Air Pollution in Urban Pakistan: Understanding, Sources, Differences and Similarities of Pollution

Umama Sumair [1] Dr. Syed Raghab Ali [2] Abbas Rashid Butt [3]

[1] Research Fellow, Lahore Institute for Research and Analysis, Lahore, Pakistan.

[2] Executive Director, Lahore Institute for Research and Analysis, Lahore, Pakistan.
Email: raghab.ali@lira.uol.edu.pk

[3] Research Fellow, Lahore Institute for Research and Analysis, Lahore, Pakistan.
Email: abbas.rashid@lira.uol.edu.pk

Corresponding Author: umama.sumair@lira.uol.edu.pk

ABSTRACT

This study investigates the persistent air pollution issues in the urban centers of Pakistan, specifically Lahore, Karachi, and Islamabad, examining the key sources, socio-environmental impacts, and mitigation strategies. It highlights the major contributors to pollution, such as vehicular emissions, industrial pollutants, and crop residue burning, with a particular focus on seasonal variations like winter smog. By utilizing a mixed-method approach, the study analyzes air quality data, health statistics, and policy effectiveness. Theoretical frameworks of Ecological Modernization Theory (EMT) and Political Ecology are applied to offer a comprehensive view of the problem, focusing on technological solutions, institutional reforms, and the socio-political dynamics of pollution. The findings underscore the need for region-specific mitigation measures, better enforcement of environmental regulations, and public awareness campaigns. This research contributes to understanding the similarities and differences in pollution across the three cities and proposes evidence-based approaches for improving air quality, including the adoption of electric vehicles, clean energy, and improved public transportation.

1. Introduction

In Pakistan, polluted air is a big concern in urban cities as it stands in line; one of the major issues being both an environmental one, a public health issue, and a cause for concern on the economic front. It is one of the worst polluted countries globally, with cities like Lahore and Karachi, Islamabad consistently being some of the cities with hazardous Air Quality Index (AQI) levels far beyond WHO indication limits. WHO states that PM2.5 should be maintained at an annual average of 5 µg/m³, but peaks during pollution seasons in Pakistan quite often surpass this guideline and go far above 150 µg/m³. This chronic air quality crisis further deteriorates in winter, as smog reduces visibility and disrupts daily life; it creates a health scare for millions (WHO, 2023). According to recent studies of Jion et al. (2023) and Liu et al. (2024), the pollution crisis has reached a point where it has been attributed to various factors, including rapid urbanization, unregulated industrial activity, vehicles, unsustainable agricultural practices, and many others. In the last two decades, major cities have witnessed tremendous population growth and industrial development.

Looking at an example: between the years 2000 and 2023, the urban population density in Karachi hiked by more than 40% (Aimun, 2024). This has led to increased construction activities and the energy demanded. However, the price for development paid is for environmental sustainability. Industrial emissions, particularly sulfur dioxide (SO2) and nitrogen oxides (NOx), are major contributors to worsening air quality (Hussein et al., 2024; Sun et al., 20234).

Transportation still plays a major role in contributing urban air pollution in Pakistan. Inefficient and non-modern vehicles with low-quality fuels contribute hence significant amounts of carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM) (Mahato et al., 2024). Pakistan has a Euro-V fuel standard, which was adopted in 2020; the process of implementation has, however, been slow, with urban conurbations congesting with old vehicles lacking appropriate emission controls. Additionally, during the winter months, Punjab and Sindh undergo seasonal burning of crop residues, compounding further air pollution. The major black carbon and PM2.5 components from burning stubble release into the atmosphere, merging with emissions from urban centers to produce very thick smog layers hovering over cities, severely degrading air quality.

The situation is made worse by weak legislation and poor enforcement in the country. Pakistan doesn't currently have adequate provisions for running a sound, comprehensive, air quality monitoring body, and strict pollution control law implementations. Also, corrupt and inefficient bureaucracy impedes policies implementation (Ehtasham et al., 2022). Seasonal differences influence all of this; in particular, it presents during winter when a temperature inversion traps pollutants close to the ground, resulting in a dangerous cocktail of industrial effluent, moves from cars, and smoke from agricultural burning. This results in persistent smog. Lahore suffers the most; AQI levels often exceed 500 in the November-December period, posing dire health risks.

The report on the Global Burden of Disease estimates over 128,000 premature deaths in Pakistan each year due to air pollution (Murray, 2022). Respiratory diseases, cardiovascular diseases, and chronic obstructive pulmonary disease, especially among vulnerable groups like children and the elderly. Economic loss due to air pollution in Pakistan is estimated at a staggering 6% of GDP annually- to be precise accounting for healthcare costs, losses due to lower productivity, and the reduced agricultural yield from soil degradation. Environmental impacts mostly include acid rains formed from pollutants like sulfur dioxide (SO2) and nitrogen oxides (NOx) that cause damage throughout ecosystems, water bodies, and crops. These would also include high stack concentrations of black carbon and PM2.5 that decrease hence reducing the entrance of solar radiation which could have otherwise worked against renewable energy initiatives.

Of course, air pollution has become transnational for Pakistan, and therefore it requires cooperation at regional and international levels to address this burning issue. The study, thus, attempts to provide an in-depth account of air pollution in Lahore, Karachi, and Islamabad, identifying the widest causes, health, and environmental impacts, and the level of effectiveness of measures that have been put in place for mitigation. With a more comparative approach, it depicts the peculiarities as well as some commonalities that these metropolitan cities grapple with, throwing some lights on the more generalized air pollution scenario of Pakistan.

It argues evidence-based policymaking and stresses regional cooperation too in handling an issue of serious concern. It relates air pollution causes and effects, thus supplementing the discourse around environmental sustainability and public health within Pakistan to which it belongs. This research may become a guide for policymakers, environmentalists, and other stakeholders as to what actions to be put in place as a means of fighting against the effects induced by air pollution. For fostering a more sustainable and healthier future for urban Pakistan, the air must be clean.

1.1 Statement of the Problem

Air pollution in urban centers of Pakistan, particularly Lahore, Karachi, and Islamabad, has reached alarming levels, posing severe health and environmental risks. The major pollutants, including PM2.5, NOx, SO2, and CO, frequently exceed both national and WHO air quality standards, leading to a significant burden on public health. Despite various efforts, including tree planting initiatives and air quality monitoring, the country's poor infrastructure, weak regulatory enforcement, and lack of public awareness continue to exacerbate the situation. Addressing these challenges requires a deeper understanding of the sources, impacts, and effectiveness of current mitigation strategies to formulate more sustainable and region-specific solutions.

1.2 Significance of the Study

The study provides the analysis of the sources, health impacts, and policy effectiveness concerning air pollution in urban Pakistan. By focusing on major cities such as Lahore, Karachi, and Islamabad, the study aims to offer actionable insights into the specific pollutants and their socio-environmental consequences. It also evaluates the effectiveness of existing policies and suggests improvements, contributing to the development of evidence-based approaches that could mitigate air pollution. The findings will be crucial for policymakers, urban planners, and public health authorities in implementing effective measures to improve air quality and protect public health.

1.3 Objectives of the Study

To identify and analyze the major sources of air pollution in urban centers of Pakistan, focusing on vehicular emissions, industrial pollutants, and biomass burning, with a particular emphasis on seasonal variations like winter smog.

To assess the health impacts of air pollution in urban Pakistan, specifically evaluating the prevalence of respiratory diseases, cardiovascular issues, and other health complications associated with high pollutant concentrations.

To evaluate the effectiveness of current air quality policies and mitigation strategies in Pakistan, and propose recommendations for strengthening enforcement mechanisms, promoting clean technologies, and improving public awareness.

1.4 Research Questions

RQ1: What are the primary sources of air pollution in urban centers of Pakistan, and how do seasonal variations like winter smog influence pollutant concentrations?

RQ2: What are the health impacts of air pollution in Pakistani urban areas, particularly in terms of respiratory and cardiovascular diseases?

RQ3: How effective are current policies and mitigation strategies in reducing air pollution in Pakistan's urban centers, and what additional measures could be implemented to address this issue?

2. Literature Review

Air pollution in urban centers of Pakistan has become a critical issue, with severe implications for public health and the environment. According to Anjum et al. (2021), particulate matter (PM), especially PM2.5, is one of the major pollutants in cities like Lahore, where levels frequently exceed both national and World Health Organization (WHO) air quality standards. The World Bank estimates that outdoor air pollution in Pakistan causes about 22,000 premature deaths annually, with a significant loss in disability-adjusted life years (DALYs). This study highlights the inadequate air quality monitoring infrastructure and weak regulatory enforcement as key challenges in addressing air pollution. It recommends the use of flexible monitoring technologies, better involvement of policymakers, and enhanced stakeholder participation to improve air quality management in the country.

The smog crisis, particularly in Lahore, has become another pressing concern. Nasar-u-Minallah et al. (2024) identify the key contributors to smog, such as PM2.5, PM10, and other gaseous pollutants like NO2, SO2, and CO, which have worsened in the last decade. The health risks associated with smog are alarming, ranging from respiratory diseases (e.g., asthma, COPD) to cardiovascular issues (e.g., heart attacks and hypertension). The study suggests that a combination of nature-based solutions, transportation reforms, industrial regulations, and public awareness programs are necessary to mitigate the smog problem. Furthermore, transboundary pollution and regional cooperation with neighboring countries are critical for addressing this cross-border issue effectively.

Siddique et al. (2023) also emphasize the critical role of vehicular and industrial emissions in contributing to the growing smog in urban Pakistan. The authors argue that public awareness programs, stricter emissions controls, promotion of public transport, and the adoption of clean energy solutions are essential for reducing pollution levels. Despite initiatives like the Billion Tree Tsunami, implementation remains insufficient, largely due to poor law enforcement, inadequate infrastructure, and a high dependence on private vehicles. They call for enhanced coordination between authorities and citizens to integrate technology, behavioral changes, and stronger policy frameworks to create a sustainable urban environment.

In addition to outdoor pollution, indoor air quality (IAQ) in Pakistan is a significant concern, particularly in rural areas where biomass fuels are commonly used, and in urban settings with poor ventilation. Kausar et al. (2023) report that indoor air pollution, fueled by biomass, tobacco smoke, and other domestic sources, poses serious health risks. High levels of particulate matter (PM) and other pollutants like COx, dust, and bioaerosols are common, leading to respiratory diseases, cancers, and infections. The study calls for better implementation of IAQ management strategies and coordination between industries, academia, and government bodies to address the challenges in managing indoor air quality and protect public health. In urban areas, the rise in brick production and the resulting emissions of harmful pollutants from traditional kilns further exacerbate air pollution, leading to additional health and environmental concerns (Khan et al., 2019).
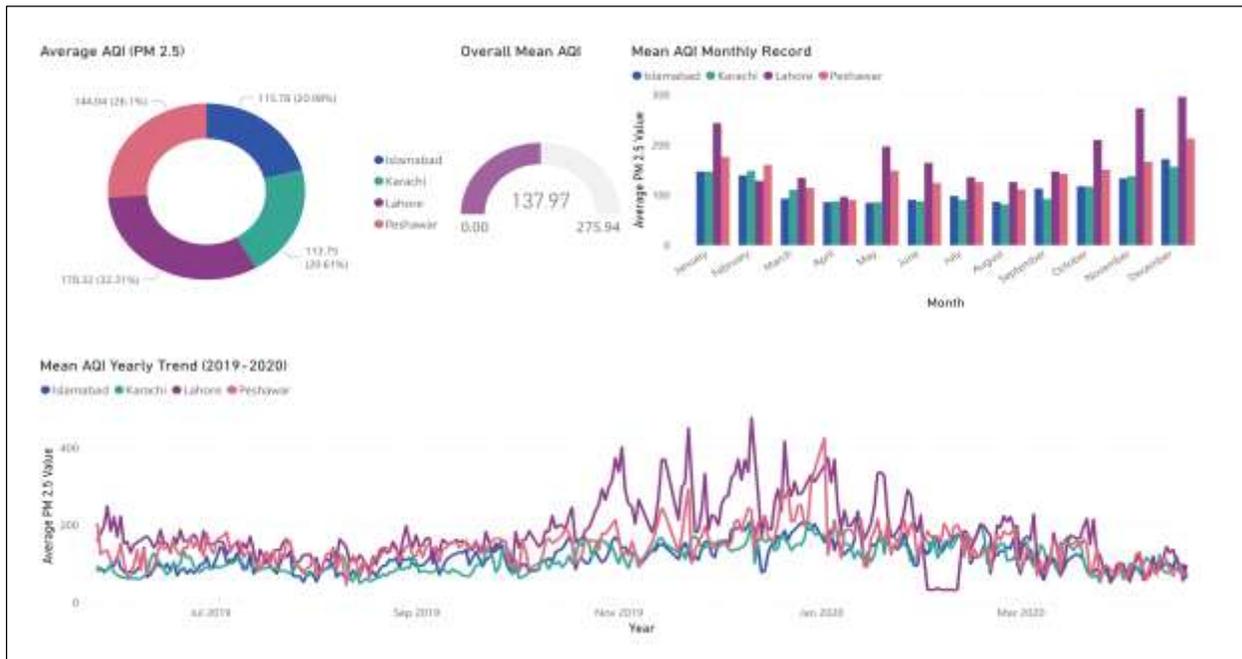
Figure 1: *Visualizing Air Quality Index (Open Data Pakistan, 2024)*

Figure 2: *City Wise Air Quality Ranking of Cities in Pakistan (IQAir, 2024)*

3. Theoretical Perspective

Analyzing air pollution in Pakistan's urban centers within EMT (Ecological Modernization theory) and Political Ecology would offer a well-balanced and comprehensive perspective on this issue.

Forward-looking from EMT stands on three fundamental perspectives: technological development, reform of institutions, and mechanisms based on market forces which address environmental problems. This view is consistent with the research focus on the solutions such as adopting electric vehicles, shifting to clean energy, and zig-zag kiln technology for brick-making. EMT puts an emphasis on innovation and policy reform, which makes it an ideal framework for analyzing causes and solutions to urban air pollution (Hanf, 2003).

Meanwhile, Political Ecology provides supplementation to EMT through considerations of socio-political and economic aspects in formulating a framework of factors influencing environmental crisis. Such an angle explores governance failure as one significant source of pollution persistence together with lopsided distribution of resources and foreign power influence. Such issues about Pakistan include weaknesses in terms of enforcing policies and trans-boundary regional pollution along the Indo-Gangetic Plain besides such socio-economic gaps that lead to a widening impact on vulnerable segments. Together, these frameworks provide a holistic lens: EMT pushes towards actionable solutions, while Political Ecology provides a critical examination of systemic barriers. In this integration, air pollution's complexities are understood better, leading to more effective and equitable strategies for mitigation (Hanf, 2003).

4. Methods

4.1. Data Collection

This research study analyzes air pollution trends and impacts using a mixed-method approach throughout Lahore, Karachi, and Islamabad.

4.2. Air quality data

It encompasses WAQI, Pakistan EPA, and local air quality monitoring stations.

4.3. Health statistics

Data on respiratory and cardiovascular diseases from the National Institute of Health (NIH) and local hospitals.

4.4. Policy analysis

Analysis of ministry reports and environmental regulations by the Ministry of Climate Change.

4.5. Comparative Structure

Quantitative comparison of AQI levels, concentration of PM2.5 and PM10, and vehicular density. This qualitative analysis will involve policy implementation, public awareness, and socio-economic factors. Case Studies: Lahore's smog crisis, industrial emissions of Karachi, and Islamabad urban construction impacts are drawn out as cases in examining the unique challenges and solutions.

5. Results & Findings

5.1. Causes of Air Pollution in Pakistan's Urban Areas

Air pollution in Pakistan's urban centers is a complex phenomenon, driven by multiple interrelated factors that exacerbate environmental degradation and public health risks. Among the major contributors are vehicular emissions, industrial pollution, and agricultural practices, particularly crop residue burning. This section provides an in-depth exploration of these causes, supported by studies and reports from national and international sources.

5.2. Vehicular Emissions

Transportation sector represents a significant emission source of air pollutants in Pakistan contributing the major share in the city's air pollution constituents that comprises of particulate matters (PM2.5 and PM10), nitrogen oxides (NO), carbon monoxide (CO) and volatile organic compounds. All this gets worse due to the significant number of outdated under-maintained vehicles as well as their consumption of poor grade fuel (Slater et.al, 2024).

The outdated vehicles do not have modern technologies for controlling emissions, which means that more pollutants are released into the atmosphere. For example, in Pakistan, Air Quality Monitoring Network reported that older than 20 years' vehicles have higher pollutants in proportion than newer models, even when catalytic converters are installed. The burning of low-grade fuels with high sulfur content exacerbates air pollution. According to a report by the World Bank, Pakistan's dependence on substandard fuels delays the introduction of cleaner technologies, thereby extending the period of environmental damage. While Pakistan has implemented Euro-V fuel standards since 2020, the transition is slow, and the adoption is limited to major cities traffic and Congestion. The rapid growth of cities, coupled with bad public transport systems, has caused the extreme traffic congestion of cities like Karachi, Lahore, and Islamabad. The idling for long periods and stop-and-go traffic increases emissions per kilometer traveled manifolds. Karachi is Pakistan's largest city, with over 4 million registered vehicles-many of which are two-stroke engines known for high emissions.

These cities are facing similar problems with growing vehicle ownership and scarce road infrastructure. According to a study by Asian Development Bank (ADB), emissions from traffic in these cities contribute more than 35% of total urban air pollution. The government has been implementing several measures to address vehicular emissions, which include; the introduction of Euro-IV and Euro-V fuels, which have lesser sulphur content, is a step towards cleaner emissions. Despite that, there are issues such as weak oversight from regulatory agencies about enforcement.

The Electric Vehicles Pakistan's EV policy increases its target to reach 30% electric vehicles by 2030. Although it seems promising, this policy's influence is only felt when costs are more and with inadequate charging infrastructure (Asim et al., 2022).

5.3 Unregulated Industrial Emissions & Industrial Growth

Principal areas of industrialization in an urban setting are Karachi, Lahore, and others as are now common occurrences have placed a significant burden on national capitals owing to the generation of unacceptably high levels of SO2, NOx, and fine particulates by power plants, brick kilns, and commercial units. The Korangi and SITE industrial zones (Sindh Industrial Trading Estate) of Karachi harbor around thousands of factories that continue to emit pollutants directly. Small- and medium-sized enterprises in Lahore largely emit, mostly during the winter months when all the industries go on peak performance (Idrees et al., 2023).

5.4 Lack of Environmental Regulations and Enforcement

In fact, even with laws controlling pollution under the Pakistan Environmental Protection Act 1997, enforcement has been very weak due to lack of resources and institutional inefficiency, which goes along with systemic corruption. Pakistan EPA cannot monitor emissions process regularly. Only some dozen air-quality monitoring stations run continuously in Karachi and Lahore. Many industries do not use pollution control devices like scrubbers or filters, attributing the high costs and lack of enforcement to non-compliance. Measures initiated for reducing industrial pollution that also promotes cleaner brick kiln technologies and promotes the

consumption of alternative fuels, in which the effort yet finds little scale as such practices hold significant financial and logistical barriers.

5.5 Crop Burning in Agricultural Practices

The major sources of air pollution in Pakistan's urban areas include seasonal burning of agricultural residues, especially in Punjab and Sindh. In the crop harvesting seasons, farmers burn the leftover crop stubble to clear the fields for the next planting cycle. This burns off huge quantities of PM2.5, black carbon, and other pollutants into the atmosphere. It hosts most of the agricultural fields in Pakistan, where the farm waste is seen on massive scale during the months of October and November, contributing towards smoke covering Lahore and its other regions. Whereas in this province, this activity occurs on a very small scale, and due to these small-scale instances, smoke contributes to the local level smog, mostly around Karachi.

Crop burning is an important reason for the heavy smoke seen in cities during the winter. It is a toxic combination of agricultural, industrial emissions and vehicular smoke. Crop burning emission accounts for respiratory sickness, the UNEP (United Nations Environmental Program) report concludes. Most victims are either children or aged people among the vulnerable lot. The provincial governments have also tried to educate the farmers of this malignancy in Punjab. Technologies such as "Happy Seeder", which does not burn residue, are promoted but the adoption rate is low due to the heavy price tag and lack of subsidy provision among the farmers (Mooventhan et al., 2018).

5.6 Impact of Air Pollution

5.6.1 Respiratory and Cardiovascular Diseases

One of the major causes of serious health problems in Pakistan is air pollution. Air pollutants such as particulate matter (PM2.5 and PM10), ozone, NOx, and SO2 cause short-term or chronic health effects. Air pollutants irritate the airways to cause inflammation and make existing conditions worse, for example, asthma, bronchitis, and chronic obstructive pulmonary disease, COPD. A 2023 NIH study in Pakistan found that the Lahore hospitals admitted 30% more patients suffering from respiratory diseases during peak pollution seasons. PM2.5 goes all the way down into the lungs and reaches the bloodstream, causing systemic inflammation, leading to heart attacks, strokes, and hypertension. The WHO (2022) has established a link between cardiovascular mortality rates in South Asia and the extended period of exposure to high levels of pollution.

Exposure to bad air for long periods can stunt lung development in children, and asthma has become rampant. UNICEF 2023 states that, of the children in urban Pakistan, three times are more susceptible to respiratory infections than children in rural areas. Risks are also increased to the older adults with chronic diseases during peaks of pollution. As reported by the Journal of Environmental Science and Health in 2022, there has been a sharp rise in mortality from heart diseases during smog events.

Air pollution takes a heavy toll on Pakistan's economy due to increasing healthcare costs. According to a World Bank (2023) report, the treatment of illnesses related to pollution costs Pakistan nearly $1.5 billion annually. Government hospitals in Lahore and Karachi are frequently running over capacity during smog seasons, with large resources dedicated to the treatment of respiratory and cardiovascular conditions, which takes away from other healthcare needs. Air pollution lowers worker productivity, thus lowering economic output. Construction workers, traffic police, and agricultural laborers suffer from shorter working hours due to heavy pollution.

According to the Asian Development Bank (ADB), in a 2022 report, it was observed that urban Pakistan outdoor productivity decreased by 20% during winter months because of pollution. School closures are quite common in Lahore and Karachi because of poor air quality during winter smog, which disrupts education and creates problems for working parents.

5.6.2 Environmental Impact

It disturbs ecosystems by contaminating the sources of water, air, and land. SO2 and NOx change the pH balance in the soil, which ultimately diminishes its fertility. The land of Punjab has witnessed losses in crop yields. A UNEP research report in 2021 reveals that crop yields declined by 8%. Acid rain, which arises as a result of sulfur and nitrogen compounds deposition, injures aquatic ecosystems by diluting the pH level of the water and killing the fishes. Urban air pollution is a source of climate change since it emits black carbon and greenhouse gases. Black carbon on the Himalayan glaciers reduces its albedo, which melts fast. This endangers the Indus River Basin water supply, which quenches millions. The increase in the concentration of aerosols intensifies monsoonal variability, causing floods that recently occurred, such as the massive flooding of 2022, forcing millions of people out.

5.7 Comparative Analysis: A Missing Perspective on Urban Air Pollution in Lahore, Karachi, and Islamabad

Urban air pollution in Pakistan has been widely studied, but there is a lack of comparative analysis between major cities such as Lahore, Karachi, and Islamabad. The socio-economic, geographical, and industrial profiles of each city make the sources and impacts of air pollution unique to that city. For example, agricultural burning in the surrounding regions heavily influences Lahore's smog crisis, whereas Karachi's pollution is dominated by industrial emissions and port activities. Islamabad faces pollution despite its relatively low industrial activity because of rapid urbanization and construction dust.

The existing studies examine these cities in isolation based on a specific pollutant or source or mitigation strategy. A comparative approach would enable an in-depth understanding of how regional differences contribute to the severity and type of air pollution. This knowledge will be useful in tailoring policies to the unique challenge faced by each city. For example, whereas Lahore may require tougher laws on agricultural residue burning, Karachi may require reforms in industrial zoning and cleaner port operations. Islamabad could target the regulations on construction and the greenery of the cities. Comparative studies would highlight common challenges, such as vehicular emissions, and help policymakers implement standardized national-level interventions while maintaining city-specific strategies. Without such research, policymakers would be likely to follow a one-size-fits-all policy that might not address effectively the pollution dynamics of every city.

Table: 1

Comparative Analysis of Air Pollution in Urban Centers

Category	Lahore	Karachi	Islamabad
Primary Sources of Pollution	Crop residue burning, vehicular emissions, brick kilns	Industrial activities, port operations, vehicular emissions	Urban sprawl, construction dust, vehicular emissions
AQI Levels	Often exceeds 300 during winter (smog episodes)	Consistently high, varying with industrial output	Increasing but relatively lower than Lahore and Karachi
Major Pollutants	PM2.5, PM10, CO, SO2	PM2.5, NO2, SO2, CO	PM2.5, PM10, construction dust
Seasonal Variation	Severe in winter due to smog	Consistent year-round	Peaks in dry seasons due to dust
Health Impacts	High prevalence of respiratory diseases, eye irritation, cardiovascular issues	Chronic respiratory issues, industrial worker health risks	Rising respiratory illnesses, reduced lung capacity
Economic Impact	Reduced agricultural productivity, increased healthcare costs	Industrial inefficiencies, healthcare burden	Increased healthcare spending, property value impacts
Policy Effectiveness	Limited implementation of anti-smog regulations	Weak enforcement of industrial emission controls	Developing regulations but gaps in enforcement
Mitigation Efforts	Anti-smog squads, vehicular emission checks	Limited industrial regulations, occasional vehicle checks	Urban greening initiatives, restricted construction activities
Recommendations	Shift to cleaner brick kiln technology, enhance public transport	Upgrade industrial technologies, stricter port regulations	Expand urban greenery, improve public transport infrastructure

The table 1 provides a clear comparison of the critical factors contributing to air pollution in each city, helping identify targeted solutions.

6. Discussion

6.1 Policy Evaluation: Assessing Effectiveness and Implementation Challenges

Air quality management policies in Pakistan are mostly idealistic but not critically evaluated to understand what works and what does not work. National frameworks like Pakistan Environmental

Protection Act and city-wise initiatives such as anti-smog measures in Lahore provide a framework for mitigation measures, but the success thereof is not well-explored. Most literature, while providing policy recommendations, does not critically examine why current regulations are not successful and where they are deficient. For example, Lahore's smog-reducing strategies of anti-smog squads and restriction on brick kilns are not very successful. Very little research is available in the form of quantifying their impact on air quality indices. Karachi's industrial emission control measures and Islamabad's urban greening initiatives have never been evaluated in depth. The policymaker does not have tangible evidence to hone these policies.

Another major gap that needs to be addressed is that of enforcement. Policies in Pakistan frequently fail because of poor implementation mechanisms, corruption, and the lack of coordination among the governmental agencies. Such systemic issues are rarely dealt with or even proposed actionable solutions to strengthen enforcement. Additionally, there is a very limited engagement with public perceptions and compliance, which are the very essence for any policy's success. Finding out how citizens perceive and comply with air quality regulations might help provide interesting insights into designing more effective interventions.

6.2 Economic Impacts: A Neglected Dimension of Air Pollution

Although the health effects of air pollution are well documented in Pakistan, research on its economic impacts remains very limited. Air pollution has very significant economic costs; it increases productivity loss, health care spending, and long-term economic growth. For example, poor air quality results in loss of workdays, productivity loss in labor, and increased healthcare spending related to the increased incidence of respiratory and cardiovascular diseases. Other countries have measured the impacts. Studies have shown that air pollution in most countries outweighs the cost of the mitigation measures. This study does not measure the same in Pakistan, though efforts are minimal to calculate these costs comprehensively. These include agricultural losses due to smog over Lahore, industrial inefficiency for which Karachi suffers presently due to lack of regulations over emissions, and the decreased property values in polluted areas of Islamabad.

There is also a lack of study on the economic benefits of cleaner air. Investment in the quality of air can bring about significant economic payback through increased productivity, lower healthcare costs, and better quality of life. Policymakers need to know this information to justify investments in air pollution control measures. Without a clear understanding of the economic stakes, air quality management will likely continue to be neglected for more pressing economic concerns such as industrial growth.

6.3 Longitudinal Studies: Understanding Trends and Predicting Future Scenarios

Most of the research done about air pollution in Pakistan represents a snapshot of current conditions, focusing on pollutants or short-term episodes such as Lahore's winter smog. Although these studies are very important and useful, they cannot catch long-term trends and what those changes mean for future air quality. Longitudinal studies are necessary to understand how air pollution progresses over time and which of the factors that have produced these changes. For instance, the long-term study of vehicular emissions in Karachi could establish how trends in vehicle ownership, fuel quality, and traffic patterns contribute to the increasing pollution levels. The historical impact of urbanization on air quality in Islamabad can be studied to know whether future development would intensify pollution. In Lahore, studying the effectiveness of anti-smog measures over multiple years would clearly establish their long-term impacts.

Longitudinal studies also aid in predictive modeling, critical for proactive policy planning. Tools like the ARIMA model enable the projection of future levels of pollution as a function of past records, helping policymakers anticipate evolving threats and develop interventions before things become a crisis. It is rare in the Pakistani context to have predictive studies that thus leave policymakers without preparation for possible future challenges.

6.4 The Way Forward: Bridging the Gaps

There is a need for concerted effort from researchers, policymakers, and funding agencies to address these gaps. Comparative studies should be prioritized to provide a holistic understanding of air pollution dynamics across major cities. Evaluations of policies should be outcomes based, but also barriers to implementation, such as institutional weaknesses and public non-compliance. Economic impact studies should have interdisciplinary approaches that integrate environmental science, economics, and public health to give comprehensive cost-benefit analyses. Longitudinal research should draw on advanced modeling techniques and long-term datasets to project future scenarios and guide sustainable urban development.

These goals can be achieved only through collaboration. The researchers work with government agencies, international organizations, and local communities to generate actionable insights. Funding for air pollution research must be increased, especially in areas such as economic impacts and longitudinal trends. Public awareness campaigns will play a significant role in bridging the gap between scientific research and policy implementation, thereby making air quality management a national priority. This detailed analysis underscores the critical gaps in existing literature on urban air pollution in Pakistan and highlights the steps needed to address them effectively. Through filling these gaps, researchers and policymakers can work together to develop targeted, evidence-based strategies that improve air quality and public health across the country.

7. Conclusion

There is a need for concerted effort from researchers, policymakers, and funding agencies to address these gaps. Comparative studies should be prioritized to provide a holistic understanding of air pollution dynamics across major cities. Evaluations of policies should be outcomes based, but also barriers to implementation, such as institutional weaknesses and public non-compliance. Economic impact studies should have interdisciplinary approaches that integrate environmental science, economics, and public health to give comprehensive cost-benefit analyses. Longitudinal research should draw on advanced modeling techniques and long-term datasets to project future scenarios and guide sustainable urban development.

These goals can be achieved only through collaboration. The researchers work with government agencies, international organizations, and local communities to generate actionable insights. Funding for air pollution research must be increased, especially in areas such as economic impacts and longitudinal trends. Public awareness campaigns will play a significant role in bridging the gap between scientific research and policy implementation, thereby making air quality management a national priority. This detailed analysis underscores the critical gaps in existing literature on urban air pollution in Pakistan and highlights the steps needed to address them effectively. Through filling these gaps, researchers and policymakers can work together to develop targeted, evidence-based strategies that improve air quality and public health across the country.

References

Aimun, F. (2024). The Political Economy of Land Development in Karachi. (Master's Thesis) Dartmouth College. https://digitalcommons.dartmouth.edu/masters_theses/187.

Ali, M., & Athar, M. (2010). Impact of transport and industrial emissions on the ambient air quality of Lahore City, Pakistan. *Environmental monitoring and assessment*, 171, 353-363.

Anjum, M. S., Ali, S. M., Subhani, M. A., Anwar, M. N., Nizami, A. S., Ashraf, U., & Khokhar, M. F. (2021). An emerged challenge of air pollution and ever-increasing particulate matter in Pakistan; a critical review. *Journal of Hazardous Materials*, 402, 123943.

Asian Development Bank. (2021). *Urban Traffic Emissions in South Asia*.

Asim, M., Usman, M., Abbasi, M. S., Ahmad, S., Mujtaba, M. A., Soudagar, M. E. M., & Mohamed, A. (2022). Estimating the long-term effects of national and international sustainable transport policies on energy consumption and emissions of road transport sector of Pakistan. *Sustainability*, *14*(9), 5732.

Bajwa, A. U., & Sheikh, H. A. (2023). Contribution of Road Transport to Pakistan's Air Pollution in the Urban Environment. *Air*, *1*(4), 237-257. https://doi.org/10.3390/air1040018.

Bano, R., & Khayyam, U. (2021). Industrial air pollution and self-reported respiratory and irritant health effects on adjacent residents: a case study of Islamabad Industrial Estate (IEI). *Air Quality, Atmosphere & Health*, *14*(10), 1709-1722.

Ehtasham, L., Sherani, S. H., Younas, K., Izbel, U., Khan, A. H., Bahadur, A., & Akbar, A. (2022). A review of the status of environmental impact assessment in Pakistan. *Integrated Environmental Assessment and Management*, *18*(2), 314-318.

Fatima, M., Ahmad, A., Butt, I., Arshad, S., & Kiani, B. (2024). Geospatial modelling of ambient air pollutants and chronic obstructive pulmonary diseases at regional scale in Pakistan. *Environmental Monitoring and Assessment*, *196*(10), 929.

Global Alliance for Clean Cookstoves. (2020). *Cleaner Technologies for Industrial Applications*.

Hanf, K. (2003). Implementing international environmental policies. *In Environmental Policy in an International Context* (Vol. 3, pp. 197-221). Butterworth-Heinemann.

Hussein, A. L. M. A., & Awad, A. L. T. H. (2024). Accounting for Air Pollution from Manufacturing Industry in Iraq. *International Journal of Economics and Finance Studies*, *16*(1), 531-546.

Hussain, S., Siddique, A., Hassan, M., Rasool, K., Shahzad, A., Naqvi, S. A. A., & Mustafa, M. R. U. (2024). Characteristics and health implications of fine particulate matter near urban road site in Islamabad, Pakistan. *Environmental Research*, 252, 118862.

Idrees, M., Nergis, Y., & Irfan, M. (2023). Industrial emission monitoring and assessment of air quality in Karachi Coastal City, *Pakistan. Atmosphere*, *14*(10), 1515.

IQAir. (2023). *Global Air Quality Report*.

Jion, M. M. M. F., Jannat, J. N., Mia, M. Y., Ali, M. A., Islam, M. S., Ibrahim, S. M., ... & Islam, A. R. M. T. (2023). A critical review and prospect of NO2 and SO2 pollution over Asia: Hotspots, trends, and sources. *Science of The Total Environment*, *876*, 162851.

Kausar, A., Ahmad, I., Zhu, T., & Shahzad, H. (2023). Impact of Indoor Air Pollution in Pakistan—Causes and Management. *Pollutants*, *3*(2), 293-319. https://doi.org/10.3390/pollutants3020021.

Khan, M. W., Ali, Y., De Felice, F., Salman, A., & Petrillo, A. (2019). Impact of brick kilns industry on environment and human health in Pakistan. *Science of the Total Environment*, 678, 383-389.

Liu, H., Guo, K., & Li, Y. (2024). Impact of technical barriers to trade on sulfur dioxide and nitrogen oxide emissions in China's manufacturing sector. *Environmental Pollutants and Bioavailability*, *36*(1), 2387682.

Mahato, D. K., Patidar, K., Badaik, S., & Ambade, B. (2024). Source apportionment and short-term variation of Black Carbon and PM2. 5 during Diwali Festivals over an industrial city in India. *International Journal for Environmental Sciences*, *13*(3), 11-19.

Ministry of Climate Change, Pakistan. (2022). *Environmental Policy Review*.

Mooventhan, P., Singh, S. R. K., Venkatesan, P., Dixit, A. N. I. L., Sharma, K. C., Sivalingam, P. N., ... & Kaushal, P. (2018). Happy seeder-a promising technology in conservation agriculture. *Harit Dhara*, *1*(1), 27-29.

Murray, C. J. (2022). The global burden of disease study at 30 years. *Nature medicine*, *28*(10), 2019-2026.

Nasar-u-Minallah, M., Zainab, M., & Jabbar, M. (2024). Exploring mitigation strategies for smog crisis in Lahore: a review for environmental health, and policy implications. *Environmental Monitoring and Assessment*, *196*(12), 1269.

National Institute of Health, Pakistan (2023). Health Impacts of Air Pollution.

Pakistan EPA. (2023). *Industrial Pollution Control Strategies*.

Punjab Agriculture Department (2022). Crop Residue Management and Pollution in Pakistan.

Punjab Agriculture Department. (2022). *Impact of Crop Burning on Air Quality*.

Siddqiue, M. U., Jamil, M., & Arshad, A. (2023). Digital Solutions and Technological Innovations Driving Public Awareness and Community Initiatives for Smog Reduction in Lahore: A Descriptive Overview. *Pakistan Social Sciences Review*, *7*(4), 425–438. https://doi.org/10.35484/pssr.2023(7-IV)39.

Slater, J., Aftab, L., Jamshaid, H., Amjad, M., Bashir, S., Shafique, S., & Malley, C. S. (2024). Modeling Air Pollutant Emission Reductions from Implementation of Pakistan's 2023 Clean Air Policy. ACS ES&T Air.

Sun, X. (2023). *Sustainable Development Integration in Coal Trading Company: Strategies, Challenges, and Societal Implications* (Master's thesis, ISCTE-Instituto Universitario de Lisboa (Portugal).

UNEP. (2021). *Crop Residue Burning in South Asia: Impacts and Alternatives*.

UNEP. (2022). *Innovative Solutions to Agricultural Pollution*.

WHO (2022). Global Health Risks from Air Pollution.

World Bank (2023). Economic Costs of Air Pollution in Pakistan.

World Bank. (2022). *Transportation Sector and Environmental Challenges in Pakistan*.

World Health Organization. (2023). WHO ambient air quality database, 2022 update: status report. World Health Organization.