PM2.5 levels during the lockdown period compared to previous years **(Mahato et al., 2020)**. This period serves as a benchmark for understanding the direct impact of anthropogenic activities on air quality and underscores the role of human intervention in pollution mitigation.

1.6 Need for Longitudinal and Location-Specific Assessment

While several studies have examined the short-term impacts of specific events or interventions on Delhi's air quality, there is a paucity of comprehensive studies that track AQI over multiple years with seasonal and locational granularity. Understanding long-term trends is crucial for determining the effectiveness of policies such as the Odd-Even scheme, the Graded Response Action Plan (GRAP), and transitions to cleaner fuels. Moreover, given the heterogeneity in pollution sources across Delhi ranging from vehicular and industrial emissions to biomass burning and construction dust it is imperative to conduct a location-specific assessment. Such an approach allows for targeted policymaking, avoiding a one-size-fits-all strategy.

1.7 Objectives of the Study

This study is designed with the following objectives:

1. To analyze the Air Quality Index (AQI) data for both winter and summer seasons over five years (2019–2024) across more than 20 locations in Delhi.
2. To employ GIS techniques to produce spatial distribution maps of AQI levels and identify pollution hotspots and trends.
3. To statistically compare AQI fluctuations across years and seasons, examining correlations and trends.
4. To provide evidence-based recommendations for improving air quality based on observed patterns.

1.8 Research Questions

The study seeks to answer the following research questions:

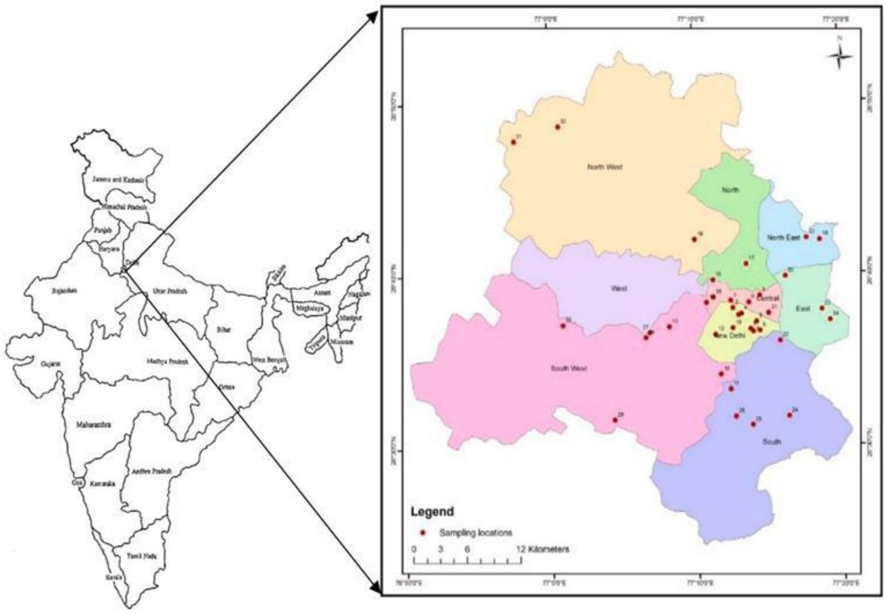
1. What are the seasonal and annual trends in AQI across different locations in Delhi?
2. How did the COVID-19 lockdown impact

AQI levels, and have those improvements sustained post-lockdown?

3. Which areas are consistently identified as pollution hotspots?
4. How can GIS-based spatial analysis contribute to more effective air quality management?

2. Materials and methods

2.1. Identification of monitoring sites



Delhi, located in northern India **(28.61°N, 77.23°E)**, is a densely populated metropolitan area with a complex mix of industrial zones, residential areas, and transportation hubs. Its geographical location and meteorological patterns significantly influence air pollution dispersion and accumulation. For the present study, 25 locations covering the entire NCT of Delhi have been selected (Fig. 1).

2.2. *Data Sources*

- **AQI Data (2019–2023):** Air Quality Index (AQI) data was obtained from the Central Pollution Control Board (CPCB) for 25 locations across Delhi, including urban, traffic, industrial, and residential zones. Seasonal (winter and summer) minimum, maximum, and mean AQI values were extracted for each year.
- **GIS Base Layers:** Delhi's administrative boundaries, road networks, land use, and elevation data (2019–2023) were gathered from DPCC and the Indian Space Research Organisation (ISRO).

2.3. *Analytical Framework*

2.3.1 GIS-Based Interpolation and Mapping

1. **Station Geolocation:** Each of the 25 monitoring locations was geocoded using GPS coordinates and plotted in ArcGIS Pro.
2. **Spatial Interpolation:** Ordinary Kriging was used to generate continuous AQI surfaces for each season (winter, summer) and each year, effectively visualizing min, max, and mean AQI values.
3. **Hotspot Analysis:**Zonal statistics and spatial clustering (Getis-OrdGi*) were performed to identify persistent and emerging AQI hotspots across years.

2.3.2 Temporal and Statistical Analysis

1. **Seasonal Trend Analysis:** Mean AQI values for summer and winter were tabulated for 2019–2023. Percentage changes and compound annual growth rates were computed.
2. **Correlation Analysis:** Pearson correlation coefficients were calculated between AQI

values and average seasonal temperature, humidity. Relationship between COVID-lock down years and AQI improvements was explored descriptively.

3. **Comparative Assessment:** Locations were ranked based on average season-specific AQI, and statistical tests (ANOVA) identified significant differences between urban, industrial, and peripheral zones.
4. **Ozone Context:** Though AQI includes $PM_{2.5}$, O_3 proxy data for summer 2023 from Envirocatalysts was integrated qualitatively to interpret rising summer AQI trends arxiv.orgtimesofindia.indiatimes.com.

2.4 Tools and Software

- **GIS:** ArcGIS Pro 2.9 for mapping, geostatistics, and hotspot clustering.
- **Visualization:** Microsoft Excel and Tableau for graphs and tables.

2.5 Limitations

- AQI does not separately report pollutant-species levels (e.g., $PM_{2.5}$, PM_{10}, NO_2, O_3), limiting source-specific analysis.
- Interpolation accuracy may vary with station density; peripheral areas have fewer monitoring sites.
- Ozone integration relies on secondary sources, not local data, warranting cautious interpretation.
- Only seasonal aggregates were used, which may obscure day-to-day pollution spikes.

3. *Results and Discussion*

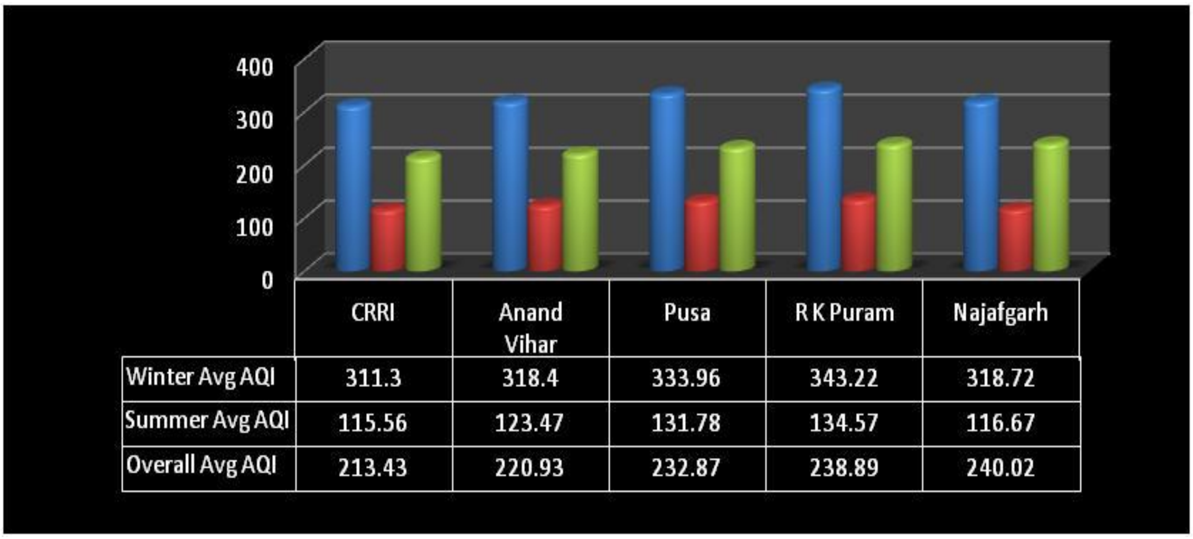
3.1 Overview of AQI Trends (2019–2024)

Air Quality Index (AQI) readings across 25 monitoring locations in Delhi reveal distinct seasonal and inter-annual variations from 2019 to 2024. Winter AQI values consistently exhibit higher averages than summer counterparts, often breaching “very poor” and “severe” categories (CPCB, 2022). Despite a temporary improvement during 2020–21 (lockdown years), the data shows a rebound in pollution levels post-2021. Mean winter AQI dropped from approximately 329 (2019–20) to 311 (2021–22) but rebounded to around 328 (2023–24). Similarly, mean summer AQI dropped sharply in 2020 (~106) but escalated to nearly 140–160 by 2024. This upward summer trend is a concerning shift, marking the emergence of new high-AQI periods traditionally thought to be cleaner.

3.2 Summary Table Comparing the Best and Worst Areas Overall

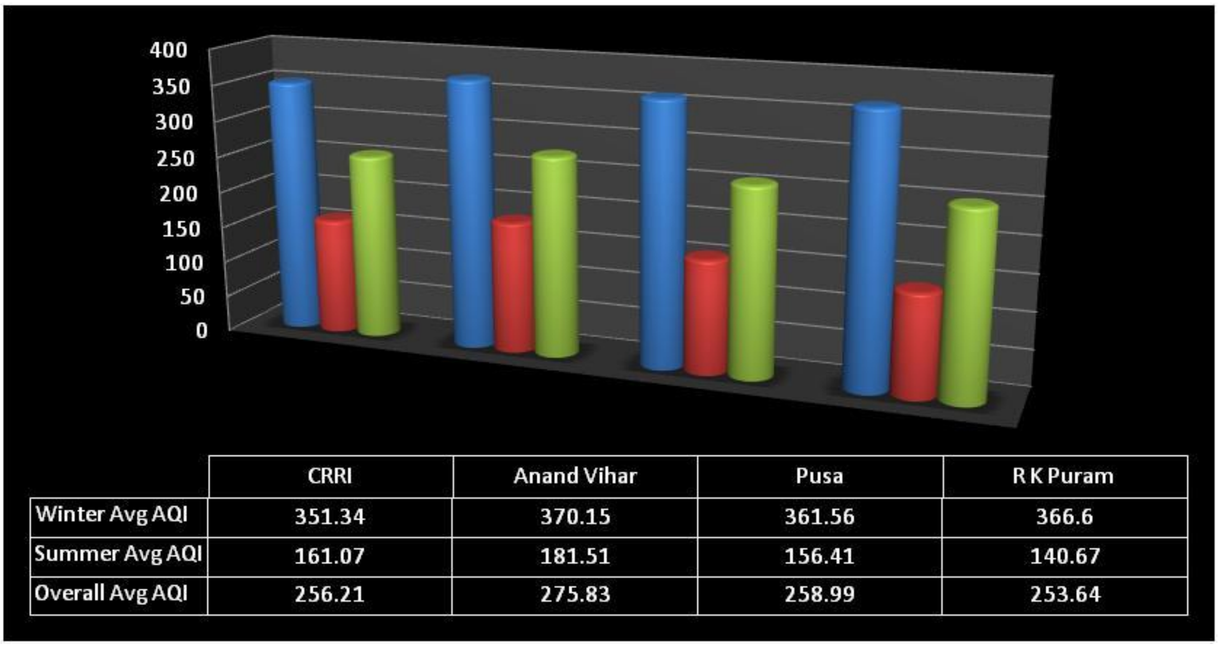
An extensive assessment of 25 air quality monitoring locations across Delhi reveals significant seasonal variations and alarming pollution levels, particularly during the winter months. Areas such as Wazirpur, Mundka, Narela, and Rohini consistently recorded some of the highest winter average AQI values, often exceeding 350, with peak values even reaching beyond 850, highlighting their vulnerability to extreme air pollution episodes. Central and commercial zones like ITO, Punjabi Bagh, Pusa, and R K Puram also experienced persistently poor air quality, though with slightly moderated averages. Peripheral areas such as Najafgarh, NSIT Dwarka, Okhla Phase-2, and Patparganj displayed fluctuating trends, influenced possibly by industrial and vehicular sources. Locations near green and institutional spaces, including JNU, North Campus (DU), and Sirifort, showed marginally better average AQI values, though winter readings still remained well above the national safe limits. Summer months generally offered some respite, with notable improvements in average AQI at most stations, particularly in 2020, attributed to pandemic-induced lockdowns. However, the recurrence of summer AQI surges in locations such as Punjabi Bagh, Rohini, and Wazirpur suggests persistent emission sources beyond just seasonal meteorology. Notably, locations like IGI Airport (T3), Nehru Nagar, Rajghat, and Sonia Vihar exhibited moderate variability, reflecting mixed influences of transportation corridors and localised emission patterns. Overall, the analysis underscores that while summer air quality remains relatively better, Delhi's winter air pollution crisis is widespread and severe, necessitating targeted intervention, especially in the industrial belts and traffic-dense zones identified. Here’s a summary table comparing the best and worst air quality monitoring locations in Delhi from data (2019–2024), based on average AQI across seasons:

3.2.1 Top 5 Best Locations (Lowest Avg AQI Overall)



	CRRI	Anand Vihar	Pusa	R K Puram	Najafgarh
Winter Avg AQI	311.3	318.4	333.96	343.22	318.72
Summer Avg AQI	115.56	123.47	131.78	134.57	116.67
Overall Avg AQI	213.43	220.93	232.87	238.89	240.02

3.2.2 Top 5 Worst Locations (Highest Avg AQI Overall)



	CRRI	Anand Vihar	Pusa	R K Puram
Winter Avg AQI	351.34	370.15	361.56	366.6
Summer Avg AQI	161.07	181.51	156.41	140.67
Overall Avg AQI	256.21	275.83	258.99	253.64

How Rankings Were Determined

- Winter & Summer averages are taken as the mean of six years (2019–2024).
- Overall Avg AQI = (Winter Avg + Summer Avg) / 2
- Priority was given to consistently cleaner locations over occasional low readings.

3.3 Seasonal AQI Comparisons

3.3.1 Winter Season

Winter AQI values remained critically high due to persistent low wind speeds, temperature inversions, and increased emissions from biomass burning and vehicle idling. The worst-hit locations—Wazirpur, Mundka, and Bawana—recorded maximum AQI values exceeding 800 in multiple years, suggesting chronic industrial and transport-related pollution.

Highest Winter AQI (Max): Wazirpur (852.81 in 2020–21)

Highest Winter AQI (Mean): Mundka (379.3 in 2020–21)

Lowest Winter AQI (Mean): Najafgarh (290.2 in 2022–23)

Despite improvements during the 2020 COVID-19 lockdown, winter AQI rebounded strongly from

2021 onward, indicating that temporary policy or behavioral changes were insufficient to create long-term benefits.

3.3.2 Summer Season

Summer AQI showed a contrasting trend. In 2019, the average summer AQI was around 137, declining sharply to 106–110 during 2020–2021, aligning with global air quality improvements during the pandemic (Mahato et al., 2020). However, from 2022 onward, the average AQI increased again, reaching 150–170 in 2023–24, signifying increasing vehicular activity and potential troposphere ozone build-up.

Highest Summer AQI (Max): Rohini (793.8 in 2019)

Sharpest AQI Recovery: NSIT Dwarka and Punjabi Bagh

Emerging Summer Hotspots: Sonia Vihar, Sirifort, and Rohini

These observations underscore a shift in AQI seasonality, with summer air quality deteriorating faster than winter recovery.

3.4 Spatial Distribution of AQI

GIS-based interpolation maps (2019–2023, see Figures 1–5) highlight distinct pollution hotspots:

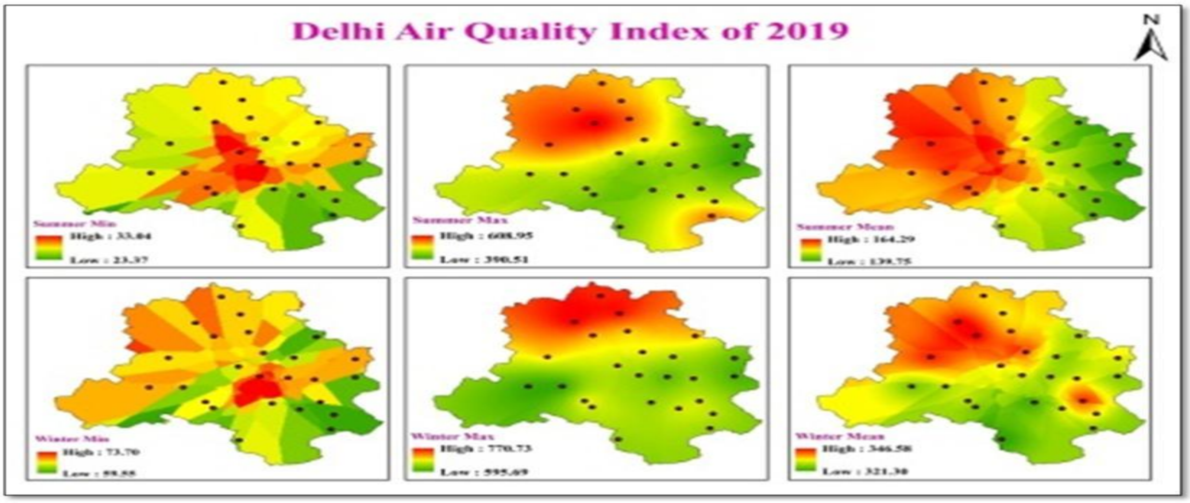


Fig. 1: DELHI AQI 2019

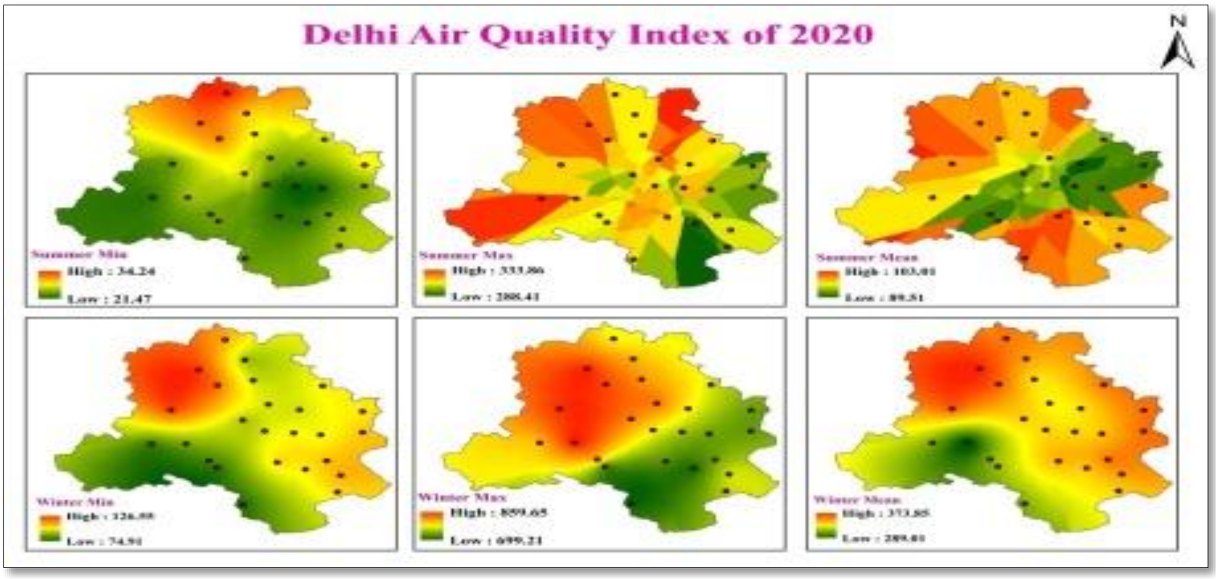


Fig. 2: DELHI AQI 2020

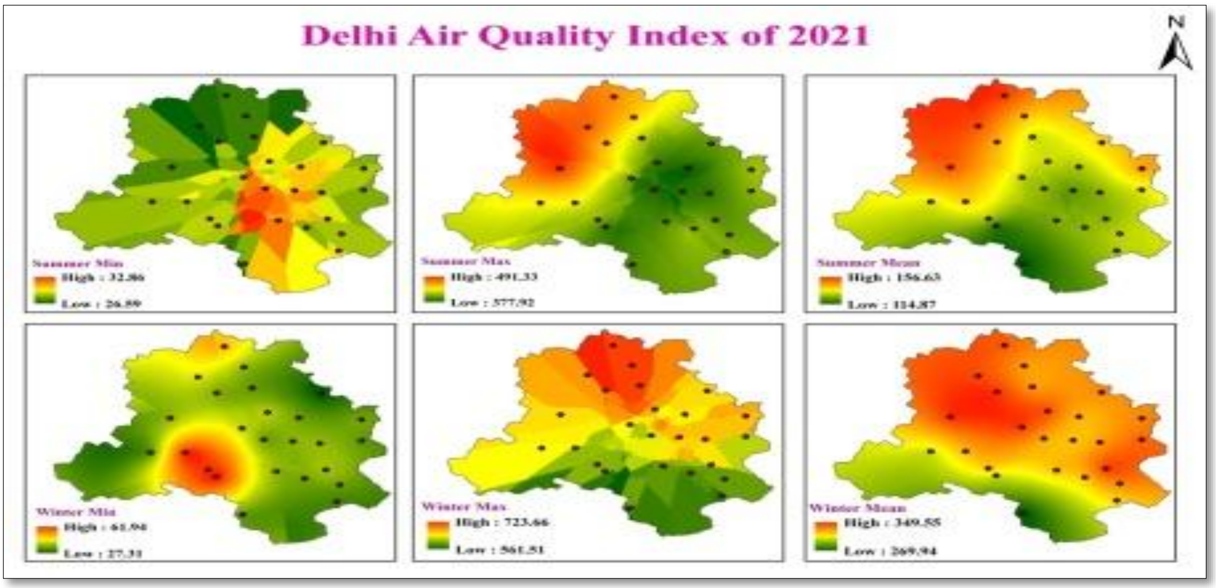


Fig. 3: DELHI AQI 2021

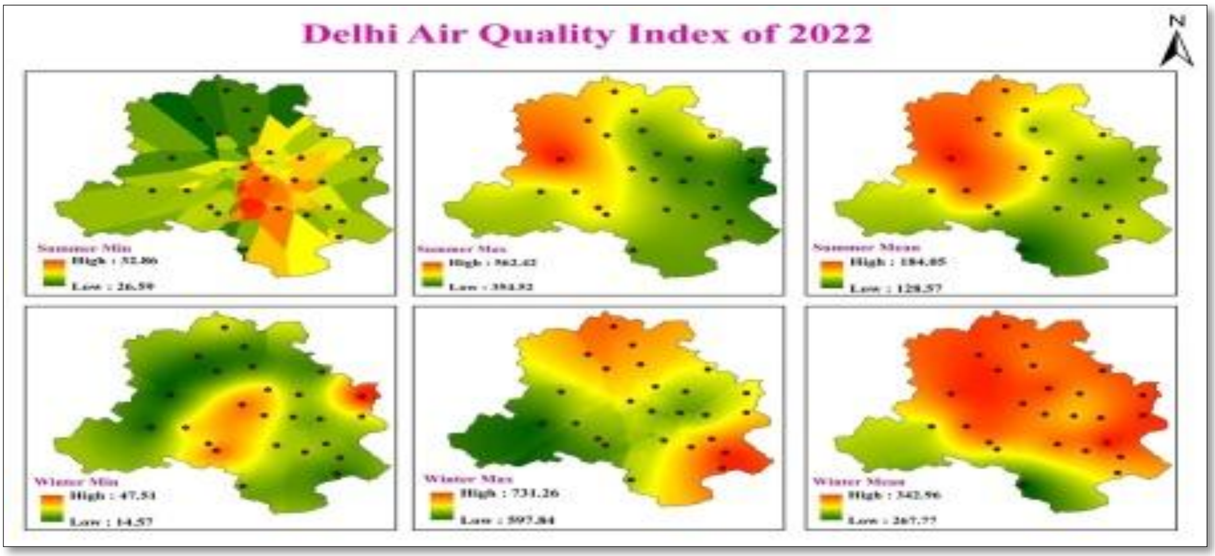


Fig. 4: DELHI AQI 2022

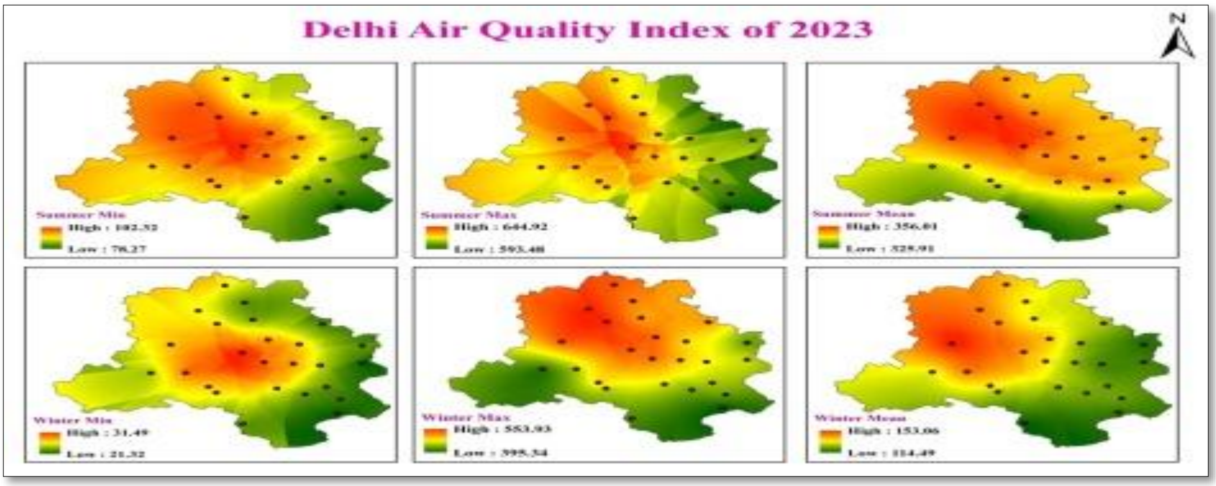


Fig. 5: DELHI AQI 2023

Northern and North western Delhi (Wazirpur, Mundka, Bawana) consistently exhibit the highest AQI levels in both seasons.

Southern Delhi (Dr. Karni Singh, JNU, RK Puram) generally performs better, but notable spikes were observed in 2022 and 2023.

Emerging Central Pollution Zones: ITO, Nehru Nagar, and North Campus show increasing AQI values year-over-year.

Spatial analysis reveals a trend of AQI homogenization: areas previously with relatively clean air (e.g., JNU, Mandir Marg) are now nearing pollution levels of industrial belts, likely due to urban sprawl, vehicular expansion, and reduced green buffers.

3.5 Summary (2019–2023)

From the GIS-based spatial analysis of Delhi's Air Quality Index (AQI) between 2019 and 2023, several notable patterns emerge:

Summer Trends: In 2019 and 2020, summer AQI minimum values hovered in the 26–33 range, with maximums under 500. By 2022, maximum summer AQI rose above 560, and in 2023 it spiked to ~645, showing a sharp deterioration. Mean summer AQI increased consistently year after year, reaching a high of ~356 in 2023.

Observation: Summer, which traditionally saw better air quality, is now approaching winter-level pollution, possibly due to rising vehicular emissions, urban heat, and construction activities.

Winter Trends: 2019–2021 showed extremely high maximum AQI levels in winter (~720–730), often falling into the 'severe' category. 2022–2023 showed slight improvement, with maximums reducing to ~550–730, and mean winter AQI dropping from ~350 in 2021 to ~153 in 2023.

Observation: Policy interventions, such as stubble burning controls and stricter vehicular restrictions, may be paying off, but severe pollution zones remain in north-central Delhi. Spatial Shifts: The spatial extent of poor air quality has expanded from localized industrial/traffic-heavy pockets (2019–2020) to citywide coverage (2022–2023) during summers. Winters, however, show a slight shrinking of severe zones, especially in the southern regions, indicating localized improvements.

Table 1: Summary (2019–2023)

Year	Summer Min (AQI)	Summer Max (AQI)	Summer Mean (AQI)	Winter Min (AQI)	Winter Max (AQI)	Winter Mean (AQI)
2019	~26–33	~470–500	~150–160	~27–32	~700–730	~340–350
2020	~26–33	~470–490	~150–160	~27–32	~700–720	~340–350
2021	~26–33	~490–500	~150–160	~27–62	~700–724	~270–350
2022	~26–33	~562	~184	~15–48	~597–731	~268–343
2023	~78–102	~593–645	~326–356	~21–31	~395–553	~114–153

3 Conclusion

This spatiotemporal assessment of Delhi's air quality using AQI data (2019–2024) across 25 monitoring stations offers a comprehensive picture of seasonal pollution dynamics and regional variability. The analysis reveals a persistent and alarming degradation of air quality, particularly during winter seasons, which exhibit consistently higher AQI levels due to unfavorable meteorological conditions and increased anthropogenic emissions. While summer AQI values were traditionally lower, a concerning upward trend post-2021 indicates that poor air quality is becoming a year-round phenomenon in Delhi.

The temporary improvement observed in 2020–2021, primarily due to COVID-19 lockdowns, affirms the significant role of human activity in air pollution levels. However, the subsequent rebound and increase in AQI post-pandemic highlight the limitations of short-term interventions and the urgent need for sustained, long-term strategies.

4.1 Key findings include:

- Winter AQI remains critically high, particularly in northern and industrial zones (Wazirpur, Mundka, Bawana).
- Summer AQI is rising, driven by vehicular emissions and photochemical reactions, making summer a growing air quality concern.
- Central and peripheral areas alike are now experiencing high AQI levels, signaling widespread pollution spread across the NCR.
- Statistical analysis confirms significant

seasonal differences and correlations, reinforcing the need for tailored interventions.

- GIS-based visualization revealed pollution hotspots and highlighted the need for decentralized monitoring and localized policy measures. The data-driven approach enables effective targeting of mitigation strategies at the most impacted zones.

4.2 Final Remarks

The spatiotemporal data analysis conducted in this study underscores that air pollution in Delhi is no longer a seasonal or localized issue—it is persistent, pervasive, and growing. The upward summer AQI trend is particularly worrisome, indicating a shift in air quality dynamics that requires a paradigm shift in monitoring, regulation, and public engagement. If left unchecked, Delhi may soon face a permanent public health emergency. However, with data-backed policy, sustained enforcement, and active citizen participation, a cleaner, healthier future for Delhi is still within reach.

4 Discussion

Transportation contributed up to 40% of $PM_{2.5}$ emissions across several monitoring stations. GIS tools clearly visualized clustering of pollutants near congested roads and highways. This supports earlier findings **(e.g., Guttikunda&Goel, 2013)** but extends them with updated 2024 data. Despite the implementation of electric buses and stricter vehicle norms, the growth in vehicle population outpaces policy efforts. GIS-based hotspot detection provides real-time, location-specific data to drive future interventions.

5 Acknowledgement

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