



weatherwalay

DATA INSIGHTS

From Green to Grey: The Deterioration of Islamabad's Air Quality

www.weatherwalay.com

Analyzing the link between Urban Sprawl, Carbon Sink Depletion, and Rising PM 2.5 Levels and AQI Concentrations

Executive Summary

This report evaluates PM_{2.5} and Air Quality Index (AQI) conditions in Islamabad from 2019 to 2025 using daily, monthly, seasonal, and station-level observations. The analysis establishes that Islamabad's air pollution is persistent, structurally embedded, and consistently exceeds health-based thresholds.

Key insights include:

- Annual mean PM_{2.5} concentrations remain between **108 and 121 $\mu\text{g}/\text{m}^3$** , exceeding WHO guideline values by 7–8 times across all assessed years.
- More than **70** percent of days fall within Unhealthy or worse air quality categories, while Good or Moderate air quality days account for less than 2 percent of observations.
- Winter smog seasons (Nov–Jan) show severe pollution amplification, with mean PM_{2.5} levels frequently exceeding **150 $\mu\text{g}/\text{m}^3$** and AQI remaining in the Very Unhealthy range.
- Spatial analysis identifies industrial and high-traffic zones as chronic hotspots, with station-level PM_{2.5} means up to **1.8 times** higher than peripheral areas.

1. Introduction

PM_{2.5} pollution poses a critical health risk due to its ability to penetrate deep into the lungs and bloodstream. Although Islamabad is often perceived as less polluted than other major Pakistani cities, recent observations indicate sustained deterioration in air quality. Long-term, data-driven evaluations of this trend have been limited.



This study analyzes PM_{2.5} and AQI data from 2019 to early 2025 to quantify pollution intensity, persistence, seasonal behavior, and spatial variation across Islamabad. The assessment integrates annual statistics, daily distributions, smog-season contrasts, time-series trends, and station-level comparisons.

The objective is to determine whether Islamabad’s air pollution reflects episodic smog events or a persistent structural condition. By linking observed air quality patterns with urban growth, emission sources, land-use change, and meteorological constraints, the analysis provides a clear characterization of the city’s long-term atmospheric trajectory.

2. Annual PM 2.5 and AQI Concentrations Statistics (2019–2025)

The figure shows that annual mean PM_{2.5} remains tightly clustered between **108 and 121** $\mu\text{g}/\text{m}^3$, indicating a stable and chronically high pollution baseline across all years. Median values closely match means, confirming that elevated pollution persists throughout most days rather than being driven by a few extreme events. Standard deviation increases sharply in 2024, reflecting a rise in day-to-day variability and more frequent pollution spikes.

A similar pattern is observed in AQI trends, where annual mean AQI consistently falls between **178 and 190**, remaining in the Unhealthy category every year. The stable median AQI values reinforce persistent annual exposure, while variability increases in 2024, mirroring the PM_{2.5} fluctuations.

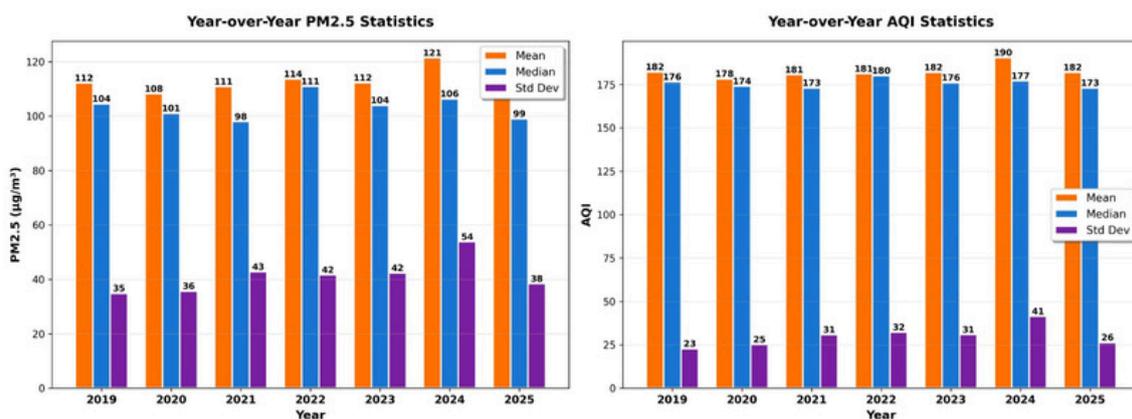


Figure 1. Annual PM 2.5 and AQI Mean, Median, and Standard Deviation for Islamabad

3. Smog Seasonal Analysis

The figure shows that smog season PM2.5 and AQI levels consistently exceed unhealthy thresholds, with all years from 2019 to 2024 recording mean PM2.5 values between **148 and 188 $\mu\text{g}/\text{m}^3$** and mean AQI values between 205 and 240. These levels are more than double the “Unhealthy for Sensitive Groups” benchmarks. Error bars reveal substantial intra-season variability, indicating frequent high-pollution spikes.

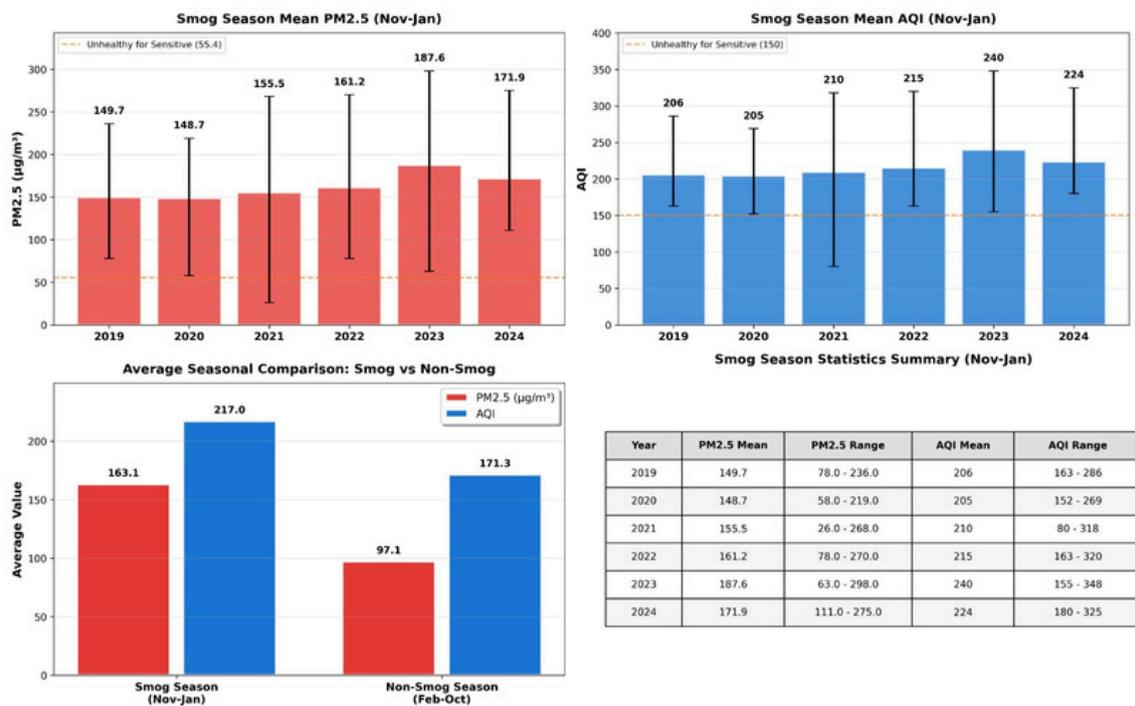


Figure 2. Smog season (Nov–Jan) PM2.5 and AQI statistics for Islamabad, 2019–2024, compared with non-smog season averages.

The seasonal comparison highlights a stark contrast: smog season averages (PM2.5: 163.1 $\mu\text{g}/\text{m}^3$, AQI: 217) are significantly higher than non-smog season values (PM2.5: 97.1 $\mu\text{g}/\text{m}^3$, AQI: 171.3). This confirms that winter meteorology combined with elevated emissions creates a recurring high-pollution regime.

4. Daily Air Quality Distribution (2019–2025)

The figure shows the distribution of 2,407 days of PM2.5 levels in Islamabad, revealing that **76 percent** of days fall within the **55–150 $\mu\text{g}/\text{m}^3$** (Unhealthy) range and 19 percent fall within 150–250 $\mu\text{g}/\text{m}^3$ (Very Unhealthy). Only 4 percent of days fall below **55 $\mu\text{g}/\text{m}^3$** , and 1 percent exceed 250 $\mu\text{g}/\text{m}^3$.

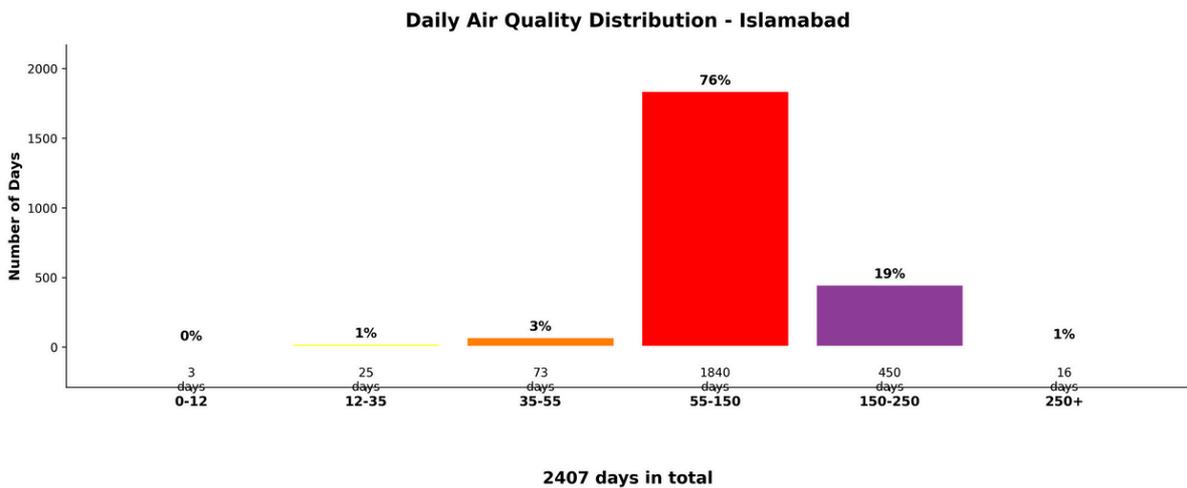


Figure 3. Distribution of daily PM2.5 levels in Islamabad

5. Islamabad Daily PM 2.5 Concentrations Calendar for 2024

The 2024 PM2.5 calendar shows that pollution remains elevated throughout the year, with winter months (Jan, Nov, Dec) dominated by Very Unhealthy concentrations and frequent Hazardous spikes. Spring and summer months show brief periods of comparatively lower values, yet daily readings largely remain in the Unhealthy range. The year records a mean PM2.5 of **121.5 µg/m³**, a median of **106.4 µg/m³**, and an extreme maximum of **298 µg/m³**, indicating that episodic peaks occur on top of an already persistently high baseline.

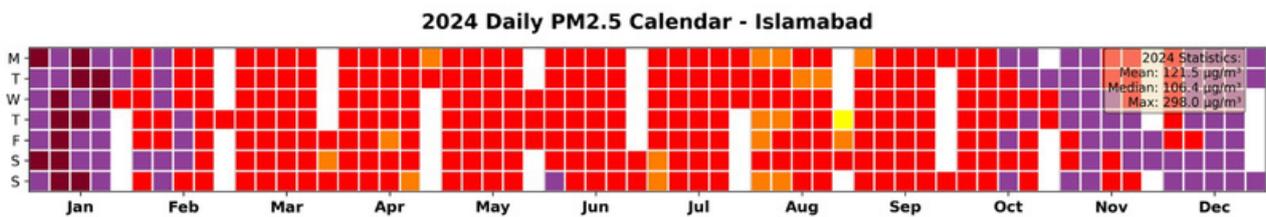


Figure 4. Calendar Heatmap of PM2.5 Levels in 2024

6. Multi Year PM 2.5 Concentrations by Category Overview (2019–2025)

The multi year overview shows that from 2019 to 2025, Islamabad experiences near continuous Unhealthy to Very Unhealthy PM2.5 levels, with only isolated brief periods of cleaner air. Winter months consistently show the worst pollution, while even summer and monsoon months remain dominated by elevated concentrations. The pattern indicates a persistent, year round pollution regime rather than episodic events.

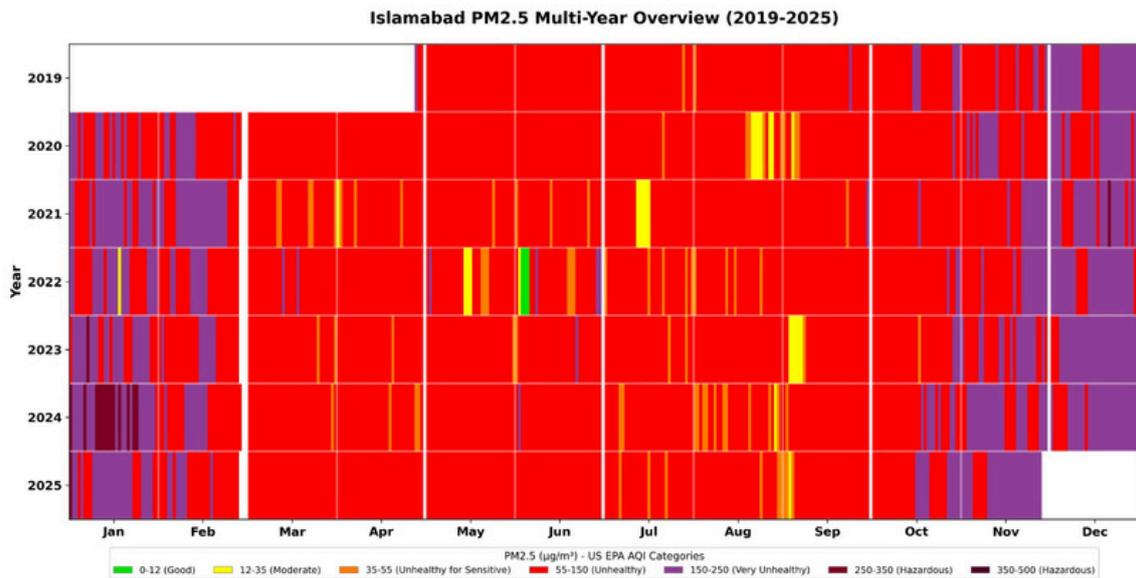


Figure 5. Multi Year Air Quality Classification Grid

7. AQI and PM2.5 Time Series for Islamabad (2019–2025) and Smog Season Analysis

The time series reveals a stable pattern of annual winter surges in both AQI and PM2.5, driven by inversion-prone meteorological conditions, while even the lowest summer values remain above unhealthy thresholds. Monthly averages show that high pollution is not episodic but structurally recurring, with no year dropping into healthy air ranges. Sharp peaks in 2021, 2023, and 2024 highlight severe seasonal pollution episodes layered on top of a chronically elevated baseline.

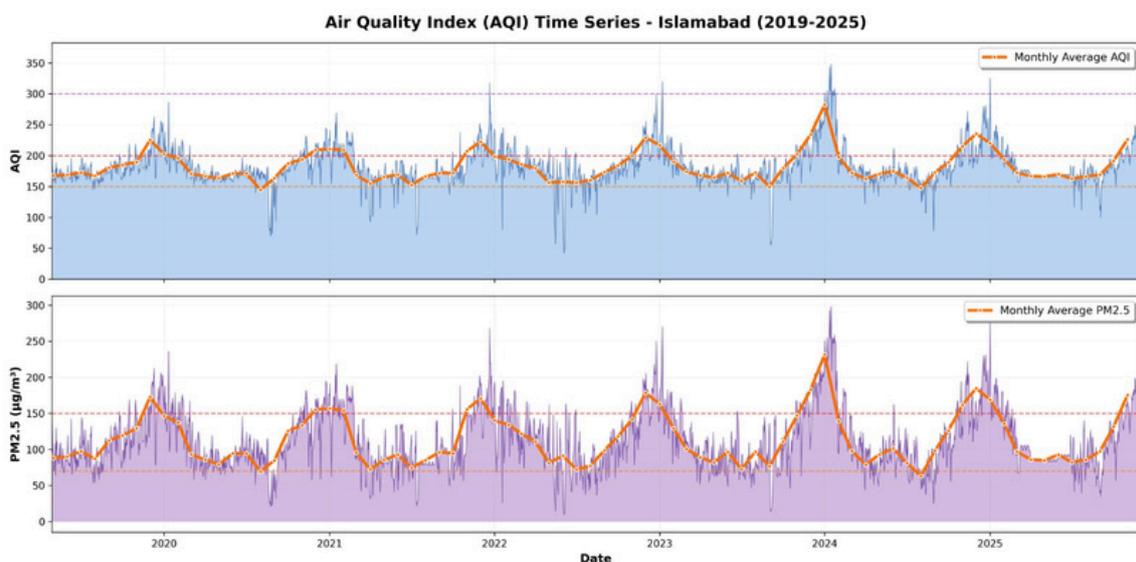


Figure 6. AQI and PM2.5 Time Series for Islamabad (2019–2025)

8. Comparative Spatio-Temporal Analysis of PM2.5 and Air Quality Patterns Across Islamabad During the 2024–2025 Smog Season

Daily average PM2.5 concentrations across three monitoring stations during the smog season. Shahnawaz I-9-2 (green) consistently shows the highest pollution levels with frequent exceedances above $150 \mu\text{g}/\text{m}^3$, particularly during mid-December to early January. Shah Allah Ditta (red) and Bahria Enclave (blue) exhibit similar moderate pollution patterns, generally ranging between $50\text{--}150 \mu\text{g}/\text{m}^3$. Shaded areas represent daily min-max ranges, indicating high intra-day variability at all stations.

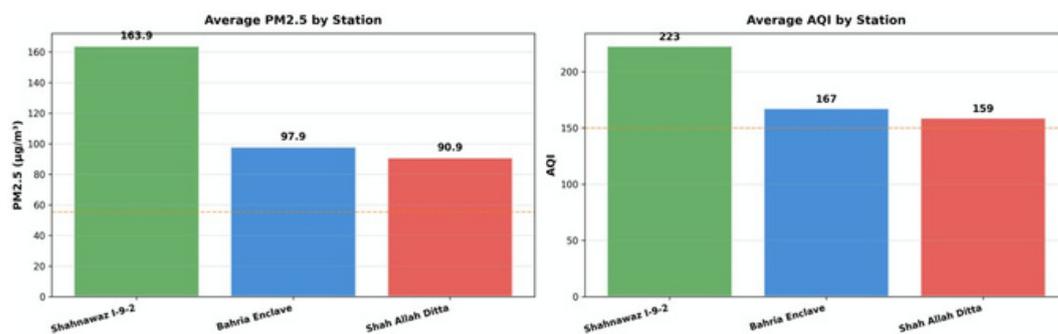


Figure 7: Average PM2.5 and AQI Comparison by Station (Nov 2024 - Jan 2025)

The orange and red dashed lines mark EPA thresholds for "Unhealthy for Sensitive Groups" ($55.4 \mu\text{g}/\text{m}^3$) and "Very Unhealthy" ($150.4 \mu\text{g}/\text{m}^3$), respectively. Corresponding AQI values show Shahnawaz I-9-2 frequently exceeding AQI 200 (Unhealthy), while the other two stations typically remain between AQI 100–200 (Moderate to Unhealthy).

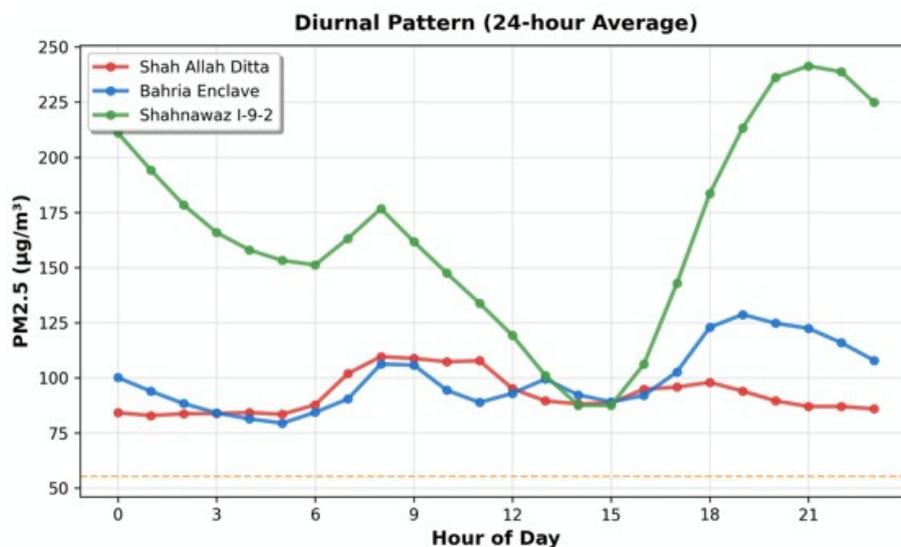


Figure 8: Diurnal Pattern (24 hr Average)

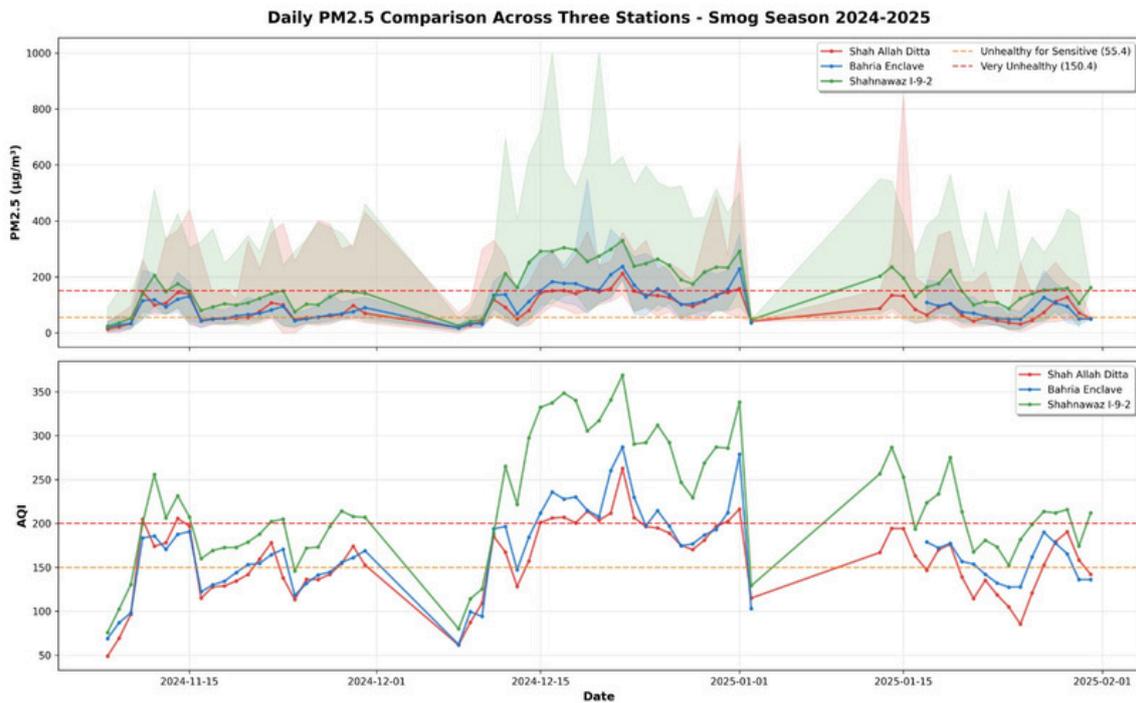


Figure 9. Comparison across stations

A complementary analysis of diurnal and daily cycles reveals that while regional meteorology dictates the timing of smog episodes, local urban factors determine their intensity. The daily time series demonstrates high temporal synchronicity across all monitoring sites, with simultaneous spikes in mid-December and January, confirming that basin-wide atmospheric stagnation affects the entire capital territory.

However, the diurnal profile exposes a critical disparity in magnitude: the industrial center (Shahnawaz I-9/2) acts as a local pollution amplifier, exhibiting a drastic nocturnal surge where PM_{2.5} levels triple after sunset due to the compounding effects of rush-hour emissions and a collapsing boundary layer. In contrast, peripheral stations like Shah Allah Ditta maintain significantly flatter profiles, illustrating that while the smog season is a regional phenomenon, the most hazardous exposure is strictly defined by proximity to the city's industrial and vehicular core.

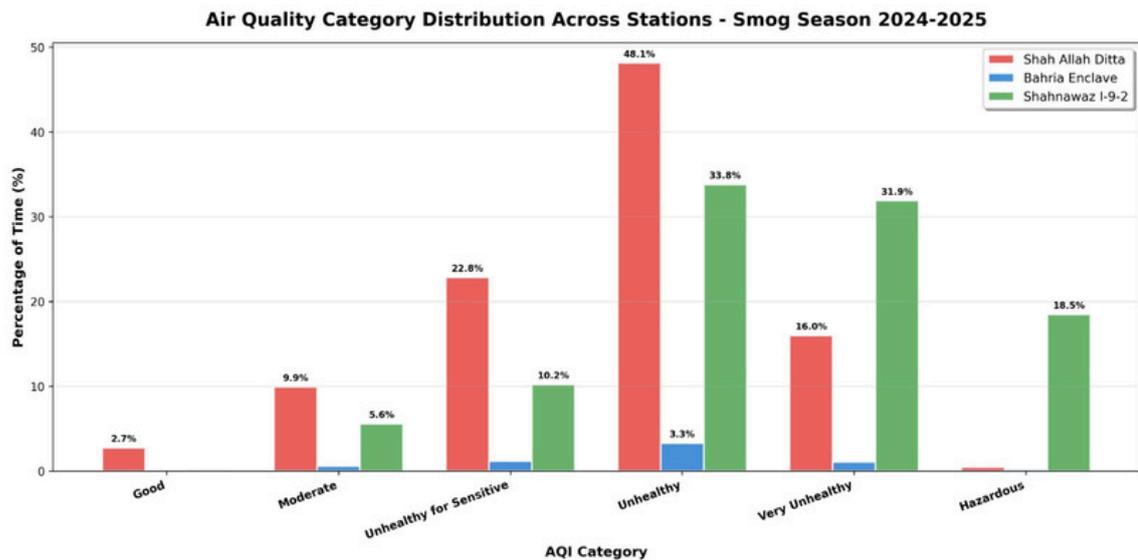


Figure 10. Air Quality Category Distribution across Station

The chart shows that during the 2024–2025 smog season, air quality was dominated by unhealthy conditions across all stations. Shah Allah Ditta spent nearly half the time in the Unhealthy category (about 48 percent), Bahria Enclave experienced very limited good or moderate air and mostly unhealthy levels, while Shahnawaz I-9/2 had a large share of Very Unhealthy and Hazardous days, indicating the most severe pollution among the three locations.

Key Findings:

- Shahnawaz I-9-2 (industrial area) experienced the most severe pollution, with mean concentrations 1.8 times higher than other stations
- All stations exceeded WHO guidelines ($15 \mu\text{g}/\text{m}^3$ annual mean) by factors of 6–11 times
- The extreme maximum value of $1003.4 \mu\text{g}/\text{m}^3$ at Shahnawaz indicates episodic industrial emission events
- Over 89% of days at Shahnawaz exceeded the "Unhealthy for Sensitive Groups" threshold

Spatial Distribution of AQI - Islamabad Smog Season (November 1 2024 - January 31 2025)

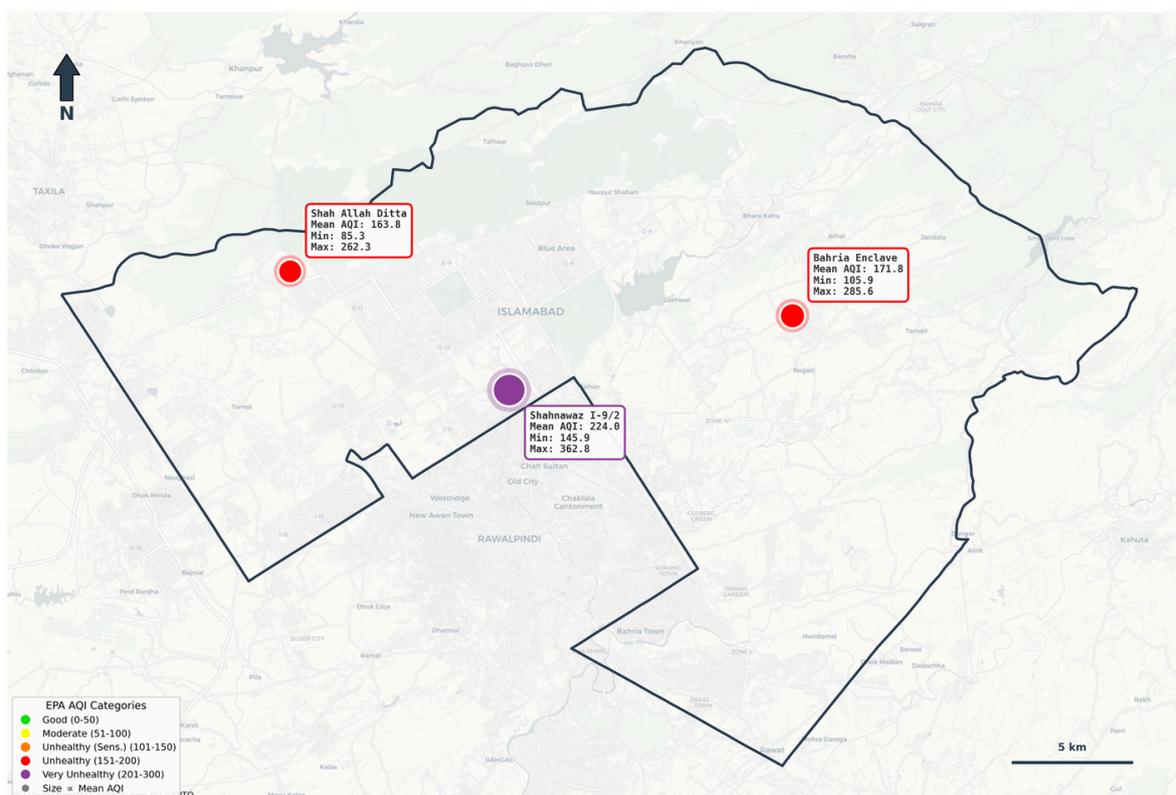


Figure 11. Spatial Distribution of AQI across Islamabad

This map illustrates the spatial variation of the mean daily Air Quality Index (AQI) across Islamabad during the critical winter smog season between November 1, 2024, and January 31, 2025. Based on US EPA standards, the analysis reveals a distinct pollution gradient emanating from the city's industrial core. The central station at Shahnawaz I-9/2 recorded the severest pollution, averaging a "Very Unhealthy" AQI of approximately 224 throughout the period. Conversely, suburban and peripheral locations to the east (Bahria Enclave) and north (Shah Allah Ditta) registered lower, yet persistently critical, mean values classified as "Unhealthy," ranging between AQI 159 and 172. The marker sizing visually reinforces this trend, demonstrating that while industrial zones are the primary hotspots, the entire capital territory experienced chronically unsafe air quality far exceeding health guidelines during these winter months.

9. Interpretation and Risk Perspective

Integrating all visual evidence reveals a stable, long duration pollution regime. The following conclusions can be drawn:

Section	Summary
Persistent Pollution	PM2.5 remains consistently high across all seasons and years, indicating a stable structural pollution regime rather than short term events.
Predominance of Harmful Air Quality	About 90 percent of days fall in Unhealthy or worse categories, making hazardous air the standard state rather than an exception.
Seasonal Amplifiers	Winter inversions and dry, stagnant conditions intensify pollutant buildup, reinforcing already elevated annual baselines.
Health and Policy Implications	Sustained PM2.5 exposure heightens cardiovascular and respiratory risks, requiring continuous emission controls and data driven air quality management.

Table 1. Key Interpretations of Islamabad’s PM 2.5 Pattern (2019–2025)

10. Structural Drivers of Islamabad’s Rising PM 2.5 concentrations (2019–2025)

Islamabad’s PM 2.5 trends reflect reinforcing demographic, land-use, meteorological, and emission factors. Together, these explain the persistent Unhealthy and Very Unhealthy air quality recorded across 2019–2025.

10.1 Population Growth and Emission Load

Islamabad’s population rose from **1.095 million** in 2019 to **1.301 million** in 2025, an increase of **~19 percent**, with annual growth near **2.9 percent**.

This expansion increases:

- household energy consumption,
- private vehicle demand,
- solid waste generation and open burning.

As the population rises, baseline PM2.5 emissions increase proportionally, matching the consistently high annual means in the data.

10.2 Urbanization, Vegetation Decline, and Loss of Carbon Sinks

Land cover analyses quantify a drastic structural shift in Islamabad’s landscape between 2000 and 2020, characterized by the replacement of natural carbon sinks with impervious surfaces:

- Vegetation cover declined from **46.97%** to **34.77%**.
- Built-up area surged from **6.37%** to **28.18%**.

This rapid urbanization has fundamentally compromised the city's atmospheric buffering capacity. The reduction in foliage has directly lowered the surface deposition of airborne particles, while the expansion of concrete has intensified the Urban Heat Island effect. This thermal alteration promotes nighttime temperature inversions, particularly during the critical **November–January** smog season, which trap pollutants near the surface. Furthermore, encroachment into the Margalla Hills has weakened a vital natural sink, reducing airflow roughness and hindering the effective dispersion of accumulated particulate matter.

10.3 Vehicular and Industrial Emissions

Transport and industrial operations remain the principal sources of PM 2.5 in Islamabad, contributing to a national transport emission total of **43.3 million tonnes** of CO₂ in 2023. The city's pollution profile is defined by specific systemic contributors:

- **Vehicular & Industrial Reliance:** The fleet is heavily reliant on older engines and sub-Euro-5 fuels, while emissions from the I-9 and I-10 industrial zones directly infiltrate residential areas.
- **Urban Congestion:** The growth in private vehicle ownership has significantly outpaced public transit capacity. This causes chronic congestion on the Islamabad–Rawalpindi corridors, where cold-start and idling emissions drive up local concentrations.

These constant sources create a relentless year-round PM 2.5 baseline, preventing the occurrence of any truly "clean" periods in the data. This baseline is further exacerbated from October to January by seasonal crop residue and waste burning along the metropolitan boundary, which stacks upon urban emissions to drive the extreme winter spikes observed in the 2023–2024 data.

10.4 Meteorological Driver: Reduced Western Disturbance Activity

Western Disturbances have historically served as a critical meteorological clearing mechanism for Islamabad, bringing winter rainfall that washes out accumulated PM 2.5 and destabilizes stagnant inversion layers. However, recent patterns indicate that these systems have become weaker and less frequent, resulting in extended dry periods with minimal atmospheric cleansing. This reduction in precipitation fosters persistent surface-level pollution retention.

11. Conclusions

Analysis of PM2.5 data from 2019 to 2025 demonstrates that Islamabad is experiencing a sustained high-pollution regime. Annual mean concentrations consistently exceed health-based limits, while daily air quality remains predominantly within Unhealthy and Very Unhealthy categories. Seasonal smog episodes significantly intensify pollution during winter months; however, air quality does not recover to safe levels during non-smog periods. Spatial and station-level assessments show that industrial zones and major transport corridors produce localized pollution amplification, increasing exposure risks in specific urban areas.

The evidence indicates that Islamabad's air quality deterioration is driven by structural factors including population growth, urban expansion, vegetation loss, vehicular and industrial emissions, and reduced atmospheric cleansing. Without structural emission control and urban planning interventions, the city is likely to remain locked into a long-term unhealthy air quality state.





Pakistan's First Private Weather Company

