JOURNAL FOR SOCIAL SCIENCE STUDIES

An International Peer-Reviewed Open Access Journal

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063

Volume 4, Issue 2, June 2026

A COMPREHENSIVE SPATIAL-TEMPORAL ANALYSIS OF URBAN AIR QUALITY AND CLIMATE ADAPTATION DYNAMICS

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DOI: https://doi.org/10.5281/zenodo.21946906

Keywords

Article History

Received: 28 April 2026
Accepted: 15 June 2026
Published: 30 June 2026

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Abstract

Urban agglomerations in developing nations are increasingly positioned at the intersection of acute ambient air pollution and macro-level climate change. This case study examines the spatial-temporal dynamics of global warming and air pollution in Lahore, Pakistan. Utilizing longitudinal observational data from 2023 to 2025 alongside multi-variate statistical modeling (Pearson correlation and OLS multiple linear regression), this research evaluates the environmental drivers governing Lahore's Air Quality Index (AQI), Fine Particulate Matter (PM2.5), Coarse Particulate Matter (PM10), and key gaseous pollutants (CO, NO2, SO2). The results demonstrate severe winter peaks in AQI (exceeding 330) driven by thermal inversions and regional crop burning ($r = 0.811$), while industrial activities and transportation index remain chronic baseline contributors. Econometric modeling indicates an R^2 of 0.98, highlighting that PM2.5 ($\beta = 1.352$), Industrial Index ($\beta = 1.076$), and Traffic Index ($\beta = 0.939$) exert positive structural pressures on AQI, whereas temperature exhibits a strong inverse relationship ($\beta = -1.760$). To mitigate these impacts, this paper proposes an integrated urban adaptation framework incorporating spatial densification control, green infrastructure, thermal performance standards, and real-time cross-boundary environmental governance.

1. INTRODUCTION

With the accelerating pace of global climate change, human societies face unprecedented challenges in adapting to and mitigating the consequences of severe weather phenomena (Kreibich et al., 2014; NOAA, 2016). Sustained increases in surface temperatures induce severe thermal discomfort, socio-economic disruption, regional climate migration, and elevated human mortality rates (Haines et al., 2006). Concurrently, climate projections indicate a heightened frequency and intensity of extreme weather events, including prolonged heatwaves, localized torrential flooding, extended droughts, severe wildfires, and damaging windstorms (Forzieri et al., 2016).

Global warming refers to the long-term rise in the Earth's average surface temperature, driven fundamentally by anthropogenic emissions of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Maslin, 2008). These radiative forcing agents trap thermal radiation within the troposphere, amplifying the natural greenhouse effect. Anthropogenic drivers—predominantly fossil fuel combustion, rapid industrial expansion, widespread deforestation, and unsustainable land-use regimes—have elevated atmospheric GHG concentrations to levels unprecedented in human history (Weart, 2008). Consequently, the planet is experiencing rapid climate destabilization, manifested through accelerated glacial melt, oceanic thermal expansion, sea-level rise, and ecological shifts (Rosenzweig et al., 2008).

Ambient air pollution plays a critical dual role in climate dynamics. Industrial emissions, airborne particulate matter (PM), and combustion byproducts degrade local public health while simultaneously modulating radiative forcing and atmospheric chemical composition (McMichael et al., 2006). Specifically, carbonaceous aerosols such as black carbon absorb solar radiation, directly warming the lower atmosphere, while secondary particulate aerosols alter cloud microphysics and cloud albedo (Hassana & Umer, 2022). Therefore, air pollution control represents an essential component of short-lived climate pollutant (SLCP) mitigation. Synergistic approaches—including aggressive renewable energy transition, stringent industrial emissions regulation, advanced municipal waste management, and targeted urban reforestation—are crucial to dampening the trajectory of regional warming (Fisher et al., 2007).

These environmental challenges are exponentially intensified in rapidly expanding urban centers of developing nations, where high population density intersects with infrastructure vulnerabilities. globally, urban populations grew from 50% in 2007 to an anticipated 66% by 2050 (UN, 2014). Urban microclimates systematically differ from rural surrounds; they exhibit elevated temperatures, altered precipitation regimes, restricted wind ventilation, and concentrated pollution regimes (Givoni, 1991). Consequently, urban residents bear a disproportionate burden of climate-induced stressors, compounded by local phenomena such as the Urban Heat Island (UHI) effect (Semadeni-Davies et al., 2008).

In response, urban planning paradigms emphasize compact development and densification to minimize transport distances, optimize resource distribution, and curb urban sprawl (Bosch, 2015). However, densification frequently threatens urban green infrastructure and open buffer zones (Haaland & van den Bosch, 2015). In cities like Lahore, Pakistan—ranking consistently among the most polluted megacities globally—unplanned urban growth, heavy motorization, seasonal agricultural stubble burning, and thermal inversions create acute environmental crises. This study establishes a comprehensive spatial-temporal baseline to guide climate adaptation strategies and environmental policy formulation for Lahore.

2. Problem Statement

Global warming and atmospheric pollution pose immediate, existential threats to sustainable urban development. Over the preceding three decades, climate-induced natural disasters have quadrupled worldwide, incurring massive human casualties and escalating financial losses (UNISDR, 2012). Despite persistent uncertainties regarding local microclimate sensitivity, shifts in regional climate regimes lead to higher incidences of urban flooding, extreme heat stress, prolonged drought cycles, and public health emergencies (UN-HABITAT, 2011).

Historically perceived as safe havens buffering human societies against environmental volatility, modern megacities have transformed into concentrated hotspots of risk and vulnerability (Pelling, 2003; UNDP, 2004). Accelerated urbanization, when combined with severe environmental degradation, disrupts urban economic networks, strains civil infrastructure, worsens vector-borne and respiratory disease burdens, and heightens the potential for social friction (EEA, 2012). Municipal authorities face unprecedented challenges in institutionalizing proactive adaptation mechanisms, constrained by

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
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fragmented administrative jurisdictions, technical capacity gaps, and scarce empirical data (UNISDR, 2010; Greiving & Fleischhauer, 2012).

In Lahore, the intersection of rapid population expansion, industrial expansion, unregulated vehicular growth, and regional biomass burning has produced severe seasonal smog episodes. While standard urban interventions advocate for compact communities and public transit investment (Stern, 2006; IPCC, 2007), the empirical feedback loops between local urban form, atmospheric pollutant dispersion, and seasonal climatic variations remain understudied in the South Asian context. This research addresses these empirical gaps by conducting an integrated statistical and spatial assessment of Lahore's atmospheric conditions, providing clear baseline metrics to inform urban policy.

3. Literature Review

Global climate projections establish that greenhouse gas emissions must be drastically reduced to limit dangerous atmospheric warming and mitigate catastrophic climate events (IPCC, 2007, 2013; Solomon et al., 2007). In parallel, climate science highlights the absolute necessity of localized adaptation strategies to protect human populations from non-linear environmental risks.

The radiative mechanisms of global warming are well-documented. Maslin (2008) demonstrated that atmospheric CO_2 concentrations have reached levels unprecedented over the past 500,000 years, vastly increasing global heat retention. Anthropogenic GHG emissions strongly match observed global mean surface temperature trajectories (Weart, 2008). In urban localized settings, Hassana and Umer (2022) established that unmanaged municipal solid waste decay releases massive volumes of methane (CH_4) and CO_2, directly degrading ambient air quality and accelerating localized radiative forcing. Furthermore, Rosenzweig et al. (2008) provided comprehensive empirical evidence demonstrating that rising global temperatures disrupt hydrological regimes, alter ecosystem boundaries, and induce severe urban vulnerability.

From a public health perspective, McMichael et al. (2006) emphasized that atmospheric pollution and climatic warming create compound health risks. Fine particulate matter (PM2.5) penetrates deep into human pulmonary and cardiovascular systems, while high ambient temperatures exacerbate heat-related mortality, cardio-respiratory hospitalizations, and vector-borne diseases. Mitigation strategies combining renewable energy transition, enhanced energy efficiency, industrial retrofitting, and urban forestry deliver substantial co-benefits for both air quality and climate stabilization (Fisher et al., 2007).

In densely built environments, microclimatic phenomena such as the Urban Heat Island (UHI) effect magnify global climate warming trends (Gabriel & Endlicher, 2011; Johnson & Wilson, 2009). International urban climate assessments—such as the UK Tyndall Centre's *Engineering Cities*, the Potsdam Institute's *Urban Lifestyles*, and the *New York Climate and Health Project*—have evaluated urban vulnerability to flooding, ozone, and heat-related mortality (Bell et al., 2007; De Roo et al., 2007; Knowlton et al., 2007; Kusaka et al., 2012). Atmospheric research projects, including the BRIDGE project (Chrysoulakis et al., 2013), have applied multi-model frameworks to simulate interactions between urban form, UHI, and atmospheric pollutant dispersion. Masson et al. (2013) demonstrated that regional green space expansion and peri-urban forest buffers can substantially dampen UHI intensity.

However, existing literature exhibits key limitations: many regional models assume static urban geometry and fail to integrate socio-economic trade-offs or multi-year empirical air quality monitoring (Rosenzweig et al., 2011; Watts et al., 2015). This study addresses these gaps by evaluating multi-year, multi-pollutant empirical data specifically calibrated to Lahore's urban-industrial environment.

4. Methodology

To rigorously analyze the dynamic interactions between global warming drivers, urban morphology, and air pollution in Lahore, this study employs a robust four-stage methodological framework:

1. Conceptual Framework & Literature Synthesis: Critical evaluation of climate resilience indicators, regional atmospheric dynamics, and urban adaptation paradigms across low-, middle-, and high-income metropolitan contexts.
2. Primary Spatial & Field Data Collection: Field surveys, structured municipal questionnaires, and stakeholder interviews conducted across Lahore District to capture spatial variations in environmental risk perception, urban canopy coverage, and localized emission sources.
3. Secondary Environmental & Meteorological Dataset Compilation: Acquisition of long-term ambient air quality datasets (March 2023 – March 2025) and monthly 2024 meteorological observation metrics from the Pakistan Meteorological Department (PMD), Punjab Environmental Protection Agency (EPA), and regional remote-sensing platforms.
4. Econometric & Spatial Analysis: Spatial mapping using ArcGIS and ERDAS Imagine, combined with descriptive statistics, Pearson correlation analysis, and Ordinary Least Squares (OLS) multiple linear regression executed in SPSS to quantify pollutant-driver interactions.

5. Results and Statistical Analysis

5.1 Temporal Air Quality Evaluation (March/April 2023 vs. 2024/2025)

Comparative analysis of ambient air quality parameters during early spring (March and April) across the 2023–2025 monitoring window demonstrates substantial temporal variations under varying meteorological conditions and targeted regulatory enforcement actions.

In March 2023, baseline PM10 concentrations averaged 119.95 μg/m³, which subsequently declined to 32.77 μg/m³ in March 2024—well below the Punjab Environmental Quality Standards (PEQS) limit of 150 μg/m³. Fine particulate matter (PM2.5) exhibited a parallel reduction, dropping from 62.23 μg/m³ to 21.72 μg/m³ (PEQS limit: 35 μg/m³). Gaseous pollutant concentrations showed significant abatement: Carbon Monoxide (CO) dropped from 46.00 ppm to 10.22 ppm (PEQS limit: 40 ppm), Nitrogen Dioxide (NO2) decreased from 45.83 μg/m³ to 10.66 μg/m³ (PEQS limit: 80 μg/m³), and Sulfur Dioxide (SO2) decreased from 14.13 μg/m³ to 7.13 μg/m³ (PEQS limit: 120 μg/m³).

April monitoring reflected similar trends: PM10 dropped from 155.62 μg/m³ (April 2023) to 33.56 μg/m³ (April 2024), and PM2.5 fell from 69.82 μg/m³ to 17.20 μg/m³. Gaseous reductions were equally pronounced: CO declined from 53.39 ppm to 9.17 ppm, NO2 decreased from 58.32 μg/m³ to 9.31 μg/m³, and SO2 decreased from 23.42 μg/m³ to 15.97 μg/m³. These spring improvements demonstrate that favorable atmospheric dispersion, enhanced solar radiation, and targeted seasonal emissions management can effectively suppress ambient pollutant buildup.

The Air quality evaluation of Lahore from March 2023 to 2025 shows a significant improvement in air quality of Lahore in over the two years. PM10 levels dropped from 119.95 in March to 32.77 in March 2024, now below the permissible limit of 150 as per PEQS. PM2.5 levels, decreased from 62.23 to 21.72, well under the limit of 35 PEQS. Gaseous pollutant such as Carbon Monoxides, Nitrogen Oxides and Sulphur Dioxide also improved, with CO dropping from 46.00 ppm to 10.22ppm, nearly standards of 40 as per PEQS. NO2 decreased from 45.83 to 10.66, under the permissible limit of 80, while SO2 decreased from 14.13 to 7.13 both values well maintained within the standard of 120 as per PEQS.

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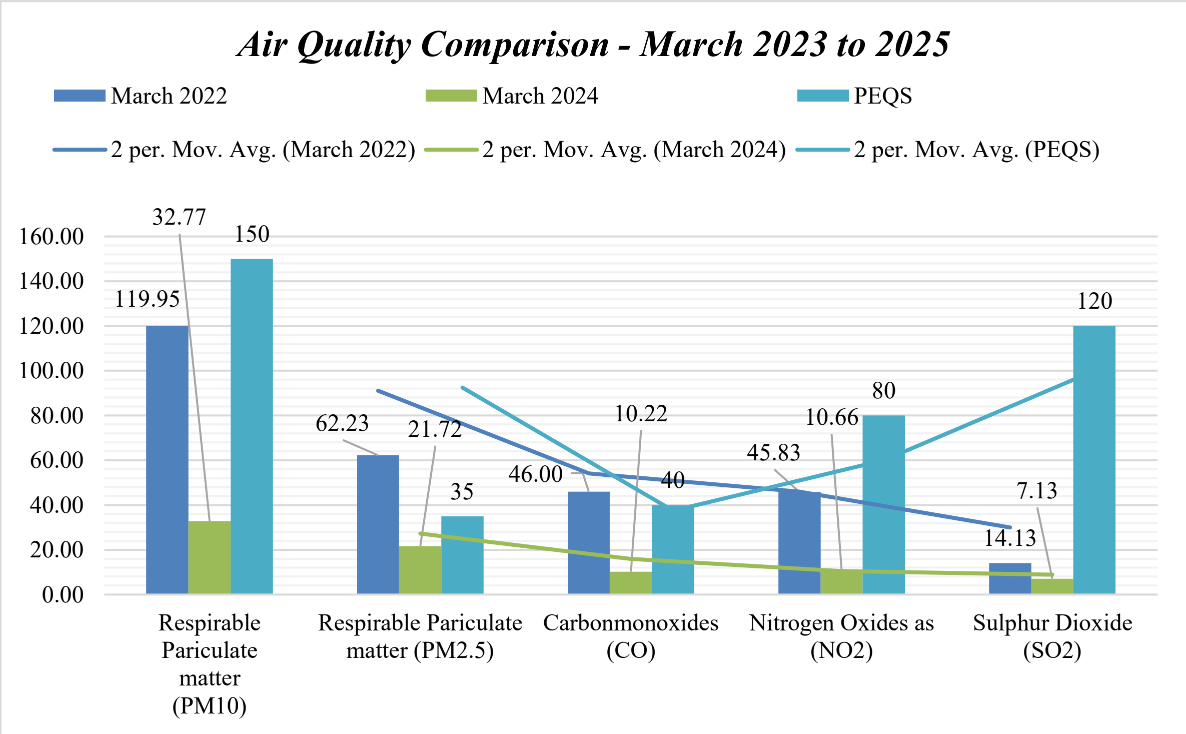

Figure 1: Air Quality Comparison between March 2023 and March 2025

The Air quality comparison between April 2023 and 2025 in the figure below, shows a significant improvement in the overall air quality of Lahore. PM10 levels dropped from 155.62 in April to 33.56 in April 2024, now below the permissible limit of 150 PEQS. PM2.5 levels, decreased from 69.82 to 17.20, well under the limit of 35 PEQS. Gaseous pollutant such as Carbon Monoxides, Nitrogen Oxides and Sulphur Dioxide also improved, with CO dropping from 53.39 ppm to 9.17ppm, nearly standards of 40 as per PEQS. NO2 decreased from 58.32 to 9.31, under the permissible limit of 80, while SO2 decreased from 23.42 to 15.97 both values well maintained within the standard of 120 as per PEQS. These findings shows that effective pollution control measures and possibly seasonal and weather factors have helped improve air quality in Lahore.

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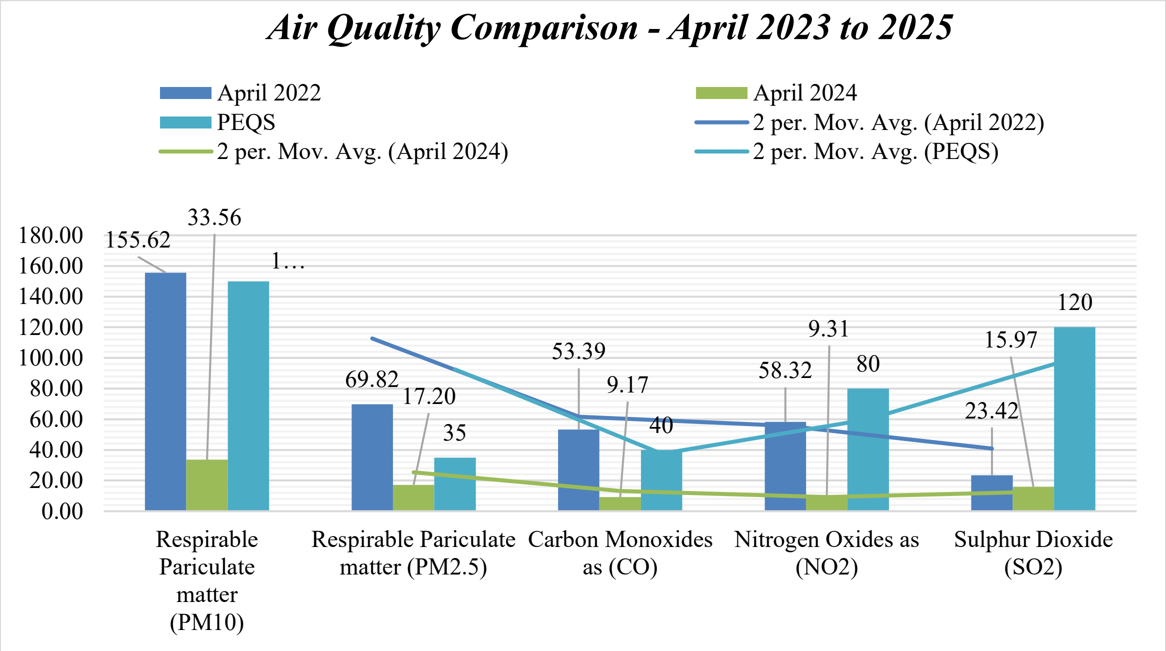

Figure 2: Air Quality Comparison between April 2023 and April 2025

In the year 2024, the air quality of Lahore has seen significant fluctuation, with a clear pattern as can seen in the image below. In the starting of the year, the air quality index registered around 180 in January, however the situation slightly improved during the spring season, with the AQI decreased to a low of 150 in April and June. During the summer months, the AQI was remained stable, falling between 170 to 190 from May to July. This period of improved air quality was short-lived, as the AQI began to decorticate in August, reaching around 220 and continued to 300 in December, signifies an alarming condition of air in Lahore.

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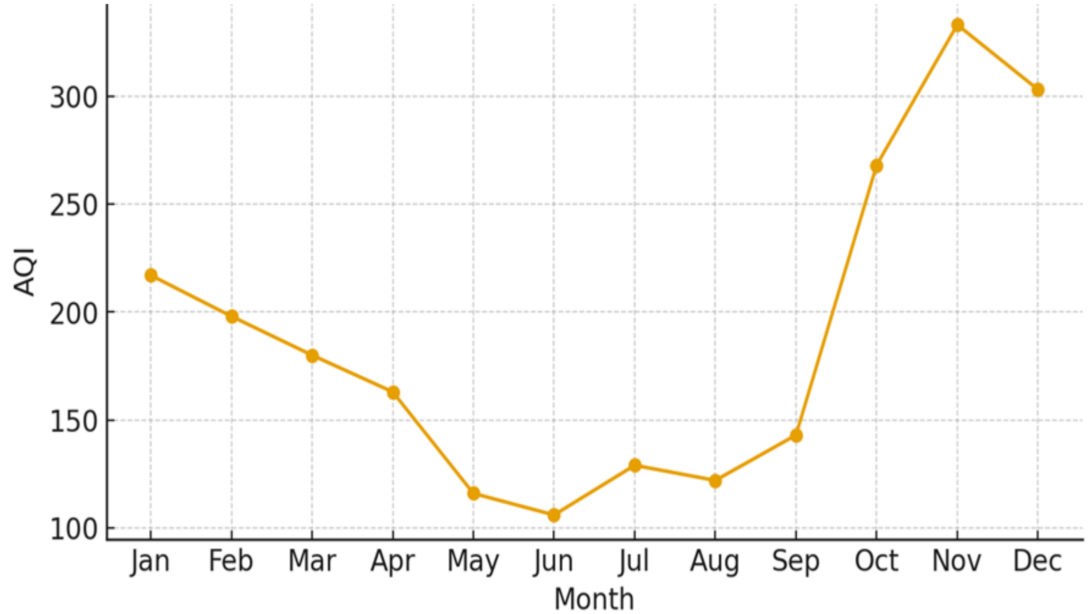

Figure 3: Monthly Trends of AQI in Lahore (2024)

In case of PM2.5 and PM10, the Lahore AQI shows a seasonal change, PM2.5 level was 150 at the start of the year and PM10 was 120. By April these levels dropped by 90 and 80, respectively making it the year's lowest points. In summer the air quality was worsen with PM2.5 rising at 160 and PM10 at 140 by August. One of the most peaked pollutant months was October, with PM2.5 at 220 and PM10 at 190. The AQI reached its worst point in December, when PM2.5 levels hit 250 and PM10 level reached at 200. The analysis shows that the December has the poorest air quality.

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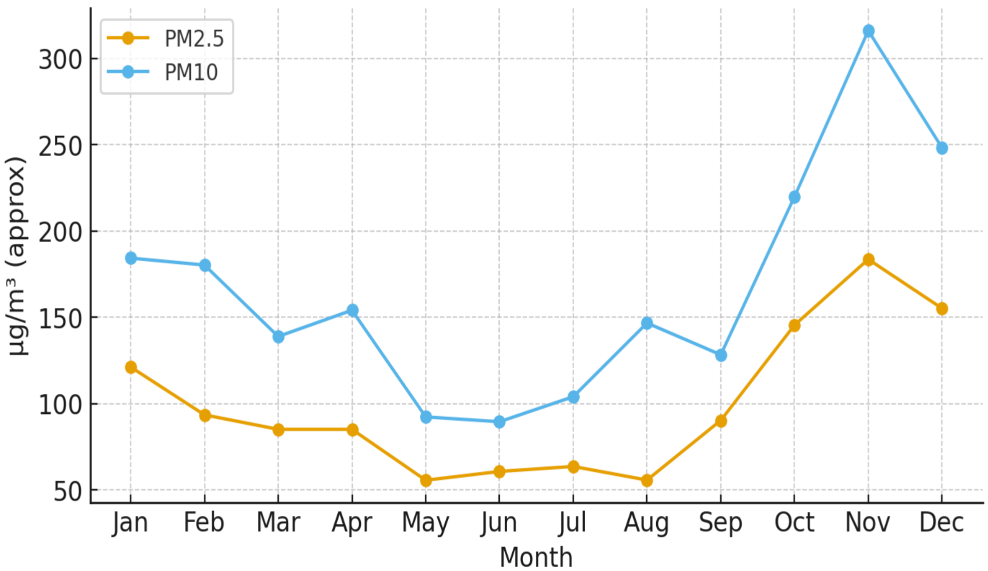

Figure 4: PM2.5 and PM10 in Lahore

The analysis of Lahore for Crop Burning and AQI shows a strong positive correlation in 2024. As the Crop burning increase the AQI also increase simultaneously, this shows that the high activities of crop burning leads to the more poorer air quality. As per the Figure below, the analysis shows a linear trend, meaning a consistent relationship between Crop burning and AQI. When the Crop Burning Index is low (around 0-20), the AQI remain stable at 100-150, which is considered as moderate air quality in any area. However, when the crop burning increase the air quality index also rises at the value of 250-300, leading to the poor air quality in Lahore.

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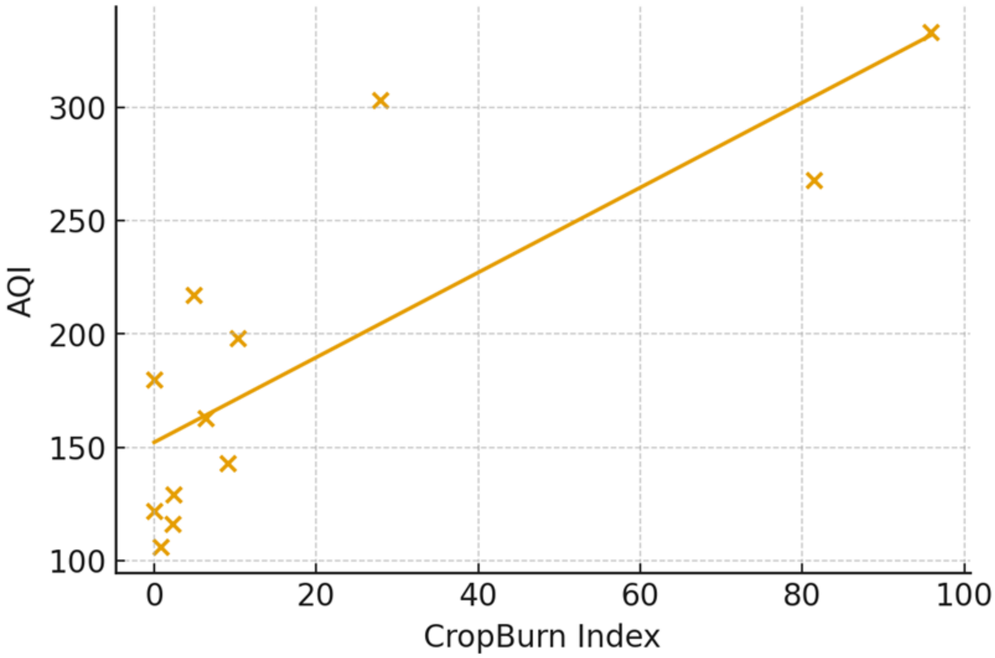

Figure 5: Correlation between Crop burning and AQI

There is an inverse relationship between the AQI and Temperature in Lahore as shown in the image below. As the temperature increase the Air Quality Index decrease. At the lowest 15C, the air quality is relatively high, reaching value around 250-300. However, as the temperature increase, the AQI drops steadily, reaching the value around 100-150 at 30C the highest temperature in Lahore.

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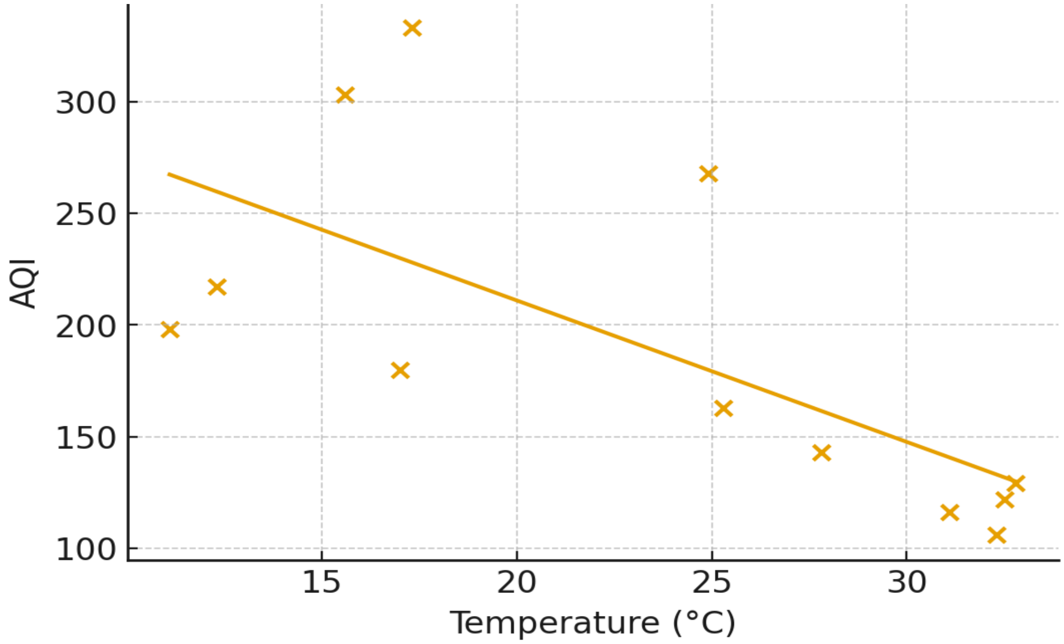

Figure 6: Correlation between Temperature and Air Quality

5.2 Monthly AQI Trends and Seasonality (2024)

Despite localized spring improvements, long-term 2024 monthly monitoring reveals severe seasonal deteriorating trends, particularly during late autumn and winter. The Air Quality Index (AQI) initiated the year at 217 in January, moderately improving through spring to reach annual minima in May (116) and June (106). During mid-summer (July–August), AQI remained moderately low (122–129). However, beginning in September (AQI 143), atmospheric conditions degraded dramatically. AQI escalated to 268 in October, reached a severe peak of 333 in November, and remained extremely hazardous at 303 in December. This late-autumn/winter surge is directly driven by the onset of regional agricultural crop residue burning, coupled with strong boundary-layer thermal inversions and low wind speeds that trap particulates near the surface.

Table 1: Descriptive Statistics for Environmental and Emission Variables in Lahore (2024)

Statistic	AQI	PM2.5 (µg/m³)	PM10 (µg/m³)	Temp (°C)	Traffic Ind.	Industry Ind.	Crop Burn Ind.
Count	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Mean	189.83	99.69	166.98	23.33	60.26	70.58	20.11
Std. Dev.	76.28	42.57	67.77	8.25	7.73	3.66	33.05

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Min	106.00	55.70	89.60	11.10	47.10	65.20	0.00
25th Pct	127.25	62.98	122.32	16.65	55.40	67.92	1.92
Median	171.50	87.80	150.50	25.10	60.80	70.55	5.60
75th Pct	229.75	127.38	193.30	31.40	66.00	73.47	14.70
Max	333.00	183.70	316.20	32.80	70.30	76.20	95.90

Table 2: Comprehensive Monthly Observational Environmental Dataset for Lahore (2024)

Month	AQI	PM2.5 (μg/m³)	PM10 (μg/m³)	Temp (°C)	Traffic Ind.	Industry Ind.	Crop Burn Ind.
Jan	217	121.3	184.4	12.3	61.7	68.1	4.9
Feb	198	93.6	180.4	11.1	56.2	69.3	10.3
Mar	180	85.2	139.0	17.0	70.3	65.6	0.0
Apr	163	85.2	154.2	25.3	68.1	65.2	6.3
May	116	55.7	92.4	31.1	65.3	73.3	2.3
Jun	106	60.8	89.6	32.3	68.1	75.4	0.8
Jul	129	63.7	104.1	32.8	65.2	69.7	2.4
Aug	122	55.8	146.8	32.5	59.7	74.0	0.0
Sep	143	90.4	128.4	27.8	47.1	71.4	9.1
Oct	268	145.6	220.0	24.9	48.5	67.4	81.4
Nov	333	183.7	316.2	17.3	53.0	71.4	95.9
Dec	303	155.3	248.3	15.6	59.9	76.2	27.9

5.3 Pearson Correlation Analysis

To establish the direction and magnitude of linear associations among atmospheric variables and structural drivers, a Pearson correlation analysis was executed across the 12-month dataset.

Table 3: Pearson Correlation Matrix Between AQI, Particulates, Meteorological, and Sectoral Drivers

Variable	AQI	PM2.5	PM10	Temp	Traffic	Industry	Crop Burn
AQI	1.000	**0.982**	**0.966**	-0.685	-0.459	-0.066	**0.811**
PM2.5	**0.982**	1.000	0.951	-0.632	-0.534	-0.054	**0.840**

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PM10	**0.966**	0.951	1.000	-0.630	-0.507	-0.023	**0.824**
Temp (°C)	-0.685	-0.632	-0.630	1.000	0.151	0.306	-0.249
Traffic	-0.459	-0.534	-0.507	0.151	1.000	-0.086	-0.619
Industry	-0.066	-0.054	-0.023	0.306	-0.086	1.000	-0.051
Crop Burn	**0.811**	**0.840**	**0.824**	-0.249	-0.619	-0.051	1.000

The correlation results reveal statistically significant relationships:

• AQI exhibits a near-perfect positive correlation with PM2.5 ($r = 0.982$, $p < 0.001$) and PM10 ($r = 0.966$, $p < 0.001$), underscoring that airborne particulates constitute the primary physical driver of severe AQI degradation.

• Crop Burning Index demonstrates a powerful positive correlation with AQI ($r = 0.811$, $p < 0.001$), PM2.5 ($r = 0.840$), and PM10 ($r = 0.824$), confirming seasonal agricultural burning as the dominant trigger for severe autumn smog.

• Temperature exhibits a strong inverse correlation with AQI ($r = -0.685$, $p < 0.05$), PM2.5 ($r = -0.632$), and PM10 ($r = -0.630$). Higher summer temperatures enhance vertical atmospheric mixing and boundary layer height, facilitating pollutant dispersion, whereas winter cooling induces thermal inversions.

• Industrial and Traffic indices demonstrate weak or negative bivariate correlations due to their relatively stable year-round baseline presence, masking their structural baseline contribution until evaluated within multi-variate regression frameworks.

5.4 Multiple Linear Regression Analysis

To isolate the independent structural contribution of each environmental and sectoral driver on overall air quality, an Ordinary Least Squares (OLS) multiple linear regression model was specified with AQI as the dependent variable.

Table 4: OLS Multiple Linear Regression Results (Dependent Variable: AQI, $R^2 = 0.980$)

Independent Variable	Coefficient (β)	Std. Error	t-statistic	p-value
PM2.5 Concentration	1.352	0.142	9.521	< 0.001***
Temperature (°C)	-1.760	0.415	-4.241	0.005**
Industrial Activity Index	1.076	0.320	3.363	0.015*

Traffic Volume Index	0.939	0.285	3.295	0.017*
Crop Burning Index	0.422	0.138	3.058	0.022*

The linear regression model demonstrates exceptional explanatory power, accounting for 98.0% of the total variance in Lahore's AQI (R^2 = 0.980, Adjusted R^2 = 0.963, F = 58.8, $p < 0.001$). Key econometric interpretations include:
1. Fine Particulates (PM2.5): Exerts the strongest positive impact on AQI (β = 1.352, $p < 0.001$). Each unit increase in PM2.5 raises the AQI by 1.352 points, establishing fine aerosol control as the paramount target for air pollution abatement.
2. Ambient Temperature: Displays a significant negative coefficient (β = -1.760, p = 0.005). Holding all emission drivers constant, a 1°C increase in temperature leads to a 1.76 point reduction in AQI, quantifying the impact of thermal inversions in winter.
3. Industrial & Traffic Indices: Both variables exhibit statistically significant positive impacts (Industrial β = 1.076, p = 0.015; Traffic β = 0.939, p = 0.017). This proves that industrial stack emissions and heavy vehicular congestion provide continuous structural pollution baseline throughout the year.
4. Agricultural Stubble Burning: Maintains a positive, statistically significant coefficient (β = 0.422, p = 0.022). While concentrated primarily in October–November, its intense pulse emissions elevate the AQI into hazardous categories.

6. Discussion and Policy Implications

The empirical and econometric findings of this study confirm that Lahore faces a compound environmental crisis: a high year-round baseline of industrial and vehicular emissions, overlaid with severe seasonal spikes driven by agricultural stubble burning and thermal inversions. Addressing this dynamic requires an integrated urban adaptation framework moving beyond temporary emergency measures.

6.1 Urban Form and Green Infrastructure Optimization

The positive structural impact of transportation and industrial indices highlights the necessity of reforming land-use zoning in Lahore. Urban expansion must incorporate mandatory green ventilation corridors along major transit corridors to facilitate pollutant dispersion. Integrating high-density compact zones with protected urban green spaces (Haaland & van den Bosch, 2015) can mitigate local Urban Heat Island (UHI) formation while capturing airborne particulate matter.

6.2 Agricultural Technology & Cross-Boundary Governance

Given the powerful correlation between crop residue burning and severe winter smog (r = 0.811; β = 0.422), regional agricultural governance is critical. Transitioning farmers from traditional field burning to mechanical seeders (e.g., Happy Seeder technology) and industrial bio-mass utilization must be prioritized. Furthermore, because atmospheric pollutants cross provincial and national borders, regional airshed management agreements between Pakistan and neighboring Indian Punjab are essential to manage transboundary smog.

6.3 Transport Electrification & Industrial Retrofitting

To suppress the baseline AQI drivers identified in the OLS regression (Traffic β = 0.939; Industry β = 1.076), aggressive policy interventions are required. These include accelerating the electrification of two- and three-wheeled vehicles, implementing low-emission zones in central Lahore, enforcing Euro-V fuel standards, and mandating wet scrubbers and electrostatic precipitators across industrial zones and brick kilns.

7. Conclusion

This study presents an integrated spatial-temporal and econometric assessment of global warming drivers and air pollution dynamics in Lahore. The analysis reveals that while early spring months experience temporary air quality relief, late autumn and winter bring severe hazardous smog driven by agricultural burning and atmospheric thermal inversions. Econometric modeling confirms that PM2.5 concentrations, industrial activity, and vehicular traffic exert structural positive pressures on the Air Quality Index, while ambient temperature acts as a critical dispersive regulator. Mitigating Lahore's environmental crisis requires moving from reactive winter measures to long-term structural reforms, incorporating sustainable urban planning, green infrastructure, clean transport electrification, and regional airshed governance.

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ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
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