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Engr. Najam Waheed has been a Council Member of Pakistan Engineering Congress for more than two decades. He has been an active member of the Congress serving as Secretary, Joint Secretary, Treasurer, and convener of all important Committees of the Congress, and was elected as the President of the Pakistan Engineering Congress in December 2021. His vision has been manifested in an digital transformation of the Congress's services and has laid a strong foundation for future growth and developments of Engineers Communities.

His dedication to engineering development and the Pakistan Engineering Congress played a significant role in developing effective synergies with important professional bodies in the country, which would significantly contribute to engineer's professional competence in a challenging environment of disruptive technologies and sustainable development.



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Table of Contents

Ser. No.	Paper No.	Title of Paper	Author's Name	Page No.
1	-	Keynote Address	Engr. Husnain Ahmad	1
3	366	Air Quality Management in Pakistan	Engr. Husnain Ahmad	9
4	367	A Review on Air Pollution Control Technologies Commonly Employed in the Industrial Sector	Tayyaba Gulzar, Abdullah Yasar, Iqra Wasif, Amtul Bari Tabinda	31
5	368	Gis-Based Health Risk Assessment of Ambient Air Quality Due to Rapid Urbanization in Lahore, Pakistan	Najma Iftikhar, Muhammad Muzammil, Arbab Jamal, Zill-e-Huma Munir Muhammad Irfan Jalees	57
6	369	A Study on the Seasonal Variability of Air Quality in Lahore City	Ali Amjad, Rashid Ahmed, Sohail Ali Naqvi, Dr. Masood Arshad, Dr. Zaeem Bin Babar	85
7	370	Towards More Effective Air Pollution Governance Strategies in Pakistan: A Systematic Review of the Literature	Hira Muzaffar, Samar Farrukh, Nazifa Butt, Abid Ali, Sahib Alam Khan, Muhammad Huzaifa, Syed Tehzeeb ul Hassain, Zain Tahir, Javaria Usman	117
8	371	Spatial and Temporal Analysis Of Pm2.5 In Lahore: Implications for Public Health and Policy Making	Dr. Rizwan Haider, Muhammad Farooq Alam, Dr. Farieha Hussain, Dr. Nusrat Naz, Fahad Ahmad Muhammad Nadeem, Nasir Saleem	141

Ser. No.	Paper No.	Title of Paper	Author's Name	Page No.
9	372	Assessment of Machine Learning Algorithms Performance for Predicting Particulate Matter Using Meteorological and Chemical Variables: A Case Study of Lahore, Pakistan	Muhammad Haseeb, Muhammad Umar Farooq, Zainab Tahir	163
10	373	Towards Clean Air in Karachi: Scientific Framework and Imperative For a Comprehensive Real-Time Air Quality Monitoring System	Naeem Ahmed Mughal, Waris Ali Gabol, Muhammad Imran Sabir, Masood Rehman Halepoto, Fayyaz Salih Hussain	189
11	374	Understanding the Relationship Between Air Pollution And Meteorological Conditions and Finding Solutions to Air Pollution Problems at the Community and Individual Level	Sahibzad Khan, Mamoona	209
List of Papers Presented at Various Symposia by Pakistan Engineering Congress				227

PAKISTAN ENGINEERING CONGRESS
ANNUAL SYMPOSIUM (DECEMBER 12, 2024)
ON THE THEME OF
AIR QUALITY MANAGEMENT IN PAKISTAN
KEYNOTE ADDRESS

Engr. Husnain Ahmad
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PAKISTAN ENGINEERING CONGRESS
ANNUAL SYMPOSIUM (DECEMBER 12, 2024)
ON THE THEME OF
AIR QUALITY MANAGEMENT IN PAKISTAN
KEYNOTE ADDRESS

By

ENGR. HUSNAIN AHMAD
CONVENER

Prelude

Air quality management is a crucial element in safeguarding public health, preserving the environment, and promoting sustainable development. As urbanization and industrialization continue to accelerate, the degradation of air quality has emerged as one of the most pressing challenges faced by many nations.

Current State of Air Quality in Pakistan

In Pakistan, this issue has reached alarming levels, with major cities consistently experiencing hazardous air pollution. In the recent years especially during the last decade, Pakistan has witnessed a significant decline in air quality, with pollutants frequently exceeding acceptable limits. According to the Pakistan Environmental Protection Agency (Pak-EPA) and various research institutions, the average annual concentration of PM2.5—a dangerous particulate matter that poses serious health risks—has consistently remained alarmingly high. In 2021, studies highlighted that major urban areas like Lahore recorded average PM2.5 levels of around 95 µg/m³, markedly higher than the World Health Organization's (WHO) safe limit of 10 µg/m³annually and25 µg/m³ daily. Unfortunately, Pakistan's air pollution levels have fallen significantly short of these standards. During, 2023 the average PM2.5 concentration in Pakistan rose to 160: 14.7 times the WHO annual air quality guideline value.

Lahore and Karachi often rank among the most polluted in the world, with particulate matter (PM2.5) and other harmful pollutants exceeding the World Health Organization's recommended safe limits. For instance, during the winter months, Lahore frequently records some of the worst air quality indices (AQI) in the world. The AQI during smog episodes in winter often surpasses 300, a level classified as hazardous. Poor air quality not only contributes to respiratory illnesses and cardiovascular diseases but also imposes significant economic burdens due to increased healthcare costs and reduced labor productivity.

In 2020, a report from the State of Global Air indicated that approximately 125,000 deaths in Pakistan were attributable to air pollution, emphasizing a severe public health crisis.

Comparatively, countries in South Asia and across the globe are also facing with air quality issues, but Pakistan's urban centers have consistently reported some of the highest levels of pollution. While some nations are making strides towards cleaner air, efforts in Pakistan are hindered by regulatory challenges and insufficient awareness regarding the health impacts of poor air quality.

Sources of air pollution

The multifaceted nature of air quality issues in Pakistan is influenced by various factors, including vehicular emissions, industrial discharge, burning of solid waste, and agricultural practices.

Understanding the sources of air pollution is critical to devising effective management strategies. In Pakistan, several key contributors have been identified:

1. Industrial Emissions: Rapid industrial growth, especially in urban areas, has led to increased emissions from factories. The lack of adherence to environmental standards has resulted in the release of harmful substances, including heavy metals, particulate matter, and volatile organic compounds.
2. Vehicular Emissions: With a rapidly growing urban population, the number of vehicles on the roads has surged. The transportation sector contributes significantly to air pollution, particularly in major cities where traffic congestion is common. According to estimates, vehicular emissions contribute over 60% of urban air pollution, especially from old and poorly maintained vehicles.
3. Household Activities: The use of cheap fuels, such as wood and coal, for cooking and heating in many households contributes to indoor and outdoor air pollution. Reports suggest that around 70% of rural households rely on solid fuels, impacting air quality and exacerbating health issues.
4. Agricultural Practices: Stubble burning is a significant environmental concern in agriculture. Farmers often set fire to crop residues post-harvest to clear fields for the next planting season. This practice releases vast amounts of smoke and particulate matter

Health Impacts of Poor Air Quality

Air pollution leads to an estimated 128,000 premature deaths annually in Pakistan (Lancet Countdown, 2021). Common health issues include asthma, chronic obstructive pulmonary disease (COPD), and ischemic heart disease. Children and the elderly are particularly vulnerable.

Poor air quality in Pakistan poses a significant threat to public health, contributing to respiratory and cardiovascular diseases, reducing life expectancy, and imposing a substantial economic burden. Addressing this issue requires a multi-faceted approach, including stricter enforcement of environmental regulations, public awareness campaigns, and investment in cleaner technologies. Improving air quality is essential for protecting the health and well-being of the population and ensuring sustainable development in Pakistan.

Environmental Consequences of Poor Air Quality in Pakistan

Air pollution is also a critical issue in Pakistan, with respect to its significant environmental consequences. The country's rapid industrialization, urbanization, and reliance on fossil fuels have led to deteriorating air quality, impacting the environment with consequences on ecosystems including forests, rivers and agricultural lands. It also contributes significantly to climate change, emissions of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and black carbon that also affect health of flora and fauna.

Economic Consequences

Air pollution imposes a heavy economic burden, with estimated annual losses of $20 - 22 billion USD, equivalent to 5.9% to 6.5% of Pakistan's GDP (World Bank, 2023). These costs arise from healthcare expenditures, lost labor productivity, and decreased agricultural yields.

Regulatory Framework and Policies in Pakistan

Pakistan's regulatory framework and policies have evolved significantly over the years to address various economic, social, and environmental challenges. The regulatory environment in Pakistan encompasses a wide range of sectors, including finance, industry, environment, and public health. Environmental protection is a critical aspect of Pakistan's regulatory framework. The Pakistan Environmental Protection Agency (Pak-EPA) is responsible for enforcing environmental laws and regulations to ensure sustainable development and protect natural resources.

Pakistan's regulatory framework and policies play a crucial role in promoting economic growth, ensuring environmental sustainability, and protecting public health. While significant progress has been made, there is a need for continuous improvement and adaptation to address emerging challenges. Strengthening regulatory institutions, enhancing enforcement mechanisms, and promoting transparency are essential for achieving sustainable development in Pakistan.

Technological Innovations and Best Practices for Air Quality in Pakistan

Technological innovations and best practices are essential to mitigate air pollution and improve air quality. Some of the key technological advancements and best practices in air quality management those may help in air quality in Pakistan includes the following;

1. Smart Air Quality Monitoring Systems using advanced sensors and data analytics to provide real-time information on air quality parameters such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3) to identify pollution hotspots and take timely action to mitigate pollution.
2. Catalytic Converters: Catalytic converters to reduce harmful emissions in vehicles can significantly reduce vehicular emissions, which are a major source of air pollution in urban areas.
3. Renewable Energy Technologies help reduce the reliance on fossil fuels. Pakistan has made significant investments in renewable energy projects, such as the Quaid-e-Azam Solar Park and the Jhimpir Wind Corridor, to promote sustainable energy production.
4. Electrostatic Precipitators: Electrostatic precipitators to remove particulate matter from exhaust gases. This technology is highly effective in reducing industrial emissions and improving air quality.
5. Bio-filtration and Bio-remediation: Biofiltration and bioremediation are innovative technologies to clean up contaminated environments. These technologies offer sustainable and cost-effective solutions for air pollution control.

Best Practices for Air Quality Management

Technological innovations and best practices are essential for addressing the air quality challenges in Pakistan. By adopting smart air quality monitoring systems, catalytic converters, renewable energy technologies, electrostatic precipitators, and biofiltration, Pakistan can significantly reduce air pollution. Implementing air quality standards, promoting public awareness, enhancing regulatory frameworks, encouraging research and

innovation, and integrating green infrastructure are key best practices for effective air quality management. International collaboration and cooperation are also crucial for achieving sustainable air quality improvements. By embracing these innovations and best practices, Pakistan can create a cleaner and healthier environment for its citizens.

Strategic Recommendations for Improving Air Quality in Pakistan

Air pollution is a pressing issue in Pakistan, with significant health, environmental, and economic impacts. To address this challenge, it is crucial to implement strategic measures that enhance public awareness and education, as well as strengthen regulatory enforcement. Here are some detailed recommendations:

Enhancing Public Awareness and Education

Conduct awareness programs to educate citizens about air pollution's health impacts and their role in mitigation.

Strengthening Regulatory Enforcement

Improving air quality in Pakistan requires a multifaceted approach that combines public awareness and education with strong regulatory enforcement. By implementing comprehensive public awareness campaigns, integrating air quality education into school curricula, engaging communities, and collaborating with NGOs, Pakistan can raise awareness and foster a culture of environmental responsibility. Strengthening environmental regulations, enhancing monitoring and reporting, building the capacity of regulatory agencies, promoting compliance through incentives and penalties, and improving interagency coordination are essential steps to ensure effective enforcement and sustainable air quality improvements. With a rapidly growing population and urban infrastructure, the challenge of managing air quality becomes even more critical. Addressing these issues is essential for ensuring the health of citizens and the sustainability of the environment. These strategic recommendations can help Pakistan address its air pollution challenges and protect the health and well-being of its citizens.

The objective of this symposium is also to bring together experts, policymakers, researchers, and stakeholders to engage in meaningful dialogue surrounding air quality management in Pakistan. This event aims to share knowledge, discuss innovative strategies, and develop actionable plans to combat air pollution. By fostering collaboration and creating a platform for the exchange of ideas, we aspire to pave the way for effective

policies and practices that will lead to improved air quality and a healthier future for all citizens of Pakistan.

I am confident that with papers covering significant aspects of Air Quality Management, starting from analysis of the existing situation with a review on Air Pollution control Technologies, GIS based Health Risk Assessment, along with meaningful pollution Governance Strategies in Pakistan shall help us in understanding and better management of Air Quality in Pakistan. Papers in this Symposium also include case studies on Seasonal Variability of Air Quality in Lahore and Spatial and Temporal Analysis aimed at highlighting implications of PM2.5 in Lahore for Public Health and Policy Making. Likewise, another paper highlights the importance and need of Scientific Framework for Clean Air in Karachi. The effort of the authors deserve not only due audience but a great appreciation for their painstaking work and efforts for presenting there work in this Symposium.

Finally, it is important to understand that together we can drive change and create a cleaner, more sustainable environment for generations to come.

Paper No.366

AIR QUALITY MANAGEMENT IN PAKISTAN

Engr. Husnain Ahmad

AIR QUALITY MANAGEMENT IN PAKISTAN

By

Engr. Husnain Ahmad[1]

1. Introduction

Air pollution is a multifaceted environmental and public health crisis in Pakistan, arising from rapid urbanization, industrialization, and insufficient regulatory oversight. With its growing population and expanding energy demands, Pakistan faces serious challenges in balancing economic development with environmental sustainability. The urban centers of Lahore, Karachi, and Islamabad frequently appear amongst the most polluted cities worldwide, with air quality indices often reaching hazardous levels (**World Health Organization [WHO], 2022**). The problem is intensified by the country's dependance on largely outdated industrial practices, inadequate vehicular emission standards, and the seasonal phenomenon of smog, which blankets large parts of Punjab and Sindh during the winter months (**Ministry of Climate Change [MoCC], 2021**).

The composition of air pollution in Pakistan includes a mix of fine particulate matter (PM2.5 and PM10), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and volatile organic compounds (VOCs). These pollutants originate from various sources, including vehicular emissions, industrial activities, crop residue burning, and fossil fuel combustion (**Iqbal & Shah, 2019**). The lack of awareness, institutional inefficiencies, and weak enforcement of environmental laws further contribute to the issue (**Ahmad et al., 2021**).

The consequences of air pollution are excessively dangerous, affecting human health, ecosystems, and the economy. Health effects range from respiratory and cardiovascular diseases to even premature mortality, while the economic burden is felt through increased healthcare costs and reduced labor productivity (**World Bank, 2020**). This paper aims to provide a comprehensive analysis of air quality management in Pakistan, highlighting the challenges and opportunities for improvement, drawing lessons from international best practices, and proposing actionable recommendations.

2. Air Quality Status in Pakistan

The state of air quality in Pakistan is alarming and has seen consistent deterioration over the years. Major cities frequently experience PM2.5

[1] Former President Pakistan Engineering Congress, Vice President (Hon) International Commission on Irrigation & Drainage (ICID)

concentrations far exceeding both national and international standards. For instance, Lahore, often labeled the "smog capital," recorded an annual average PM2.5 concentration of 86.5 µg/m³ in 2021 (17 times higher than the World Health Organization's (WHO) recommended limit) rose to 99.5 µg/m³ in 2023, which is 20 times higher than the WHO recommended limit of 5 µg/m³ (**IQAir, 2022**) **average During 2023 PM2.5 overall average concentration in Pakistan** remained 14.7 times the WHO annual air quality guideline value with Lahore topping the list of the most polluted cities of the world. Other cities such as Karachi, Faisalabad, and Peshawar also face severe air quality challenges, though with varying pollutant profiles (**Khan et al., 2020**). The AQI during smog episodes in winter often surpasses 300, a level classified as hazardous. Poor air quality not only contributes to respiratory illnesses and cardiovascular diseases but also imposes significant economic burdens due to increased healthcare costs and reduced labor productivity.

In 2020, a report from the State of Global Air indicated that approximately 125,000 deaths in Pakistan were attributable to air pollution, emphasizing a severe public health crisis. Although, the Air Quality Management is not an issue limited to Pakistan alone, yet, Pakistan's urban centers are consistently reported as amongst the most polluted places on the globe. While other nations make efforts for cleaner air, efforts in Pakistan are hindered by regulatory challenges and lack of requisite awareness amongst masses regarding the impact of poor air quality on health.

Seasonal Variations and Smog

One of the most significant seasonal air quality phenomena in Pakistan is winter smog, particularly in Punjab. This smog results from a combination of factors, including the burning of crop residues, lower temperatures leading to atmospheric inversion, and increased emissions from vehicles and industries. The smog not only reduces visibility but also has severe health impacts, leading to respiratory problems and increased hospital admissions during the winter months (**Ahmad et al., 2021**).

Urban vs. Rural Air Quality

While urban areas face pollution from vehicular and industrial emissions, rural areas are not exempt. The practice of open burning of agricultural residues, combined with the use of biomass fuels for cooking and heating, contributes significantly to air pollution in rural settings (**Iqbal & Shah, 2019**). This duality of sources makes air pollution a nationwide issue rather than a problem confined to urban centers.

Monitoring Limitations

A major impediment to addressing air quality issues in Pakistan is the lack of an extensive and reliable air quality monitoring network. The Pakistan Environmental Protection Agency (Pak-EPA) operates a limited number of monitoring stations, primarily in urban centers. Many of these stations are outdated, and the data they provide are often insufficient for comprehensive policy-making (**MoCC, 2021**). Additionally, the absence of real-time air quality reporting systems in most regions limits public awareness and engagement (**World Bank, 2020**).

Contributing Factors

1. **Vehicular Emissions:** Pakistan's vehicle fleet predominantly consists of older, inefficient vehicles that fail to meet modern emission standards. The widespread use of two-stroke engines and low-quality fuels further exacerbates urban air pollution. The transport sector contributes significantly to air pollution, particularly in major cities. According to estimates vehicular emissions contributes over 60% of urban air pollution (**Khan et al., 2020**).
2. **Industrial Activities:** The lack of adherence to environmental standards has resulted in the release of harmful substances, including heavy metals, particulate matter, and volatile organic compounds. Industries, including brick kilns, cement plants, and steel mills, operate without adequate pollution control measures. Many brick kilns continue to use traditional methods, which are highly polluting (**Ahmad et al., 2021**).
3. **Energy Generation:** Pakistan relies heavily on coal and other fossil fuels for electricity generation. Coal-fired power plants are major contributors to SO_2 and NO_x emissions (**MoCC, 2021**).
4. **Agricultural Residue Burning:** The post-harvest burning of crop residues in Punjab and Sindh is a seasonal contributor to fine particulate matter, with severe implications for regional air quality (**Iqbal & Shah, 2019**).
5. **Solid Waste Burning:** The open burning of municipal solid waste is a common practice, particularly in peri-urban areas, adding to the burden of toxic air pollutants (**Ahmad et al., 2021**).

3. Sources of Air Pollution

3.1 Vehicular Emissions

Vehicular emissions are a primary source of urban air pollution. The lack of emission standards enforcement and the use of outdated vehicles exacerbate the problem (Ministry of Climate Change [MoCC], 2021).

3.2 Industrial Emissions

Industries such as cement manufacturing, steel production, and brick kilns are significant contributors to particulate matter and gaseous pollutants. Many operate without pollution control technologies.

3.3 Agricultural Practices

Burning of crop residues, particularly in Punjab, generates high levels of fine particulates, contributing to smog during winter (Khan et al., 2020).

3.4 Energy Sector

Reliance on fossil fuels for energy generation, including coal-fired power plants, is a substantial source of SO_2 and NO_x emissions.

3.5 Waste Management

Open burning of solid waste contributes significantly to air pollution in urban and rural areas alike (Iqbal & Shah, 2019).

4. Health and Economic Impacts

4.1 Public Health

Air pollution is a significant environmental and public health issue in Pakistan. The country consistently ranks among the top five nations with the poorest air quality globally. This pollution has severe health impacts on the population, contributing to a range of respiratory and cardiovascular diseases, and reducing life expectancy.

- **Respiratory Diseases:** One of the most immediate and severe health impacts of poor air quality is on the respiratory system. Exposure to high levels of particulate matter (PM2.5 and PM10) can lead to chronic respiratory diseases such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). Children and the elderly are particularly vulnerable to these conditions. In Pakistan, it is estimated that over 128,000 deaths occur annually due to illnesses related to air pollution.
- **Cardiovascular Diseases:** Air pollution also has a significant impact on cardiovascular health. Fine particulate matter can penetrate deep

into the lungs and enter the bloodstream, leading to inflammation and oxidative stress. This can result in a range of cardiovascular diseases, including heart attacks, strokes, and hypertension. Studies have shown that long-term exposure to air pollution increases the risk of cardiovascular mortality.

- **Impact on Life Expectancy:** The overall impact of air pollution on life expectancy in Pakistan is profound. According to a report by the Energy Policy Institute at the University of Chicago, air pollution decreases the average life expectancy in Pakistan by 3.8 years. In the most polluted areas, such as Lahore, Sheikhupura, Kasur, and Peshawar, the reduction in life expectancy can be as much as seven years. This highlights the urgent need for effective measures to improve air quality in the country.
- **Economic Burden:** The health impacts of air pollution also translate into a significant economic burden. The cost of healthcare for treating diseases caused by air pollution is substantial. Additionally, there are indirect costs related to lost productivity and reduced workforce participation due to illness. The World Bank estimates that air pollution costs Pakistan around 5.88% of its GDP annually.
- **Vulnerable Populations:** Certain populations are more vulnerable to the health impacts of air pollution. These include children, the elderly, and individuals with pre-existing health conditions. Children are particularly at risk because their lungs are still developing, and they breathe more air per unit of body weight compared to adults. The elderlies are also more susceptible due to the natural decline in physiological functions and the presence of chronic diseases.
- **Government and Policy Response:** The government of Pakistan has recognized the severity of the air pollution problem and has taken steps to address it. Policies aimed at reducing emissions from industrial and vehicular sources have been implemented. However, enforcement remains a challenge. There is also a need for greater public awareness and community involvement in efforts to improve air quality.

Conclusion: Poor air quality in Pakistan poses a significant threat to public health, contributing to respiratory and cardiovascular diseases, reducing life expectancy, and imposing a substantial economic burden. Addressing this issue requires a multi-faceted approach, including stricter enforcement of environmental regulations, public awareness campaigns, and investment in cleaner technologies. Improving air quality is essential for

protecting the health and well-being of the population and ensuring sustainable development in Pakistan.

4.2 Economic Burden

There are a number of costs attached with air degradation and environmental pollution, including but not limited to the following:

- **Healthcare Costs:** The health impacts of air pollution translate into substantial economic costs. The treatment of respiratory and cardiovascular diseases caused by poor air quality places a significant burden on Pakistan's healthcare system. According to the World Bank, the economic cost of health impacts from air pollution in Pakistan is estimated to be around 5.88% of the country's GDP. This includes direct costs such as medical expenses and indirect costs such as lost productivity due to illness.
- **Loss of Agricultural Productivity:** Air pollution can reduce agricultural productivity by affecting crop health and yields. Pollutants such as ozone and particulate matter can damage crops, leading to lower yields and reduced quality of produce. This has economic implications for farmers and the agricultural sector, which is a vital part of Pakistan's economy. Reduced agricultural productivity can also lead to higher food prices and increased food insecurity.
- **Impact on Tourism:** Poor air quality can deter tourists from visiting affected areas, leading to a decline in tourism revenue. Pakistan's natural beauty, including its mountains, rivers, and cultural heritage sites, attracts tourists from around the world. However, air pollution can obscure scenic views, damage historical monuments, and pose health risks to visitors. This can result in a loss of income for local communities and businesses that rely on tourism.
- **Reduced Labor Productivity:** Air pollution can affect labor productivity by causing health problems that reduce workers' ability to perform their jobs effectively. Respiratory and cardiovascular diseases, as well as other health issues related to air pollution, can lead to increased absenteeism and reduced work capacity. This has economic implications for businesses and the overall economy, as reduced productivity can lower economic output and growth.
- **Infrastructure Damage:** Air pollution can also cause damage to infrastructure, including buildings, bridges, and roads. Pollutants such as sulfur dioxide and nitrogen oxides can lead to the corrosion

of materials, reducing the lifespan of infrastructure and increasing maintenance and repair costs. This has economic implications for both the public and private sectors, as resources must be allocated to address these issues.

Conclusion: The environmental and economic consequences of poor air quality in Pakistan are profound and far-reaching. Addressing this issue requires a comprehensive approach that includes stricter enforcement of environmental regulations, investment in cleaner technologies, and public awareness campaigns. Improving air quality is essential for protecting the environment, safeguarding public health, and ensuring sustainable economic development in Pakistan as air pollution imposes a heavy economic burden, with estimated annual losses of $20 - 22 billion USD, equivalent to 5.9% to 6.5% of Pakistan's GDP (World Bank, 2023). These costs arise from healthcare expenditures, lost labor productivity, and decreased agricultural yields.

5. Environmental Consequences of Poor Air Quality in Pakistan

Air pollution is also a critical issue in Pakistan, with respect to its significant environmental and economic consequences. The country's rapid industrialization, urbanization, and reliance on fossil fuels have led to deteriorating air quality, impacting both the environment and the economy.

- **Environmental Consequences:** Impact on Ecosystems: Air pollution adversely affects ecosystems, including forests, rivers, and agricultural lands. Pollutants such as sulfur dioxide (SO2) and nitrogen oxides (NOx) contribute to acid rain, which can damage soil, water bodies, and vegetation. Acid rain alters the pH balance of soil and water, making it difficult for plants and aquatic life to survive. This disruption in ecosystems can lead to a loss of biodiversity and negatively impact food chains.
- **Climate Change:** Air pollution is a significant contributor to climate change. Emissions of greenhouse gases (GHGs) such as carbon dioxide (CO2), methane (CH4), and black carbon from industrial activities, transportation, and agriculture increase the atmospheric concentration of these gases, leading to global warming. In Pakistan, the effects of climate change are already evident, with increased frequency and intensity of extreme weather events such as floods, droughts, and heatwaves. These changes pose a threat to agriculture, water resources, and human health.

- **Health of Flora and Fauna:** Air pollutants, particularly ground-level ozone (O3), can cause direct harm to plants by damaging their leaves, reducing photosynthesis, and impairing growth. This not only affects crop yields but also the health of natural vegetation. Wildlife is also impacted, as air pollution can lead to habitat degradation and reduced availability of food and water sources.

6. Air Quality Management Frameworks in Pakistan

6.1 Legislative and Policy Frameworks

The Environmental Protection Act (1997) is the cornerstone of air quality management in Pakistan. It mandates the establishment of air quality standards and monitoring systems. However, weak enforcement and limited institutional capacity hinder its effectiveness (MoCC, 2021). In March 2023, Pakistan approved the National Clean Air Policy (NCAP), followed by the Punjab Clean Air Plan (PbCAP) in April, aiming to address the country's deteriorating air quality. The major challenge that persist is the enforcement mechanism and its implementation. Pakistan's regulatory framework and policies have evolved significantly over the years to address various economic, social, and environmental challenges. The regulatory environment in Pakistan encompasses a wide range of sectors, including finance, industry, environment, and public health.

- **Environmental Regulations:** Environmental protection is a critical aspect of Pakistan's regulatory framework. The Pakistan Environmental Protection Agency (Pak-EPA) is responsible for enforcing environmental laws and regulations to ensure sustainable development and protect natural resources.
- **Air Quality Regulations:** The government has implemented various measures to control air pollution, including the establishment of air quality standards, the regulation of industrial emissions, and the promotion of cleaner technologies. The National Environmental Quality Standards (NEQS) set limits for various pollutants, including particulate matter, sulfur dioxide, and nitrogen oxides.
- **Public Health Regulations:** Public health is a priority for the government of Pakistan, and various regulations have been implemented to ensure the safety and well-being of the population. The Ministry of National Health Services, Regulations, and Coordination (NHSRC) oversees public health policies and regulations.

- **Challenges and Future Directions:** Despite significant progress, Pakistan's regulatory framework faces several challenges. These include weak enforcement mechanisms, limited resources, and bureaucratic inefficiencies. Corruption and lack of transparency also hinder effective regulation. To address these challenges, the government needs to strengthen regulatory institutions, enhance capacity building, and promote public awareness.

  In the future, Pakistan's regulatory framework must adapt to emerging challenges, such as climate change, digital transformation, and global economic shifts. This requires a proactive approach, with continuous monitoring and updating of regulations to ensure they remain relevant and effective.

Conclusion: Pakistan's regulatory framework and policies play a crucial role in promoting economic growth, ensuring environmental sustainability, and protecting public health. While significant progress has been made, there is a need for continuous improvement and adaptation to address emerging challenges. Strengthening regulatory institutions, enhancing enforcement mechanisms, and promoting transparency are essential for achieving sustainable development in Pakistan.

6.2 Monitoring Systems

The Pakistan Environmental Protection Agency (Pak-EPA) oversees air quality monitoring. However, the network is limited to a few cities, with outdated equipment and insufficient data reliability (Ahmad et al., 2021).

6.3 Role of Provincial Authorities

After the 18th Amendment, environmental management became a provincial responsibility. While Punjab has made strides with the Punjab Clean Air Action Plan, other provinces lag in implementing effective strategies.

7. Challenges in Air Quality Management

Air quality management in Pakistan faces several systemic, logistical, and socio-economic challenges. These barriers hinder the effective implementation of policies and exacerbate the deteriorating air quality across the country. Addressing these challenges is crucial for ensuring sustainable improvements in air quality.

7.1. Weak Regulatory Enforcement

Although Pakistan has laws like the Environmental Protection Act of 1997 and air quality standards, enforcement remains weak.

- Limited Penalties: Industries and individuals violating pollution regulations often face minimal or no penalties due to corruption, lack of oversight, or inefficiencies within regulatory bodies (Ministry of Climate Change [MoCC], 2021).
- Outdated Legislation: The existing laws are outdated and fail to address modern environmental challenges, such as the rise of e-waste and hazardous chemicals (Ahmad et al., 2021).

7.2. Insufficient Monitoring Infrastructure

A robust monitoring network is essential for tracking air pollution levels and identifying sources. However:

- Limited Coverage: Monitoring stations are concentrated in urban centers, leaving rural and peri-urban areas unmonitored.
- Outdated Equipment: Many monitoring systems are outdated and provide unreliable data, which hampers effective policymaking (World Bank, 2020).
- Real-Time Data Deficiency: The absence of real-time air quality reporting reduces public awareness and delays responses during pollution episodes like smog.

7.3. Institutional Fragmentation

The division of responsibilities among federal, provincial, and local governments leads to:

- Lack of Coordination: Overlapping jurisdictions and conflicting priorities among agencies undermine a unified approach to air quality management.
- Post-Devolution Challenges: After the 18th Amendment to the Constitution, environmental management became a provincial subject, resulting in uneven enforcement and policy gaps across provinces (Aslam et al., 2020).

7.4. Financial Constraints

Air quality management requires significant investment in monitoring equipment, pollution control technologies, and public awareness campaigns. However:

- Limited Budgets: Environmental protection receives a low allocation in national and provincial budgets.

- Reliance on Donor Funding: Many initiatives depend on foreign aid, which is not sustainable in the long term (Khan et al., 2020).

7.5. Public Awareness and Behavior

Low levels of public awareness and engagement exacerbate the problem:

- Lack of Knowledge: Most citizens are unaware of the health impacts of air pollution and the role of individual behavior in contributing to it.
- Cultural Norms: Practices such as open waste burning and reliance on biomass fuels for cooking persist due to cultural and economic reasons (Iqbal & Shah, 2019).
- Resistance to Change: Adoption of cleaner technologies, such as electric vehicles, faces resistance due to high initial costs and lack of incentives.

7.6. Agricultural Practices

Agriculture contributes significantly to seasonal air pollution, particularly in Punjab:

- Crop Residue Burning: Farmers often burn crop residues due to a lack of affordable alternatives, contributing to smog.
- Lack of Awareness: Despite efforts to introduce alternatives like Happy Seeders, many farmers are unaware of or unwilling to adopt them (Khan et al., 2020).

7.7. Industrial Pollution.

Industries are among the largest contributors to air pollution but operate with minimal oversight:

- Brick Kilns: Traditional kiln methods are highly polluting, yet many remain operational due to weak regulations and limited incentives for modernization.
- Energy Sector: The reliance on coal and other fossil fuels for energy generation results in high levels of SO_2 and NO_x emissions.
- Lack of Pollution Control: Most industries do not employ modern pollution control technologies due to cost concerns (Ahmad et al., 2021).

7.8. Transboundary Pollution

Air pollution does not respect national borders, and regional factors exacerbate Pakistan's challenges:

- Smog from India: Crop residue burning in northern India contributes to smog in Punjab and Sindh.
- Lack of Regional Cooperation: Despite the shared nature of the problem, there is minimal collaboration between South Asian countries to address transboundary air pollution (World Health Organization [WHO], 2022).

7.9. Urbanization and Traffic Congestion

Rapid urbanization has outpaced the development of infrastructure, contributing to:

- Vehicular Emissions: The use of outdated vehicles, poor fuel quality, and lack of emission standards enforcement are significant contributors.
- Poor Public Transport: Limited access to reliable public transport forces reliance on private vehicles, increasing pollution levels (Lancet Countdown, 2021).

7.10. Climate Change and Environmental Factors

Climate change exacerbates air quality challenges by altering weather patterns and intensifying pollution episodes:

- Atmospheric Inversions: Cooler temperatures during winter trap pollutants near the surface, leading to smog.
- Extreme Weather Events: Dust storms and wildfires contribute to particulate pollution, particularly in arid regions.

8. International Strategies for Air Quality Management and Best Practices

Countries worldwide have faced similar air pollution challenges and have implemented successful strategies to improve air quality. Pakistan can draw valuable lessons from these experiences and adapt them to its unique context.

8.1 Case Study: China's Air Pollution Control

China's Air Pollution Prevention and Control Action Plan (2013–2017) serves as a global benchmark for rapid improvements in air quality. Over four years, China achieved a 33% reduction in PM2.5 concentrations in the Beijing-Tianjin-Hebei region (Chen et al., 2020). The following strategies underpinned its success:

- **Strict Emission Standards:** China enforced stringent emission standards for industries and vehicles, phasing out older, inefficient models and equipment.
- **Coal Control Policies:** A transition away from coal-burning industries and residential heating significantly reduced SO_2 emissions.
- **Enhanced Monitoring Systems:** An extensive air quality monitoring network provided real-time data, enabling effective policymaking and public awareness.
- **Public Transportation Investments:** Expansion of subway and bus networks reduced vehicular emissions in urban centers.

8.2 Case Study: India's National Clean Air Programme (NCAP)

Launched in 2019, India's NCAP is a time-bound initiative aiming to reduce PM2.5 and PM10 concentrations by 20–30% by 2024. Key measures include:

- **City-Specific Action Plans:** Each city develops customized action plans addressing local sources of pollution.
- **Electric Vehicle Promotion:** Subsidies and incentives have accelerated the adoption of electric vehicles (EVs).
- **Crop Residue Management:** India introduced machines such as Happy Seeders and awareness campaigns to discourage burning of crop residues (Central Pollution Control Board, 2019).

8.3 European Union (EU): Integrated Policies

The EU Clean Air Policy Package emphasizes an integrated approach combining climate and energy policies to tackle air pollution:

- **Renewable Energy Targets:** Transitioning to wind, solar, and hydropower reduced dependency on fossil fuels.
- **Cross-Border Collaboration:** EU nations coordinate on transboundary air pollution control, a model relevant for Pakistan's regional smog issue with India.
- **Citizen Engagement:** Public awareness campaigns ensure that citizens understand the link between daily activities and air pollution.

8.4 Lessons for Pakistan

Strengthen Monitoring and Transparency: Pakistan can enhance its air quality monitoring systems, leveraging low-cost sensors and mobile

technologies to provide real-time data. Collaboration with international organizations such as WHO and UNDP could assist in technology transfers.

Adopt Regional Cooperation Models: Cross-border air pollution issues, such as the seasonal smog from crop burning, require joint efforts between Pakistan and neighboring India. Bilateral agreements could mitigate regional impacts.

Public Awareness and Education: Nationwide awareness campaigns, similar to China's "War on Smog," can educate the public on reducing pollution at individual and community levels. Schools, workplaces, and religious institutions could be platforms for spreading these messages.

Urban Planning and Public Transport: Investments in public transport and green urban planning can mitigate vehicular emissions. Introducing congestion charges in high-traffic zones, as implemented in London, could also be considered.

Technological innovations and best practices are essential to mitigate air pollution and improve air quality. Some of the key technological advancements and best practices in air quality management those may help in air quality in Pakistan are as follows:

Key Technological Innovations: Technological innovations are important to mitigate air pollution and improve air quality. Some of the key technological advancements in air quality management those may help in air quality in Pakistan are as follows:

- **Smart Air Quality Monitoring Systems:** Smart air quality monitoring systems are essential tools for tracking and managing air pollution. These systems use advanced sensors and data analytics to provide real-time information on air quality parameters such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3). By continuously monitoring air quality, these systems enable authorities to identify pollution hotspots and take timely action to mitigate pollution.
- **Introduce Cleaner Technologies:** Modernizing brick kilns using zigzag technology, as piloted in Punjab, should be expanded nationally. Similarly, subsidies for industries adopting pollution control mechanisms can incentivize cleaner production methods.
- **Catalytic Converters:** Catalytic converters are devices used in vehicles to reduce harmful emissions. They work by converting toxic gases such as carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbons (HC) into less harmful substances like carbon dioxide

(CO2) and water vapor. The widespread adoption of catalytic converters in vehicles can significantly reduce vehicular emissions, which are a major source of air pollution in urban areas.

- **Renewable Energy Technologies:** Renewable energy technologies, such as solar and wind power, play a crucial role in reducing air pollution. By generating electricity from clean energy sources, these technologies help reduce the reliance on fossil fuels, which are major contributors to air pollution. Pakistan has made significant investments in renewable energy projects, such as the Quaid-e-Azam Solar Park and the Jhimpir Wind Corridor, to promote sustainable energy production.
- **Electrostatic Precipitators:** Electrostatic precipitators are devices used in industrial processes to remove particulate matter from exhaust gases. They work by applying an electric charge to particles in the gas stream, causing them to be attracted to and collected on charged plates. This technology is highly effective in reducing industrial emissions and improving air quality.
- **Biofiltration and Bioremediation:** Biofiltration and bioremediation are innovative technologies that use biological processes to remove pollutants from the air. Biofilters use microorganisms to degrade and remove pollutants from air streams, while bioremediation involves the use of plants and microorganisms to clean up contaminated environments. These technologies offer sustainable and cost-effective solutions for air pollution control.

8.5 Best Practices for Air Quality Management

- **Implementing Air Quality Standards:** Establishing and enforcing air quality standards is a fundamental best practice for managing air pollution. The World Health Organization (WHO) provides global air quality guidelines that set recommended levels for key pollutants. Adopting these guidelines and setting legally binding standards can help protect public health and ensure cleaner air.
- **Pollution Prevention and Control:** Pollution prevention and control strategies are essential for reducing emissions at the source. This includes using cleaner production techniques, adopting low-emission technologies, and implementing best practices in industrial processes. For example, industries can use cleaner fuels, improve energy efficiency, and install pollution control devices to minimize emissions.

- **Promoting Public Awareness and Education:** Raising public awareness and educating communities about the health impacts of air pollution and the importance of air quality management is crucial. Public awareness campaigns can encourage individuals to adopt environmentally friendly practices, such as reducing vehicle use, conserving energy, and supporting clean energy initiatives.
- **Enhancing Regulatory Frameworks:** Strengthening regulatory frameworks and ensuring effective enforcement of environmental regulations are critical for improving air quality. This includes updating existing laws, introducing new regulations, and enhancing the capacity of regulatory agencies to monitor and enforce compliance. Effective regulation can drive industries and businesses to adopt cleaner technologies and practices.
- **Encouraging Research and Innovation:** Investing in research and innovation is essential for developing new technologies and solutions for air pollution control. Governments, academic institutions, and private sector organizations should collaborate to support research initiatives and promote the development and deployment of innovative air quality management technologies.
- **Implementing Green Infrastructure:** Green infrastructure, such as urban forests, green roofs, and parks, can help improve air quality by absorbing pollutants and providing cleaner air. Integrating green infrastructure into urban planning and development can create healthier and more sustainable cities.
- **International Collaboration:** Air pollution is a global issue that requires international collaboration and cooperation. Countries can share best practices, technologies, and resources to address air pollution effectively. Participating in international agreements and initiatives, such as the Paris Agreement, can help Pakistan align its air quality management efforts with global standards and goals.

Conclusion: Technological innovations and best practices are essential for addressing the air quality challenges in Pakistan. By adopting smart air quality monitoring systems, catalytic converters, renewable energy technologies, electrostatic precipitators, and biofiltration, Pakistan can significantly reduce air pollution. Implementing air quality standards, promoting public awareness, enhancing regulatory frameworks, encouraging research and innovation, and integrating green infrastructure are key best practices for effective air quality management. International collaboration and cooperation are also crucial for achieving sustainable air

quality improvements. By embracing these innovations and best practices, Pakistan can create a cleaner and healthier environment for its citizens.

9. Recommendations

9.1 Strengthen Policy Enforcement

To effectively address air pollution, it is essential to have robust environmental regulations in place and to enforce existing laws with stricter penalties for violations. Develop sector specific emission reduction targets. This includes:

- Updating and enforcing National Environmental Quality Standards (NEQS) for air pollutants.
- Implementing stricter emission standards for vehicles and industries.
- Regulating the use of solid fuels and promoting cleaner alternatives.

9.2 Expand Monitoring Networks

Accurate monitoring and reporting of air quality data are critical for effective regulatory enforcement. This can be achieved by Investing in modern air quality monitoring systems and establish monitoring stations in all major urban centers:

- Expanding the network of air quality monitoring stations across the country.
- Using advanced technologies, such as satellite imagery and remote sensing, to monitor air pollution levels.
- Ensuring that air quality data is publicly accessible and regularly updated.

9.3 Capacity Building for Regulatory Agencies: Strengthening the capacity of regulatory agencies is essential for effective enforcement of air quality regulations. This includes:

- Providing training and resources to environmental inspectors and enforcement officers.
- Enhancing the technical capabilities of regulatory agencies to monitor and analyze air quality data.
- Establishing clear protocols for inspection, enforcement, and penalties for non-compliance.

9**.4 Promoting Compliance through Incentives and Penalties:** Encouraging compliance with air quality regulations requires a balanced approach of incentives and penalties. This can include:

- Offering financial incentives, such as tax breaks and subsidies, for industries and businesses that adopt cleaner technologies and practices.
- Implementing strict penalties for violations of air quality regulations, including fines and legal action.
- Recognizing and rewarding businesses and communities that demonstrate exemplary efforts in reducing air pollution.

9.5 Strengthening Inter-agency Coordination: Effective air quality management requires coordination among various government agencies, including environmental, health, transportation, and energy departments. This can be achieved by strengthening coordination between federal, provincial, and local authorities. Establish a centralized body for air quality management.

- Establishing interagency task forces to develop and implement comprehensive air quality management plans.
- Facilitating regular communication and collaboration among agencies to address cross-cutting issues.
- Ensuring that air quality considerations are integrated into policies and planning processes across sectors.

9.6 Promote Sustainable Practices

Encourage public transport, electric vehicles, and clean energy transitions. Incentivize industries to adopt pollution control technologies.

9.7 Public Awareness Campaigns

9.7.1 Enhancing Public Awareness and Education

Launching comprehensive public awareness campaigns is essential to educate the population about the sources and health impacts of air pollution. These campaigns can utilize various media platforms, including television, radio, social media, and print media, to reach a wide audience. The campaigns should focus on:

- The health risks associated with air pollution, such as respiratory and cardiovascular diseases.
- The importance of reducing emissions from vehicles, industries, and households.
- Practical steps individuals can take to reduce their exposure to air pollution, such as using public transportation, carpooling, and reducing the use of solid fuels for cooking and heating.

9.7.2 School Education Programs: Integrating air quality education into school curricula can help raise awareness among young people. Educational programs should include:

- Lessons on the causes and effects of air pollution.
- Activities that encourage students to engage in environmental protection, such as tree planting and recycling.
- Projects that involve monitoring local air quality and developing solutions to reduce pollution.

9.7.3 Community Engagement: Engaging communities in air quality improvement initiatives can foster a sense of ownership and responsibility. Community-based programs can include:

- Workshops and seminars to educate residents about air pollution and its impacts.
- Community-led monitoring programs where residents use low-cost sensors to measure local air quality.
- Initiatives to promote the use of clean energy sources, such as solar panels and biogas.

9.7.4 Collaboration with NGOs and Civil Society: Non-governmental organizations (NGOs) and civil society groups play a crucial role in raising awareness and advocating for cleaner air. Collaborating with these organizations can amplify the reach and impact of public awareness efforts. NGOs can:

- Conduct research and disseminate information on air quality issues.
- Organize events and campaigns to mobilize public support for air quality initiatives.
- Provide training and resources to communities and schools.

10. Conclusion

Air pollution poses a significant threat to Pakistan's public health, economy, and environment. While existing frameworks provide a foundation, proactive measures, stakeholder collaboration, and international best practices are essential to achieve sustainable air quality management. Addressing these challenges will ensure healthier lives, a robust economy, and a resilient environment for future generations.

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