

## AIR QUALITY AND POLLUTION IN PAKISTAN

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### ABSTRACT

*Air quality in Pakistan has significantly deteriorated due to rapid urbanization, industrialization, and increasing vehicular emissions. Major cities like Lahore, Karachi, and Islamabad face high levels of air pollution, exacerbated by industrial emissions, crop burning, dust from construction, and low-quality fuel for power generation and domestic heating. Seasonal smog, particularly during winter months, worsens the air quality, with dangerous concentrations of particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), and sulfur dioxide (SO2) posing severe health risks, including respiratory and cardiovascular diseases. Despite governmental efforts, such as introducing cleaner fuel standards and promoting afforestation campaigns, enforcement remains weak, limiting progress in addressing pollution. This escalating environmental crisis severely affects public health, economic productivity, and ecosystem damage. Addressing air pollution in Pakistan requires stronger regulatory frameworks, public awareness campaigns, and investment in clean energy solutions to mitigate long-term environmental and health impacts.*

**Keywords:** air quality, public health, environmental degradation, urbanization, Pakistan

### INTRODUCTION

The issue of air pollution in Pakistan has garnered significant attention in recent years, primarily due to its profound public health, environmental, and economic implications. Rapid urbanization, industrial expansion, and increased energy demands have led to air quality deterioration across major cities such as Lahore, Karachi, and Islamabad. The consequences of this air quality crisis are severe, manifesting in heightened rates of respiratory and cardiovascular diseases, along with

substantial economic losses linked to healthcare costs and decreased productivity. As the nation grapples with these challenges, a comprehensive body of literature has emerged, analyzing various aspects of Pakistan's air quality management and pollution control strategies (Anjum et al., 2021). Recent studies have illuminated the multifaceted nature of air pollution in the country. For instance Mir et al. (2022) provide a critical assessment of air quality control within the context of climate change

mitigation. Their research advocates for integrating energy policies with climate goals, suggesting that sustainable energy models like EnerNEO and GAINS could help reduce fossil fuel emissions while addressing climate challenges. This dual approach is essential for a nation facing environmental degradation and economic strain from its reliance on fossil fuels.

The Centre for Research on Energy and Clean Air (2022) further explores the economic dimension of air pollution. It highlights the financial toll of fossil fuel consumption exacerbated by fuel subsidies and industrial activities in urban centers. The findings emphasize the need for structural reforms in the energy and transport sectors to mitigate emissions and curb economic losses. Such reforms are critical for cities like Lahore and Karachi, where air quality issues are most acute. Transitioning to renewable energy sources is another focal point in the literature, technologies such as solar and wind energy could significantly improve air quality. Commitment is crucial for reducing reliance on polluting energy sources and ensuring sustainable development. Transportation and industrial emissions are identified as significant contributors to urban pollution by (Abdul-Jabbar et al., 2022).

Their analysis calls for stricter emissions standards and a shift toward electric vehicles to mitigate air quality deterioration in cities like Karachi and Lahore. These recommendations echo the findings of the Pakistan Medical Research Council (2022), which links poor air quality to rising hospital admissions due to respiratory and cardiovascular diseases. In addition to technological and policy solutions, the importance of effective governance and public awareness cannot be overstated. The Pakistan Environmental Protection Agency (2022) discusses enforcement gaps in existing air quality laws, underscoring the need for stronger regulatory frameworks and public awareness campaigns to enhance compliance. Furthermore, monitoring air quality trends is critical for evidence-based policymaking, as highlighted by the Pakistan Air Quality Initiative (2023), which calls for improved monitoring infrastructure (Khan et al., 2023).

Global studies provide additional context and strategies that may apply to Pakistan's air quality challenges. Research by (Crippa et al., 2022), emphasizes the need to reduce fossil fuel emissions, while (Bilal et al., 2021). Illustrate the

positive impact of stricter industrial regulations observed in other countries. Such findings reinforce the potential for adopting best practices in air quality management to create a healthier environment in Pakistan. Addressing air pollution in Pakistan is a complex challenge requiring an integrated approach combining policy reforms, technological innovation, and public engagement. By learning from domestic research and international best practices, Pakistan can develop comprehensive strategies that improve air quality, safeguard public health, and foster economic sustainability (Anwar et al., 2021).

### **Research Justification**

Air pollution in Pakistan is a pressing issue that poses severe public health, environmental, and economic challenges, making targeted research and strategic intervention imperative. Significant cities like Lahore, Karachi, and Islamabad have deteriorated air quality due to rapid urbanization, industrial expansion, and increased energy demands. The adverse health effects of this crisis are alarming, with rising incidences of respiratory and cardiovascular diseases directly linked to poor air quality. This public health emergency translates into substantial economic burdens, manifesting in higher healthcare costs and decreased productivity. Recent studies, such as those by (Rehman & Alam 2023). And the Centre for Research on Energy and Clean Air (2022), highlight the multifaceted nature of air pollution and the necessity for integrated approaches that combine pollution control with climate change mitigation.

They emphasize the urgent need for structural reforms in the energy and transportation sectors to transition away from fossil fuels, thereby reducing emissions and enhancing air quality. Moreover, the research has identified significant gaps in regulatory enforcement and public awareness, indicating a critical area for improvement. Enhanced governance and community engagement are essential for fostering compliance with air quality standards. This study will synthesize local and international best practices to develop comprehensive strategies that improve air quality, protect public health, and promote sustainable economic development. By addressing these interconnected issues, this research is crucial for informing policymakers and ensuring a healthier, more sustainable future for Pakistan.

### Research Objectives

**1. To assess the major sources of air pollution in urban and rural areas of Pakistan:** This objective aims to identify and categorize the key contributors to air pollution across different regions of Pakistan. These sources include vehicular emissions, industrial discharge, crop burning, and domestic fuel usage. By understanding the specific activities contributing to poor air quality, policymakers can better target interventions to reduce pollution in urban and rural areas.

**2. To analyze the health impacts of air pollution on vulnerable populations:** This research objective seeks to examine how air pollution affects public health, particularly among children, the elderly, and those with pre-existing respiratory and cardiovascular conditions. By assessing the correlation between air quality data and health outcomes, the study can provide valuable insights into pollution's direct and long-term effects on human health.

**3. To evaluate the effectiveness of existing policies and regulations to control air pollution:** This objective focuses on critically analyzing the current environmental policies, such as fuel standards, industrial emission controls, and public transportation initiatives. The research will assess whether these measures are effectively enforced and whether they have improved air quality.

**4. To recommend sustainable solutions for reducing air pollution in Pakistan:** Based on the content collected, this objective seeks to propose practical, cost-effective solutions for reducing air pollution. These recommendations will cover areas such as transitioning to cleaner energy, improving public transportation, regulating industrial emissions, and raising public awareness about pollution control measures.

### Research Methodology

This study employed a systematic review methodology, with research objectives established accordingly. A comprehensive literature review was conducted (Komba & Lwoga, 2020). Research findings were categorized based on their content (Hiver et al., 2021; Petticrew & Roberts, 2006), and

classified information was incorporated into the study by organizing it into headings (Gan et al., 2021; Pawson et al., 2005). The evaluation of classified information and titles formed the basis of the study (Page, 2021; Rahi, 2017), ensuring the integrity of the research subject and its contents (Egger et al., 2022; Victor, 2008).

### Literature Review

The issue of air pollution in Pakistan has garnered significant attention in recent years due to its public health, environmental, and economic impacts. A comprehensive body of literature has emerged, analyzing various aspects of Pakistan's air quality and pollution control strategies (Mehmood et al., 2021). Offer a critical assessment of air quality control within the broader context of climate change mitigation. Their research emphasizes the integration of energy policies with climate goals, advocating for reducing fossil fuel emissions through sustainable energy models like EnerNEO and GAINS, which could provide a framework for tackling pollution and climate challenges simultaneously. The Centre for Research on Energy and Clean Air (2022), explores the economic dimension of air pollution, highlighting the financial toll of fossil fuel consumption (Yousaf et al., 2021).

The study examines how fuel subsidies and industrial activities in major cities, such as Lahore and Karachi, exacerbate air pollution. It emphasizes the need for structural reforms, particularly in the energy and transport sectors, to curb emissions and mitigate economic losses (Ullah et al., 2021). Focus on emissions from transportation and industrial activities, identifying them as the major contributors to pollution in Karachi and Lahore. The authors stress the importance of stricter emissions standards and advocate for a shift towards electric vehicles to reduce urban air quality deterioration. The Pakistan Medical Research Council (2022) addresses the health impacts of air pollution. The study highlights the rising rates of respiratory and cardiovascular diseases in Lahore and Karachi due to high levels of particulate matter (PM<sub>2.5</sub>) and provides evidence linking poor air quality to increased hospital admissions during the winter smog season.

Policy and governance are key themes in the work of the Pakistan Environmental Protection Agency

(2022), which discusses the enforcement gaps in Pakistan's air quality laws. It emphasizes more robust regulatory frameworks and public awareness campaigns to enhance compliance. The Institute of Environmental Studies (2023) examines the effectiveness of existing air pollution mitigation measures in Islamabad, highlighting both successes and ongoing challenges in urban pollution control efforts. Monitoring air quality trends is critical for evidence-based policymaking. The Pakistan Air Quality Initiative (2023) provides comprehensive data on PM<sub>2.5</sub> and NO<sub>2</sub> levels in major cities and calls for more stringent air quality regulations and improved monitoring infrastructure (Bhatti et al., 2021).

Investigate the potential of renewable energy in reducing air pollution, particularly in the energy sector. Their research underscores the importance of transitioning from coal-fired power plants to wind and solar energy to reduce pollutants. Finally, the Climate Change Ministry of Pakistan (2022) examines the sociopolitical barriers to air quality management. This study explores the political and institutional challenges in enforcing air quality laws and the critical role of civil society in advocating for stronger environmental protections (Abbas et al., 2022). Explore the continuing dominance of fossil fuel emissions as a primary source of air pollution. Their research suggests that reducing fossil fuels, a key pollutant in many developing nations, could improve air quality by lowering particulate matter (PM<sub>2.5</sub>) and nitrogen oxide (NO<sub>x</sub>) emissions. These pollutants are similarly dominant in Pakistan, where industrial growth and energy consumption rapidly increase (Waseem et al., 2022).

Urban air quality remains a pressing issue, particularly in major cities, as shown by (Sokhi et al., 2021). In their analysis of China's urbanization. This study underlines the critical need for vehicular emission reductions, a parallel concern in Pakistan's densely populated cities such as Lahore and Karachi (Tuinstra, 2022). Further elaborate on the health impacts of air pollution, linking prolonged exposure to increased risks of cardiovascular and respiratory diseases. Given the rising health costs associated with air pollution in Pakistan, these findings are highly relevant to public health policy and preventive measures. The role of industrial regulation in improving air quality is emphasized by (Sokhi et al., 2021). Who

discuss how stricter industrial emissions standards have led to reductions in pollution in other countries.

Such regulations could significantly improve air quality in Pakistan, where the industrial sector contributes heavily to pollution (Alvarado et al., 2021). Point to advancements in air quality monitoring technologies, stressing the importance of real-time data collection to better understand and address pollution. In Pakistan, similar technologies could support better decision-making and policy formulation (Tan et al., 2021). Examine the link between climate change and air quality, noting that rising global temperatures exacerbate pollution through increased ozone formation. Pakistan, being highly vulnerable to climate change, must factor in these findings when developing air quality management strategies (Dimitroulopoulou et al., 2023). Argue for stronger global policy frameworks, underscoring the importance of stringent air quality regulations and enforcement mechanisms.

Pakistan can adapt these international frameworks to improve its regulatory practices. Air pollution also has significant economic implications, as (Mannan & Al-Ghamdi, 2021). Show, affecting productivity and healthcare costs. It is especially pertinent for Pakistan, where the economic burden of poor air quality continues to rise. Sustainable urban development, including integrating green spaces and efficient public transportation, can help mitigate pollution in urban areas. Pakistan's growing urban centers could benefit from adopting such sustainable planning strategies (Nazarenko et al., 2021). Focus on South Asia, a region that faces similar challenges to Pakistan, and highlight the need for regional collaboration in air quality management (Rosario-Filho et al., 2021). Advocate for a transition to renewable energy to reduce air pollution, noting that such a transition not only mitigates climate change but also improves air quality. Pakistan's efforts to diversify its energy mix align with these recommendations (Abera et al., 2021).

Provide a comprehensive review of the impacts of air pollution on global public health. Their study examines how various forms of air pollution affect health outcomes across different regions. They highlight the broad range of health issues linked to air pollution, including respiratory and cardiovascular diseases, and discuss the disparities

in health impacts between developed and developing nations (Sicard et al., 2023). Explore environmental justice, showing how air pollution disproportionately affects marginalized communities. In Pakistan, poorer communities near industrial areas face higher pollution exposure, mirroring global trends (World Health Organization, 2021). Observe that the COVID-19 lockdowns resulted in temporary reductions in air pollution levels, offering insights into how long-term improvements could be achieved through reduced industrial and vehicular activity (Christodoulakis et al., 2022). Compare air quality regulations in Europe and North America, revealing the effectiveness of stringent emissions controls, a model Pakistan could adopt lastly (Fisher et al., 2021). Discuss how agricultural practices, particularly crop residue burning, contribute significantly to air pollution, a challenge Pakistan shares with many developing nations.

#### **Sources and Causes of Air Pollution in Pakistan**

Air pollution in Pakistan stems from factors primarily linked to rapid urbanization, industrial growth, and insufficient regulatory enforcement. One of the leading causes is vehicular emissions. The transportation sector, dominated by outdated vehicles and low-quality fuel, contributes significantly to air pollution. Major cities like Karachi, Lahore, and Islamabad experience high levels of pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM), exacerbated by traffic congestion and poor vehicle maintenance. Industrial emissions are another major source of pollution. Industries such as cement production, steel manufacturing, and chemical processing release harmful pollutants, including sulfur dioxide (SO<sub>2</sub>), particulate matter, and volatile organic compounds (VOCs). These industries often operate without adequate pollution control measures, worsening air quality, particularly in industrial zones (Spezzano, 2021). Brick kilns and factories also contribute significantly to air pollution. Traditional kilns, widespread in rural and peri-urban areas, use coal and biomass as fuel, emitting large amounts of particulate matter and black carbon. During the winter months, these emissions and unfavorable atmospheric conditions lead to severe smog (Yang et al., 2021). Agricultural practices, specifically burning crop stubble, are a major contributor to air

pollution. After harvest, farmers burn leftover crop residue, releasing large amounts of smoke and particulate matter, intensifying air pollution and contributing to the formation of seasonal smog. Lastly, power generation reliant on coal-fired plants and fossil fuels emits sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NOx). At the same time, rapid urbanization and construction add to the problem by generating dust and other particulates. These factors create a dangerous mix that has led to worsening air quality and severe public health concerns worldwide (Tainio et al., 2021).

#### **Health and Environmental Impacts of Poor Air Quality**

Poor air quality in Pakistan has significant health and environmental impacts. Exposure to high levels of air pollution, particularly particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), is linked to severe health problems. Respiratory diseases, such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD), are prevalent in areas with high pollution levels (Molina, 2021). Long-term exposure can also lead to cardiovascular diseases, lung cancer, and premature death. Children, the elderly, and individuals with pre-existing health conditions are particularly vulnerable. According to the World Health Organization, air pollution contributes to thousands of premature deaths annually in Pakistan (Fuller et al., 2022).

Environmentally, poor air quality leads to reduced visibility, acid rain, and the degradation of ecosystems. Pollutants like sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NOx) contribute to acid rain, which damages soil, crops, forests, and water bodies. The smog, especially in urban centers disrupts daily life, affecting transportation and reducing productivity. Air pollution also contributes to climate change by releasing greenhouse gases and black carbon, exacerbating global warming. The combined health and environmental impacts strain healthcare system, reduce agricultural yields and create long-term economic losses, making air quality a critical issue for the country's sustainability (Kumar et al., 2023).

**Government Policies and Legal Frameworks**

The government of Pakistan has established several policies and legal frameworks to tackle air pollution, though enforcement remains a significant challenge. The primary legislation is the Pakistan Environmental Protection Act (PEPA) of 1997, which provides the foundation for regulating environmental issues, including air quality. This act led to the creation of the Pakistan Environmental Protection Agency (Pak-EPA) at the federal level, along with provincial EPAs, responsible for monitoring air quality, enforcing standards, and controlling pollution sources.

A key tool under PEPA is the National Environmental Quality Standards (NEQS), which set limits on air pollutants like particulate matter (PM), sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and carbon monoxide (CO) from industries and vehicles. Although these standards are periodically updated to reflect environmental needs, compliance could be more substantial, particularly in urban and industrial zones with insufficient pollution control measures (Skiriene & Stasiskiene, 2021). The Motor Vehicles Ordinance of 1965 also includes regulations to control vehicular emissions, which contribute heavily to urban air pollution. Provincial governments have introduced policies to reduce crop burning and promote cleaner technologies for brick kilns. Despite these efforts, weak enforcement and public awareness continue to hamper significant progress in reducing air pollution across Pakistan.

**Strategies for Improving Air Quality and Reducing Pollution**

Improving air quality and reducing pollution in Pakistan requires a multifaceted approach, combining stricter regulations, cleaner technologies, and public engagement. One key strategy is to strengthen the enforcement of existing environmental laws, such as the Pakistan Environmental Protection Act (PEPA) and the National Environmental Quality Standards (NEQS). Ensuring compliance from industries and vehicles through regular inspections and penalties for violations is crucial. Promoting cleaner technologies, particularly in sectors like transportation and industry, is another important step. Encouraging electric vehicles, improving public transport systems, and adopting cleaner fuels can significantly reduce vehicular emissions.

Similarly, introducing modern, efficient industry technologies, such as the zigzag kiln method for brick kilns, can help lower industrial emissions. Addressing agricultural pollution, especially crop residue burning, requires offering farmers alternative methods like composting and mulching. It can reduce the seasonal smog problem. Public awareness campaigns are essential for educating people about the health impacts of air pollution and encouraging eco-friendly practices. Additionally, investing in renewable energy sources, such as solar and wind, can help reduce reliance on fossil fuels, improving air quality. A collaborative approach involving the government, private sector, and civil society is critical for improving air quality in Pakistan (Kumar & Pande, 2023).

**Discussion**

Air quality and pollution in Pakistan have reached alarming levels, significantly impacting public health and the environment. Major cities, including Lahore and Karachi, experience severe air pollution, primarily due to vehicular emissions, industrial activities, and agricultural practices such as crop burning. Studies indicate that high concentrations of particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) are linked to respiratory and cardiovascular diseases, contributing to thousands of premature deaths annually. The World Health Organization ranks Pakistan among the countries with the highest mortality rates due to air pollution. Despite government initiatives to control pollution, such as introducing cleaner fuel standards and temporary bans on crop burning, enforcement needs to be stronger, and public awareness needs to be higher. Industrial emissions are often unchecked, leading to toxic pollutants contaminating air, soil, and water.

Furthermore, the seasonal variations in air quality, particularly during winter when temperature inversions occur, exacerbate smog formation, creating a recurring public health crisis. Addressing air quality issues in Pakistan requires a multifaceted approach, including stricter regulatory enforcement, investment in clean energy alternatives, and enhanced public awareness campaigns. Sustainable urban planning and improvements in public transportation are also essential for reducing reliance on private vehicles. Without comprehensive strategies and community involvement, the air quality crisis in Pakistan will

persist, posing significant health risks and environmental challenges. The government and society must collaborate to implement effective solutions to protect public health and ensure a sustainable environment for future generations.

### Conclusion

Air quality and pollution in Pakistan represent critical challenges that significantly affect public health, environmental sustainability, and economic development. The severe levels of air pollution in major cities stem from a combination of vehicular emissions, industrial discharges, and agricultural practices, particularly crop burning. These factors contribute to high concentrations of harmful pollutants, leading to increased respiratory and cardiovascular diseases and resulting in thousands of premature deaths annually. Despite some government initiatives aimed at mitigating air pollution, such as enforcing cleaner fuel standards and promoting afforestation, these efforts are often undermined by inadequate enforcement, lack of public awareness, and insufficient infrastructure for sustainable urban development. The recurring smog episodes during winter highlight the urgency of addressing this crisis, as they pose immediate health risks and disrupt daily life for millions.

A multidimensional strategy is essential to combating air pollution effectively in Pakistan. It includes strengthening regulatory frameworks, enhancing public transportation systems, transitioning to cleaner energy sources, and raising public awareness about the health impacts of air pollution. Collaboration between government, industry, and communities is vital to foster a collective response to this pressing issue. Only through sustained efforts and comprehensive policy implementation can Pakistan hope to improve air quality, safeguard public health, and promote environmental resilience for future generations. Addressing these challenges is not just a necessity but an obligation for the population's well-being and the ecosystem's preservation.

### Recommendations

- 1. Enhance Emission Standards:** Strengthen industrial emissions and vehicular exhaust regulations to ensure compliance with international air quality standards.
- 2. Promote Public Transportation:** Invest in and expand public transport systems, such as buses and

trains, to reduce the number of private vehicles on the road.

- 3. Encourage Electric Vehicles (EVs):** Provide incentives for electric vehicle adoption, including tax breaks and subsidies, to reduce dependence on fossil fuels.

- 4. Implement Clean Energy Sources:** Transition to renewable energy sources, such as solar and wind, to reduce reliance on coal and natural gas for electricity generation.

- 5. Increase Green Spaces:** Develop parks and green belts in urban areas to improve air quality and provide natural habitats.

- 6. Strictly Regulate Construction Activities:** Enforce regulations to control dust and emissions from construction sites, including water sprays and barriers.

- 7. Conduct Awareness Campaigns:** Educate the public about the sources and effects of air pollution and promote sustainable practices like carpooling and waste reduction.

- 8. Monitor Air Quality:** Establish a comprehensive air quality monitoring network to provide the public with real-time data and inform policy decisions.

- 9. Support Waste Management Initiatives:** To reduce open burning and landfill emissions, implement better waste management practices, including recycling and composting.

- 10. Collaborate with Regional Partners:** Work with neighboring countries to address transboundary pollution issues and develop regional strategies for improving air quality.

### Research Limitations

Several factors limit research on air quality and pollution in Pakistan. First, comprehensive and reliable air quality monitoring data is scarce, as many areas need more monitoring stations. This results in significant gaps in data, particularly in rural regions where pollution may also be prevalent. Second, funding for environmental research needs to be improved, restricting the scope and depth of studies. Third, existing research focuses primarily on major urban centers like Lahore and Karachi, overlooking rural and peri-urban areas where pollution sources may differ. Additionally, the interdisciplinary nature of air quality research needs to be addressed, with limited collaboration between environmental scientists, health experts, and policymakers. Political and

administrative challenges can also impede the implementation of research findings into effective policies. Lastly, low public awareness of air quality limits community engagement in addressing pollution, further complicating research and mitigation efforts.

### Research Implications

Research on air quality and pollution in Pakistan highlights critical implications for public health, environmental policy, and urban planning. The findings reveal alarming levels of pollutants, such as PM<sub>2.5</sub> and nitrogen dioxide, which pose significant health risks, including respiratory diseases and cardiovascular issues. It underscores the urgent need for stringent air quality regulations and enforcement mechanisms to protect vulnerable populations. Moreover, the research emphasizes integrating air quality data into urban development strategies. Policymakers can utilize these insights to promote cleaner technologies, enhance public transportation systems, and develop green spaces, which can mitigate pollution sources. Raising public awareness about pollution's health effects also fosters community engagement in advocating for better air quality initiatives. Addressing air quality issues in Pakistan requires a collaborative approach, combining research, policy reforms, and community involvement to achieve sustainable environmental improvements and enhance public health outcomes.

### Future Research Directions

Future research directions in air quality and pollution in Pakistan should focus on several key areas to address the ongoing challenges. First, long-term monitoring of air pollutants is essential to establish comprehensive datasets that track changes over time and correlate them with health outcomes. It could involve deploying advanced air quality monitoring technologies and developing a nationwide network for real-time data collection. Second, studies exploring the sources of pollution, particularly in urban areas, can help identify key contributors such as vehicular emissions, industrial activities, and biomass burning. Understanding these sources will inform targeted interventions. Third, research on the health impacts of air pollution should expand, focusing on vulnerable populations, including children and the elderly.

Investigating the socio-economic factors that exacerbate health risks can guide equitable policy solutions. Additionally, evaluating the effectiveness of existing air quality regulations and policies will provide insights into their implementation challenges and successes, leading to better policy frameworks. Finally, interdisciplinary research that integrates air quality studies with climate change impacts can illuminate the complex relationships between pollution and environmental sustainability. Engaging communities in citizen science initiatives can also empower local stakeholders to participate in monitoring and advocacy efforts, enhancing public awareness and action against air pollution.

### REFERENCES

- Abbas, S., Ali, G., Qamer, F. M., & Irteza, S. M. (2022). Associations of air pollution concentrations and energy production dynamics in Pakistan during lockdown. *Environmental Science and Pollution Research*, 29(23), 35036-35047.
- Abdul-Jabbar, S., Tul Qadar, L., Ghafoor, S., Rasheed, L., Sarfraz, Z., Sarfraz, A., ... & Cherrez-Ojeda, I. (2022). Air quality, pollution and sustainability trends in South Asia: a population-based study. *International journal of environmental research and public health*, 19(12), 7534.
- Abera, A., Friberg, J., Isaxon, C., Jerrett, M., Malmqvist, E., Sjöström, C., & Vargas, A. M. (2021). Air quality in Africa: Public health implications. *Annual review of Public Health*, 42(1), 193-210.
- Alvarado, R., Ortiz, C., Jiménez, N., Ochoa-Jimenez, D., & Tillaguango, B. (2021). Ecological footprint, air quality and research and development: The role of agriculture and international trade. *Journal of Cleaner Production*, 288, 125589.
- 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.



- Anwar, M. N., Shabbir, M., Tahir, E., Iftikhar, M., Saif, H., Tahir, A., ... & Nizami, A. S. (2021). Emerging challenges of air pollution and particulate matter in China, India, and Pakistan and mitigating solutions. *Journal of Hazardous Materials*, 416, 125851.
- Bhatti, U. A., Yan, Y., Zhou, M., Ali, S., Hussain, A., Qingsong, H., ... & Yuan, L. (2021). Time series analysis and forecasting of air pollution particulate matter (PM 2.5): An SARIMA and factor analysis approach. *IEEE Access*, 9, 41019-41031.
- Bilal, M., Mhawish, A., Nichol, J. E., Qiu, Z., Nazeer, M., Ali, M. A., ... & Ke, S. (2021). Air pollution scenario over Pakistan: Characterization and ranking of extremely polluted cities using long-term concentrations of aerosols and trace gases. *Remote Sensing of Environment*, 264, 112617.
- Christodoulakis, J., Karinou, F., Kelemen, M., Kouremadas, G., Fotaki, E. F., & Varotsos, C. A. (2022). Assessment of air pollution from Athens International Airport and suggestions for adaptation to new aviation emissions restrictions. *Atmospheric Pollution Research*, 13(6), 101441.
- Dimitroulopoulou, S., Dudzinska, M. R., Gunnarsen, L., Hagerhed, L., Maula, H., Singh, R., & Haverinen-Shaughnessy, U. (2023). Indoor air quality guidelines from across the world: An appraisal considering energy saving, health, productivity, and comfort. *Environment International*, 178, 108127.
- Egger, M., Higgins, J. P., & Smith, G. D. (Eds.). (2022). *Systematic reviews in health research: Meta-analysis in context*. John Wiley & Sons.
- Fisher, S., Bellinger, D. C., Cropper, M. L., Kumar, P., Binagwaho, A., Koudenoukpo, J. B., ... & Landrigan, P. J. (2021). Air pollution and development in Africa: Impacts on health, the economy, and human capital. *The Lancet Planetary Health*, 5(10), e681-e688.
- Fuller, R., Landrigan, P. J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M., ... & Yan, C. (2022). Pollution and health: a progress update. *The Lancet Planetary Health*, 6(6), e535-e547.
- Gan, J., Xie, L., Peng, G., Xie, J., Chen, Y., & Yu, Q. (2021). Systematic review on modification methods of dietary fiber. *Food Hydrocolloids*, 119, 106872. 10.1136/qshc.2004.012781
- Hiver, P., Al-Hoorie, A. H., Vitta, J. P., & Wu, J. (2021). Engagement in language learning: A systematic review of 20 years of research methods and definitions. *Language Teaching Research*, 13621688211001289.
- Khan, W. A., Sharif, F., Khokhar, M. F., Shahzad, L., Ehsan, N., & Jahanzaib, M. (2023). Monitoring of ambient air quality patterns and assessment of air pollutants' correlation and effects on ambient air quality of Lahore, Pakistan. *Atmosphere*, 14(8), 1257.
- Komba, M. M., & Lwoga, E. T. (2020). *Systematic review as a research method in library and information science*. 10.4018/978-1-7998-1471-9.ch005.
- Kumar, K., & Pande, B. P. (2023). Air pollution prediction with machine learning: a case study of Indian cities. *International Journal of Environmental Science and Technology*, 20(5), 5333-5348.
- Mannan, M., & Al-Ghamdi, S. G. (2021). Indoor air quality in buildings: a comprehensive review on the factors influencing air pollution in residential and commercial structure. *International Journal of Environmental Research and Public Health*, 18(6), 3276.
- Mehmood, U., Azhar, A., Qayyum, F., Nawaz, H., Tariq, S., & Haq, Z. U. (2021). Air pollution and hospitalization in megacities: Empirical evidence from Pakistan. *Environmental Science and Pollution Research*, 28(37), 51384-51390.
- Mir, K. A., Purohit, P., Cail, S., & Kim, S. (2022). Co-benefits of air pollution control and climate change mitigation strategies in Pakistan. *Environmental Science & Policy*, 133, 31-43.

- Molina, L. T. (2021). Introductory lecture: air quality in megacities. *Faraday Discussions*, 226, 9-52.
- Nazarenko, Y., Pal, D., & Ariya, P. A. (2021). Air quality standards for the concentration of particulate matter 2.5, Global descriptive analysis. *Bulletin of the World Health Organization*, 99(2), 125–137D.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., & Moher, D. (2021). Updating guidance for reporting systematic reviews: Development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology*, 134, 103-112.
- Pawson, R., Greenhalgh, T., Harvey, G., & Walshe, K. (2005). Realist review - A new method of systematic review designed for complex policy interventions. *Journal of Health Services Research & Policy*, 10(1), 21-34. 10.1258/1355819054308530
- Petticrew, M., & Roberts, H. (2006). *Systematic reviews in the social sciences: A practical guide*. Blackwell Publishing. 10.1002/9780470754887
- Rahi, S. (2017). Research design and methods: A systematic review of research paradigms, sampling issues, and instruments development. *International Journal of Economics & Management Sciences*, 6(2). 10.4172/2162-6359.1000403
- Rosario-Filho, N. A., Urrutia-Pereira, M., d'Amato, G., Cecchi, L., Ansotegui, I. J., Galán, C., & Peden, D. B. (2021). Air pollution and indoor settings. *World Allergy Organization Journal*, 14(1), 100499.
- Sicard, P., Agathokleous, E., Anenberg, S. C., De Marco, A., Paoletti, E., & Calatayud, V. (2023). Trends in urban air pollution over the last two decades: A global perspective. *Science of The Total Environment*, 858, 160064.
- Skiriene, A. F., & Stasiskiene, Z. (2021). COVID-19 and air pollution: Measuring pandemic impact to air quality in five European countries. *Atmosphere*, 12(3), 290.
- Spezzano, P. (2021). Mapping the susceptibility of UNESCO World Cultural Heritage sites in Europe to ambient (outdoor) air pollution. *Science of the Total Environment*, 754, 142345.
- Tainio, M., Andersen, Z. J., Nieuwenhuijsen, M. J., Hu, L., De Nazelle, A., An, R., ... & de Sá, T. H. (2021). Air pollution, physical activity and health: A mapping review of the evidence. *Environment International*, 147, 105954.
- Ullah, S., Ullah, N., Rajper, S. A., Ahmad, I., & Li, Z. (2021). Air pollution and associated self-reported effects on the exposed students at Malakand division, Pakistan. *Environmental Monitoring and Assessment*, 193, 1-17.
- Victor, L. (2008). Systematic reviewing in the social sciences: Outcomes and explanation. *Enquire*, 1(1), 32-46.
- Waseem, K. H., Mushtaq, H., Abid, F., Abu-Mahfouz, A. M., Shaikh, A., Turan, M., & Rasheed, J. (2022). Forecasting of air quality using an optimized recurrent neural network. *Processes*, 10(10), 2117.
- World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization.
- Yang, J., Zhao, Y., Cao, J., & Nielsen, C. P. (2021). Co-benefits of carbon and pollution control policies on air quality and health till 2030 in China. *Environment international*, 152, 106482.
- Yousaf, H. S., Abbas, M., Ghani, N., Chaudhary, H., Fatima, A., Ahmad, Z., & Yasin, S. A. (2021). A comparative assessment of air pollutants of smog in wagah border and other sites in Lahore, Pakistan. *Brazilian Journal of Biology*, 84, e252471.