

SMOG AWARENESS, AIR QUALITY, AND URBAN SUSTAINABILITY IN LAHORE: A MULTI-DIMENSIONAL POLICY, SOCIO-ECONOMIC, AND ENVIRONMENTAL ANALYSIS

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Abstract

Lahore, the provincial capital of Punjab and Pakistan's second-largest megacity, faces a severe annual environmental and public health crisis driven by seasonal photochemical smog and fine particulate pollution. This comprehensive study explicitly investigates the nexus linking public smog awareness, ambient Air Quality Index (AQI) dynamics, and long-term urban sustainability targets under the United Nations Sustainable Development Goals (SDGs 3, 11, and 13). Drawing upon physical air monitoring datasets from 2017 to 2025, socio-economic surveys across income strata, legal policy evaluations, and economic impact modelling, this paper provides an exhaustive diagnosis of Lahore's toxic atmosphere. During peak winter months, peak 1-minute AQI levels in Lahore have repeatedly exceeded 1,000 to 1,900, far surpassing international safety thresholds and reducing average life expectancy by an estimated 7.5 years. We demonstrate that public smog awareness acts as a critical institutional catalyst: without behavioral awareness and socio-economic equity in preventive practices, regulatory initiatives such as the 'Policy on Controlling Smog 2017' fail to achieve operational sustainability. Socio-economic stratification reveals severe climate health disparities, wherein low-income, non-science educated daily wage earners suffer disproportionate pulmonary, cardiovascular, and economic damage. The paper concludes with an actionable, inter-sectoral roadmap incorporating environmental diplomacy, and inclusive public health

INTRODUCTION

Background

Pakistan stands as the most rapidly urbanizing nation in South Asia, characterized by swift demographic shifts, unplanned urban sprawl, and hyper-dense industrial clusters (World Bank, 2021). At the epicenter of this urban expansion is Lahore, the historical and economic heart of Punjab, whose population has ballooned from

6.3 million in 1998 to over 13 million citizens today (GOP, 2017). Unmanaged urban development, coupled with high vehicular growth and agricultural stubble burning, has subjected Lahore to severe environmental degradation, transforming its historic reputation as the 'City of Gardens' into one of the world's most polluted megacities (Rana et al., 2020; IQAir, 2024).

Every year, between October and February, Lahore is engulfed in a thick, toxic blanket of photochemical smog—a complex atmospheric mixture composed of fine particulate matter (PM_{2.5} and PM₁₀), ground-level ozone (O₃), nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), and volatile organic compounds (VOCs) (EPD Punjab, 2017). This persistent crisis stems from a convergence of structural factors: a rapid increase in private motor vehicle ownership, unregulated industrial emissions, seasonal crop residue burning across regional agricultural belts, uncontrolled deforestation, and widespread dust from construction sites (Anjum et al., 2021; Ahmed & Rana, 2022).

Meteorological phenomena further aggravate this situation. During winter months, atmospheric thermal inversion layers trap heavy, cold air near the surface, preventing vertical dispersion of industrial and vehicular pollutants. Lahore's geographic location within the broader Indo-Gangetic Basin creates a bowl-like topographic trap, holding stagnant air masses in place for weeks (WHO, 2021; CREA, 2023). Peak daily AQI levels frequently exceed 400–600, with extreme localized spikes reaching hazardous thresholds above 1,000 to 1,900 on Mall Road and in outer industrial zones like Kot Lakhpat and DHA Phase 8 (Wikipedia, 2024; Global South Research, 2025).

While technical measurements quantify physical toxicity, public health outcomes and environmental sustainability depend heavily on public awareness, civic engagement, and institutional enforcement (Landrigan et al., 2018). Smog awareness is not merely an abstract metric; it directly shapes preventive behavior, public compliance with environmental mandates, political prioritization, and local adoption of sustainable urban practices (Rana et al., 2020). This paper critically examines the multi-dimensional relationships connecting public smog awareness, physical air quality dynamics, socio-economic equity, and urban sustainability frameworks in Lahore.

2. Conceptual Framework: Linking Awareness, Air Quality, and Sustainability

To understand the smog crisis in Lahore, environmental dynamics must be analyzed through an integrated socio-ecological systems framework. Air quality is directly influenced by human behavioral patterns and institutional policies, which are governed by public knowledge, risk perception, and socio-economic capabilities (Anjum et al., 2021). Figure 1 illustrates the functional relationship among the three pillars of this study.

2.1 Smog Awareness as an Institutional and Behavioral Driver

Public awareness serves as the primary mechanism through which citizen's transition from passive recipients of environmental degradation to active participants in pollution mitigation (Rana et al., 2020). High environmental literacy enables communities to:

- **Adopt Self-Protective Behaviors:** Using N95/KN95 respirators, installing HEPA air purifiers, and restricting vulnerable populations (children and elderly) from outdoor activity during extreme pollution warnings.
- **Modify Daily Urban Transport Choices:** Consolidating vehicular trips, utilizing public transit networks (e.g., Lahore Metrobus and Orange Line), reducing idling times, and eliminating non-essential weekend travel.
- **Demand Institutional Accountability:** Advocating for strict enforcement of industrial environmental regulations, transparent air quality reporting, and court-mandated environmental protections.

2.2 Ambient Air Quality Dynamics

Air quality represents the physical state of the atmospheric ecosystem. When atmospheric loading exceeds natural carrying capacities, hazardous particulate matter (PM_{2.5}) accumulates, directly degrading public health, reducing atmospheric visibility, and damaging agricultural output (WHO, 2021; CREA, 2023). Maintaining ambient PM_{2.5} levels within World Health Organization guidelines (annual mean $\leq 5 \mu\text{g}/\text{m}^3$; 24-hour mean $\leq 15 \mu\text{g}/\text{m}^3$) is a primary

ecological indicator of sustainable urban governance.

2.3 Sustainable Urban Development Goals (SDGs)

The urban sustainability framework links air quality management directly to the United Nations Sustainable Development Goals (SDGs):

- **SDG 3 (Good Health and Well-Being):** Target 3.9 aims to substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution.
- **SDG 11 (Sustainable Cities and Communities):** Target 11.6 focuses on reducing the adverse per capita environmental impact of cities, including special attention to municipal air quality management.
- **SDG 13 (Climate Action):** Target 13.2 requires integrating climate change and air

pollutant mitigation measures into national strategies, policies, and planning.

3. Air Quality and Meteorological Profile of Lahore (2017–2025)

Quantitative monitoring by the Punjab Environmental Protection Agency (EPD), private sensor networks (e.g., Pakistan Air Quality Initiative - PAQI), and global environmental monitors reveals a steady worsening of Lahore's air shed (IQAir, 2024; Weatherwalay, 2025).

3.1 Comparative Empirical Air Quality Metrics

Data collected across urban monitoring stations (including Mall Road, Gulberg, Kot Lakhpat, DHA, and Punjab University) demonstrates chronic exceedance of National Environmental Quality Standards (NEQS) and WHO guidelines throughout the winter smog season (October to February).

Year / Season	Average AQI	Peak 1-Min AQI	Average PM2.5 (µg/m³)	Days Exceeding WHO Limit
2017 (Nov)	285 (Unhealthy)	680 (Hazardous)	128.4	100%
2019 (Jan)	310 (Hazardous)	750 (Hazardous)	145.0	100%
2021 (Nov)	340 (Hazardous)	820 (Hazardous)	158.2	100%
2023 (Oct-Nov)	219 (Unhealthy)	775 (Hazardous)	142.0	99.96%
2024 (Oct-Nov)	237 (Unhealthy)	1,902 (Hazardous)	161.1	100.0%
2025 (Oct-Nov)	150 (Moderate-Unhealthy)	390 (Hazardous)	159.0	99.84%

As detailed in Table 1, October 2024 recorded the highest continuous concentration of PM2.5, averaging 161.1 µg/m³ more than 10 times the WHO 24-hour safety limit (Weatherwalay, 2025; Wikipedia, 2024). In early November 2024, localized monitor stations recorded unprecedented 1-minute AQI peaks of 1,902 on Mall Road and Samanabad, establishing Lahore as the most polluted urban center on Earth during that period (Al Jazeera, 2024; Wikipedia, 2024).

3.2 Anthropogenic and Meteorological Drivers
Lahore's high air pollution stems from an accumulation of local and regional anthropogenic emissions, compounded by seasonal weather conditions:

- **Vehicular Fleet Expansion:** Lahore's registered vehicular fleet has grown exponentially over the past two decades. Over 70% of vehicles utilize sub-standard fuel (Euro-II or lower grade) lacking modern emissions suppression systems such as catalytic converters (EPD Punjab, 2017). Heavy diesel trucks entering the city at night contribute disproportionately to primary black carbon emissions.
- **Unregulated Industrial Emissions:** Over 2,500 industrial units—including steel re-rolling mills, chemical processing plants, and traditional bull's trench brick kilns operating in and around Lahore combust low-grade rubber, waste tires, and high-sulfur furnace oil without scrubbers (Ahmed & Rana, 2022).
- **Agricultural Stubble Burning:** In October and November, rice farmers across Punjab (in both

- Pakistan and neighboring Indian states of Punjab and Haryana) clear crop residue by open burning. Satellite remote sensing (Sentinel-5P and MODIS) confirms transboundary smoke plumes crossing the border, accounting for 20% to 40% of peak seasonal PM2.5 loads (EPD Punjab, 2017; ResearchGate, 2025).
- **Thermal Inversion & Atmospheric Stagnation:** Cooler winter temperatures combined with low wind speeds (under 5–10 km/h) restrict horizontal air movement. Warm air layers sit above cold surface air, trapping emissions within a narrow atmospheric boundary layer under 100–150 meters (WHO, 2021).

4. Public Health Consequences and Socio-Economic Disparities

The public health consequences of Lahore's chronic smog crisis are severe, affecting bodily systems well beyond the respiratory tract and exacerbating socio-economic inequalities across the city.

4.1 Systemic Epidemiological Burden

Fine particulate matter (PM2.5) bypasses the upper airway filtration mechanics, penetrating deep into pulmonary alveoli and translocating directly into systemic circulation (Landrigan et al., 2018). Clinical hospital surveys across major Lahore medical institutions (Mayo Hospital, Jinnah Hospital, and Services Hospital) show significant surges in admissions during smog months (PJHS, 2025; Pak Heart Journal, 2024):

- **Respiratory Morbidity:** A 40% to 50% increase in acute upper/lower respiratory tract infections, severe asthma exacerbations, bronchitis, and chronic obstructive pulmonary disease (COPD) progression (Sana et al., 2019; Scribd, 2025).
- **Cardiovascular & Vascular Pathology:** Systemic vascular inflammation and oxidative stress cause marked elevations in both systolic and diastolic blood pressure among heavily exposed populations, including university students and outdoor workers (Anjum et al., 2021). Long-term exposure increases incidence rates of ischemic heart disease, stroke, and acute myocardial infarction (Pak Heart Journal, 2024).
- **Ophthalmic & Dermatological Distress:** High concentrations of atmospheric acid aerosols and volatile organic compounds cause widespread chemical conjunctivitis, ocular surface irritation, and allergic dermatological conditions (PJHS, 2025).
- **Life Expectancy Deficit:** According to the Energy Policy Institute at the University of Chicago (AQLI, 2023), sustained high particulate levels reduce average life expectancy for Lahore residents by approximately 7.5 years (CREA, 2023; Global South Research, 2025).

4.2 Socio-Economic Stratification and Environmental Justice

A central finding of this research is the pronounced socio-economic disparity in smog awareness, exposure risk, and adaptive capacity across Lahore's population:

Socio-Economic Class	Awareness Level	Primary Exposure Risk	Adoption of Preventive Measures	Economic Health Vulnerability
High-Income (Upper Class)	High (Scientific & Policy Literacy)	Low (Climate-controlled indoor living/working)	High (HEPA purifiers, N95 masks, private transport)	Low (Absorbed by comprehensive private healthcare)
Middle-Income (Working Class)	Moderate-High (Awareness of health risks)	Moderate (Daily commuting, public transit)	Moderate (Basic cloth/surgical masks, limited indoor filtration)	Moderate (High out-of-pocket medical expenses)

Low-Income (Daily Wage Earners)	Low-Moderate (Experiential awareness, low scientific)	Extreme (Occupational outdoor labor, informal housing)	Low (Minimal access to N95 masks or air purification)	Severe (Loss of daily wages, crippling medical debt)
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As outlined in Table 2, marginalized populations such as street vendors, construction workers, auto-rickshaw drivers, and traffic wardens—face disproportionate environmental hazards. While higher-income households can insulate themselves using indoor air purification and private transport, low-income daily wage earners lack the financial means and institutional support to mitigate their exposure (World Bank, 2021; Scribd, 2025).

5. Economic Valuation of Smog Impacts on Urban Sustainability

The economic costs of Lahore's chronic air pollution threaten the long-term financial viability and sustainable growth of Punjab's capital region. Air pollution imposes direct and indirect financial burdens that drag down regional gross domestic product (GDP) (Scribd, 2025; World Bank, 2021).

5.1 Sectoral Economic Losses

• **Healthcare Expenditures:** Out-of-pocket medical spending on emergency respiratory treatments, bronchodilators, antibiotics, and

cardiovascular admissions drains household savings, pushing low-income families below the poverty line (Scribd, 2025).

• **Labor Productivity Losses:** Worker productivity drops significantly during heavy smog weeks due to illness, increased absenteeism, and physical fatigue. Empirical economic models indicate worker productivity reductions between 20% and 45% during extreme smog events (Scribd, 2025; CREA, 2023).

• **Agricultural Yield Penalties:** Ground-level ozone and fine particulate deposition (black carbon) reduce photosynthetic activity in surrounding peri-urban farming belts. Rice, wheat, and vegetable yields in the Lahore division experience reductions between 12% and 25%, contributing to urban food price inflation (Scribd, 2025).

• **Commercial and Educational Disruption:** Frequent emergency closures of schools, markets, commercial centers, and outdoor leisure facilities interrupt retail trade, service sectors, and educational delivery (Al Jazeera, 2024; Wikipedia, 2024).

Economic Sector	Primary Impact Mechanism	Estimated Productivity / Output Reduction	Long-Term Sustainability Threat
Public Health	Surge in acute respiratory/cardiac care	15% - 25% increase in household health budget	Depletion of human capital & strain on hospitals
Industrial & Labor	Worker absenteeism & reduced stamina	20% - 45% decrease in worker efficiency	Declining industrial competitiveness
Agriculture	Ozone toxicity & reduced photosynthesis	12% - 25% reduction in crop yields (wheat/rice)	Food insecurity & rural-urban migration
Transportation & Trade	Logistical delays, low visibility, accidents	50% - 75% increase in transit disruptions	Supply chain paralysis & trade bottlenecks

6. Comprehensive Evaluation of Policy and Governance Frameworks

Pakistan's legislative framework for environmental protection includes federal and provincial enactments, most notably the Punjab

Environmental Protection Act 1997 (amended 2012). However, structural gaps between legislative intent and on-the-ground enforcement persist (Pak-EPA, 2010; EPD Punjab, 2017).

6.1 Analysis of the 'Policy on Controlling Smog 2017'

In response to judicial pressure and public outcry, the Environment Protection Department of Punjab introduced the landmark “Policy on

Controlling Smog 2017” (EPD Punjab, 2017). The policy established an ambitious multi-sectoral strategy focused on Lahore. Table 4 systematically evaluates the implementation status and ongoing challenges of its core pillars.

Policy Intervention Pillar	Mandated Target Strategy	Current Implementation Status (2021-2025)	Key Operational Challenges
1. Euro-II Standard Enforcement	Mandate fuel quality standards & low-emission transit	Partial (Fuel imported, but sub-standard diesel persists)	Lack of fuel testing laboratories & border checks
2. Vehicular Emission Devices	Install catalytic converters & smog inspection	Low (Unregulated private & heavy commercial fleet)	Weak inspection infrastructure & corruption
3. Traffic Management	Remove encroachments & streamline traffic flow	Moderate (SPS squads formed, localized clearings)	Rapid growth in motorbikes and auto-rickshaws
4. Waste & Crop Burning Ban	Enforce legal bans under Section 144 on stubble burning	Moderate-High (Fines imposed, satellite tracking)	High cost of mechanized harvesters (Happy Seeder)
5. Air Monitoring Network	Expand AQI monitoring stations across Punjab	Moderate (New monitors added, open data increased)	Sparse coverage in industrial zones; calibration gaps
6. Urban Woodland Creation	Afforestation and urban forest green belts	Moderate (Miyawaki forest initiatives launched)	Land scarcity, urban real estate pressure
7. Fugitive Dust Control	Water sprinkling on roads & construction guidelines	Low-Moderate (Intermittent spraying during emergencies)	Lack of enforced construction dust barriers
8. Planned Urban Zoning	Separate industrial hubs from residential areas	Low (Unchecked urban sprawl into peri-urban zones)	Weak master planning enforcement
9. Greening Industrial Processes	Convert brick kilns to Zig-Zag technology	High (~96% traditional kilns converted or halted)	High operational costs for small kiln operators
10. Regional Diplomacy	Transboundary talks with India on crop burning	Stalled (Geopolitical tensions hinder formal talks)	Lack of active cross-border environmental treaties

While progress has been achieved in converting traditional brick kilns to cleaner Zig-Zag technology (~96% compliance rate across Punjab) (ResearchGate, 2025), enforcement across the transportation sector, construction dust control, and transboundary diplomacy remains inconsistent (European Commission, 2020; WHO, 2021).

7. Strategic Recommendations for Sustainable Urban Governance

Transitioning Lahore from a state of seasonal environmental crisis toward long-term urban sustainability requires an integrated approach that connects technical controls, public awareness, and inclusive equity:

7.1 Accelerating Clean Fuel and Transit Transitions

- **Mandatory Euro-VI Fuel Standards:** Phase out Euro-II fuel imports entirely and enforce Euro-VI fuel specifications nationwide alongside strict emission limits for heavy diesel vehicles (EPD Punjab, 2017).
- **Electrification of Urban Public Transport:** Accelerate the transition of Lahore's public bus fleet and auto-rickshaws to electric power (EVs), supported by subsidized charging infrastructure (Rana et al., 2020).

7.2 Community-Centered Awareness and Health Equity

- **Tailored Awareness Campaigns for Vulnerable Groups:** Environmental protection agencies must design non-technical, audio-visual, and vernacular educational content tailored for low-literacy daily wage workers, outdoor laborers, and school children.
- **Public Mask Distribution Programs:** Establish municipal programs to distribute free or subsidized high-filtration respirators (N95/KN95) to vulnerable outdoor workers during high-AQI alerts (PJHS, 2025).

7.3 Nature-Based Solutions and Urban Greening

- **Aggressive Afforestation and Canopy Targets:** Expand the deployment of dense urban forests (Miyawaki method) along green belts, industrial buffers, and highway corridors to trap fine particulates and reduce urban heat island effects (PJHS, 2025).
- **Dust Control Mandates:** Enforce strict construction site dust suppression standards, requiring wet suppression, perimeter barriers, and covered transportation of loose construction material.

7.4 Transboundary Environmental Diplomacy

- **Regional Air Quality Management Frameworks:** Establish a formal joint environmental dialogue between Pakistan and India under ASEAN-style regional pollution treaties to coordinate satellite monitoring, harmonize agricultural residue management, and

address transboundary emissions (ResearchGate, 2025).

8. Conclusion

The seasonal smog crisis in Lahore represents an urgent environmental, public health, and economic challenge that threatens the long-term sustainability of Punjab's capital city. Addressing this challenge requires moving beyond emergency, reactive measures such as short-term school closures and temporary traffic bans—toward sustained structural reforms. This research highlights the vital role of public smog awareness as a key driver of environmental compliance and health equity. Public awareness campaigns must be combined with technical enforcement, clean transit investments, urban forest protection, and socio-economic support for vulnerable populations. By aligning local air quality policies with the United Nations Sustainable Development Goals (SDGs 3, 11, and 13), Lahore can mitigate its toxic seasonal smog, protect public health, and rebuild its historic legacy as a green, resilient, and sustainable city.

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