Paper No.374

UNDERSTANDING THE RELATIONSHIP BETWEEN AIR POLLUTION AND METEOROLOGICAL CONDITIONS AND FINDING SOLUTIONS TO AIR POLLUTION PROBLEMS AT THE COMMUNITY AND INDIVIDUAL LEVEL

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By

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Abstract:

Air pollution and particulate matter have merged as a global challenge in recent years so much that smog is being called a fifth season in Pakistan, especially in big cities, and urbanization, industrialization, and increasing fossil fuel consumption are generally identified as the main contributors to poor air quality making it an alarming and global issue of the modern scientific world. Air pollution can have several impacts on weather patterns. However, the relationship is complex and can vary depending on the type and concentration of pollutants, as well as regional meteorological conditions. Additionally, the feedback mechanisms between air pollution and weather are intricate, and research in this field is ongoing to better understand these complex interactions. The intensity and impacts of the risks associated with air pollution have become more pronounced, especially in developing countries like Pakistan that lack adequate warning, protection, and management systems. Adequate abatement and prevention measures should be established at National, Provincial, community and individual levels which cover the legislative frameworks, policy gaps, and targeted solutions. Mere monitoring is not going to be helpful anymore. London, Chicago, Los Angeles, and a host of other Western cities have all done remarkably well on this front. Closer to home, the example of Chinese cities and their ability to improve domestic environmental conditions over the preceding three decades is frequently cited as an example worthy of emulation. However, the Pakistani state is a low-capacity country with limited infrastructural power. Citizens can also take charge and initiate some community-based projects and start businesses that promote not only environmentally friendly strategies, but entrepreneurs can develop technologies which can help with the control of existing pollution.

Introduction:

Air pollution in Pakistan, particularly in urban locales, manifests as a pronounced environmental concern, with smog emerging as a consequential type of pollution resulting from the amalgamation of smoke and fog. This atmospheric phenomenon contains a spectrum of pollutants including particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO), and volatile organic compounds (VOCs). Principal contributors to smog pollution encompass industrial emissions, vehicular exhaust, the combustion of crop residues following agricultural activities, and the utilization of substandard fuels. The agricultural sector, especially the practice of post-harvest burning of crop residues, releases substantial quantities of particulate matter and diverse pollutants into the atmosphere (Waseem, R. *et al*., 2021). Concurrently, the industrial sector, comprising factories and power plants, significantly contributes to air pollution through the emission of pollutants such as sulfur dioxide, nitrogen oxides, and particulate matter. The escalating number of vehicles, particularly those employing obsolete technology or substandard fuels, amplifies air pollution levels, with traffic congestion exacerbating the issue. In addition, the use of antiquated technology in energy production and consumption, exemplified by brick kilns and outdated power plants, further contributes to air pollution (Anwar, M.N. *et al*., 2021). Geographical features, notably surrounding mountains, can induce temperature inversions, ensnaring pollutants in the atmosphere and fostering smog formation. Inadequate enforcement of environmental regulations, coupled with a deficiency in stringent emission standards for industrial and vehicular sources, compounds elevated pollution levels. Improper disposal of solid waste, encompassing the incineration of materials, releases deleterious pollutants into the air. Insufficient public awareness regarding the ramifications of air pollution and the imperative of sustainable practices perpetuates environmental degradation. The consequences of smog pollution extend comprehensively, encompassing respiratory and cardiovascular health issues, as well as environmental ramifications, such as adverse effects on crops and ecosystems. Effectively mitigating smog pollution in Pakistan necessitates a comprehensive approach, encompassing the stringent enforcement of environmental regulations, the advocacy and adoption of cleaner technologies, widespread public awareness campaigns, and the promotion of sustainable agricultural practices. International collaboration and support are imperative in devising and implementing solutions to this pressing environmental challenge (Anjum M.S. *et al*., 2021).

The complex relationship between Meteorology and Ambient air pollution:

It is a well-established concept that air pollution, especially particulate matter (PM) and aerosols, can absorb and scatter sunlight. This alters the energy balance in the atmosphere, leading to changes in temperature patterns impacting the overall energy balance in the atmosphere, the interaction between air pollution and temperature regulation is not always straightforward. For instance, certain pollutants can have both heating and cooling effects depending on their altitude and other atmospheric conditions (UCAR Center for Science Education). In urban areas with high pollution levels, the surface temperature may increase due to the absorption of solar radiation by pollutants (Baklanov A. *et al*., 2016). Study by Baklanov A. *et al*., explores the historical relationship between air pollution and meteorological conditions and provides insights into potential future impacts. It discusses the complex interactions between pollutants and meteorology, including the influence of pollutants on regional climate patterns. In a few reported cases, sulfur aerosols can cause a drop in temperatures causing harsh winter conditions. Sulfur dioxide (SO2) is released into the atmosphere primarily through the combustion of fossil fuels, especially coal and oil. Sulfur dioxide undergoes chemical reactions in the atmosphere, particularly in the stratosphere, to form sulfate aerosols. These aerosols consist of tiny particles of sulfuric acid. The formation of sulfate aerosols is a key step in the cooling process, as these particles have the ability to reflect incoming solar radiation back into space (US EPA). Sulfate aerosols can have a more pronounced impact on winter weather, contributing to harsher winter conditions in some areas. Aerosols can also act as cloud condensation nuclei (CCN) (Bowen Zhang, 2020), affecting the formation and properties of clouds. Increased aerosol concentrations can lead to more numerous but smaller cloud droplets, influencing cloud microphysics, Fiore A. M., *et al*., 2015 used modelling techniques to investigate the impact of air pollution on weather patterns. It considers the effects of aerosols on cloud properties and precipitation, highlighting the role of pollution in modulating regional meteorological conditions. this study examines the bidirectional relationship between air pollution and meteorological conditions. It discusses how pollutants like particulate matter and aerosols can influence cloud formation, precipitation patterns, and temperature, ultimately impacting the meteorological environment. Changes in cloud properties can impact precipitation patterns and the overall energy balance of the atmosphere, it can also impact the timing, intensity, and spatial distribution of rainfall (Yang, Y. *et al*., 2022). A study done by Alizadeh-Choobari, O. and Gharaylou, M. 2017 delves into the

relationship between air pollution and cloud properties. It discusses how aerosols can influence cloud condensation nuclei and affect precipitation processes, providing evidence of the impact of pollution on meteorological phenomena. High concentrations of pollutants can reduce visibility and can alter local wind patterns. For example, tall buildings and urban structures can disrupt natural wind flow, leading to the development of localized wind patterns known as urban heat islands. The presence of pollutants in the atmosphere can also affect atmospheric stability, influencing the vertical and horizontal movement of air masses. Prolonged exposure to high levels of air pollution can have long-term impacts on regional climate patterns. These effects may include changes in temperature, precipitation, and atmospheric circulation (Pérez I. A. *et al*., 2020), The study done by Pérez I. A. *et al* investigates the effects of air pollution on local climate, specifically focusing on how aerosols can alter the radiative balance, affect cloud properties, and modify precipitation patterns. It emphasizes the need to consider both meteorological and pollution factors in climate modelling. It's important to note that the specific impact of air pollution on meteorological conditions can vary depending on the type and concentration of pollutants, local geography, and weather patterns. Additionally, the interactions between air pollution and meteorology are complex and can involve feedback loops and nonlinear relationships. Literature also proves the impact of air pollution on meteorological conditions. The complex interactions between climate change and air quality imply that future policies to mitigate these twin challenges will benefit from greater coordination (Mir, K.A. *et al*., 2022) (The World Bank).

Strategies for Mitigation and Control of Smog in Pakistan:

Implementing measures to prevent smog in Pakistan necessitates a strategic, long-term approach, as relying solely on reactive solutions post-calamity proves inadequate for addressing the intricacies of this environmental challenge. Comprehensive planning and policy formulation are imperative to proactively avert air pollution disasters. Successful examples from various global cities, such as London, Chicago, Los Angeles, and notably, Chinese cities over the past three decades, underscore the efficacy of sustained efforts in improving air quality and public health outcomes. It is essential to recognize that the primary precursors of smog predominantly arise from anthropogenic emissions, emphasizing the critical need for effective "prevention and control" measures to counteract smog formation. Numerous strategies have been devised at local, regional, and international levels to address this issue. However, the prevention of smog necessitates a multifaceted approach,

often requiring a combination of regulatory, economic, social, and technical interventions working synergistically. While each documented activity independently contributes to mitigating smog formation and associated risks, their collective implementation yields the most impactful results. An in-depth exploration of diverse potential preventive measures, encompassing technical, fundamental, and administrative aspects, tailored specifically to the context of Pakistan, is indispensable for devising a comprehensive and effective strategy.

1: Technological Interventions for Smog Mitigation:

The Republic of Pakistan has experienced a pronounced surge in population and economic development, leading to a substantial increase in transportation activities, consequently emerging as a primary catalyst for smog incidents. Approximately fifty percent of global emissions of volatile components with detrimental effects on air quality originate from vehicular sources. The transportation sector in Pakistan confronts significant challenges, necessitating a paradigm shift towards cleaner vehicle models and the enforcement of legislation concerning vehicle maintenance and monitoring (Shah and Arooj, 2019).

The proliferation of private vehicles, particularly evident in Punjab province, housing approximately 19.6 million vehicles, including 6.2 million in Lahore alone (Zahid, 2020), poses a formidable threat to air quality. Notably, two-stroke engine vehicles such as motorcycles and motorized rickshaws, prevalent in Lahore, stand out as highly polluting combustion engine vehicles. The substantial number of private vehicles substantially contributes to the emission of gaseous pollutants, serving as prominent precursors for smog production. To address this burgeoning issue, a reduction in private car usage and the endorsement of public transport, potentially through the establishment of "low emissions zones" akin to those in London (2020), represent pivotal measures. The implementation of mass transit railway systems, such as high-speed electric trains, could profoundly improve air quality, a step exemplified by the introduction of the orange train line in Lahore by the previous government. Furthermore, effective policies for monitoring and managing traffic congestion play a pivotal role in curtailing harmful emissions and subsequent smog formation. Reinforcing monitoring and emission policies for new automobiles, diminishing direct emissions per unit distance, advocating for renewable energy vehicles, and embracing clean technologies constitute fundamental measures to progressively mitigate the likelihood of smog events. Routine vehicle maintenance and inspections significantly contribute to emission reduction. The engine's condition holds crucial importance in determining pollutant

emissions, emphasizing the imperative need for regular tuning and consistent inspection of components such as the engine case ventilating system, muffler, and fuel system. Recent advancements in the automobile industry have introduced the concept of hybrid motors to promote the use of environmentally friendly energy sources (Prajapati *et al*., 2014). Additionally, advanced combustion modes employ plug-in hybrid electric vehicle technology to reduce CO2, nitrogen oxides, and soot emissions by 12-30%. Nevertheless, considerations regarding operational and manufacturing costs, as well as extended recharging times, necessitate thorough evaluation, as consumer reluctance may persist until such options are deemed more user-friendly compared to existing technologies. Not only that companies like “Chakr Innovations Graviky Labs” (start-up businesses by young engineers in the neighbour country) have introduced devices which can convert smoke in exhaust fumes into an ink product. This ink is used globally by renowned painters and artists to symbolize and encourage sustainable practices (The World Economic Forum).

2: Strategies to Mitigate Industrial Air Pollution in Pakistan:

As an emerging economy, Pakistan encounters challenges in consistently adopting preventative measures to mitigate emissions responsible for smog and alleviate its consequential impacts. The country harbours a significant number of registered vehicles and industries that often lack advanced technologies to curtail emissions leading to smog formation. Notably, the brick manufacturing process, a key contributor to industrial emissions, typically involves chimney-based brick kilns fueled by wood, crop residue, and coal (Sarfraz, 2020; Shabbir *et al*., 2019). With approximately 20,000 brick kilns in operation, many situated in close proximity to urban centres, substantial environmental challenges arise due to emitted pollutants (Khan *et al*., 2019). To mitigate smog incidents emanating from industrial activities, the brick industry in Pakistan must prioritize emission reduction. Implementing solutions such as smoke treatment with wet or dry filters, utilization of purifiers, and adoption of modern artisanal brick kilns are pivotal steps in addressing this environmental concern. Incorporating air pollution control equipment, including baffle arrangements within chimneys, and integrating gas bypass systems can significantly contribute to pollution mitigation. Technological upgrades, such as the introduction of mechanical feeders and cleaner methods like vertical shaft kilns, can ensure more efficient coal combustion, consequently reducing emissions (Skinder *et al*., 2014). In the quest for sustainable industrial practices, the transition from conventional fossil fuels to renewable energy sources, such as solid waste and biomass fuels, is being explored as a viable option to power future

industries in Pakistan. This transition aims to decrease methane and NOx emissions originating from landfills. Chemical pollution resulting from anthropogenic activities, notably industrial emissions, significantly contributes to environmental degradation with global implications. Coal, a predominant source accounting for over 90% of industrial emissions worldwide, surpasses other anthropogenic sources such as mercury mining, gold smelting, nonferrous smelting, iron steel production, domestic wastes, and cement production (Huang *et al*., 2017). To address this, substituting industrial fuels with alternatives such as oil and gas, coupled with the exploration of renewable energy sources for energy generation, emerges as an effective strategy to mitigate smog formation in Pakistan (Liu *et al*., 2016).

The escalation of smog in Pakistan due to rapid industrialization and domestic activities necessitates a strategic approach. Ali *et al*. (2019) employed the fuzzy VIKOR model to formulate suitable environmental policies, showcasing the potential to diminish industrial contributions to smog formation. The model suggests curtailing industrial waste and educating various communities, particularly farmers, on emission reduction strategies as effective measures. This model holds promise for guiding the Pakistani government in shaping future policies. In a recent initiative, Saeed and colleagues have undertaken the construction of a 25-foot solar-powered smog-cleaning tower in Pakistan. This project, designed to deliver smog-free, clean air to approximately 90,000 residents in the surrounding area, reflects a pioneering effort towards sustainable solutions.

3: Enhancing Air Quality through the Expansion of Greenery: A Scientific Perspective:

The reduction of smog levels by 10% can be achieved through strategic afforestation efforts, as trees play a crucial role in lowering air temperature, according to studies conducted by Roheela Yasmeen *et al*., 2021. Notably, Lahore experiences severe air pollution between November and February, leading to a pervasive haze enveloping the city and extending to districts of Khyber Pakhtunkhwa province in Pakistan (Jahan *et al*., 2019). Scholars underscore the pivotal role of augmenting green cover in mitigating environmental pollution, including smog (Saxena, 2014). Globally, governments have implemented policies, such as afforestation projects around major industrial cities, establishing green barriers between industrial and urban zones. The government of Pakistan has launched the Billion Tree Tsunami Afforestation Project, a successful nationwide initiative aimed at bolstering plantation efforts (Kamal, A. *et al*., 2019).

The proliferation of greenery and forested areas contributes significantly to microclimate regulation, providing shelter from heat waves and enhancing the atmosphere with oxygen. Research conducted by Leung *et al*. (2011) indicates that shade can reduce extreme smog concentrations by 5%, equivalent to a substantial reduction in smog precursor NOx by 175 tons/day, (25 times more effective than the 4 tons/day reduction achieved by cutting power plant emissions). In response to escalating pollution levels, particularly in densely populated urban centres like Lahore, Karachi, and Islamabad, Pakistan has initiated the gradual adoption of electric vehicles (EVs) (Abedullah. 2022). The government incentivizes EV usage by providing tax benefits to manufacturers and consumers. Challenges, such as high initial costs, limited charging infrastructure, and consumer concerns about range limitations, have impeded widespread EV adoption. Nonetheless, select companies have introduced electric cars and bikes into the market, marking a promising albeit nascent step towards an eco-friendly transportation system in Pakistan. Ongoing efforts are focused on expanding charging facilities and formulating policies to encourage the transition to EVs, aiming to reduce carbon emissions and promote cleaner transport alternatives in the country.

Furthermore, the introduction of Green Roofs and Walls on personal properties emerges as a viable strategy to absorb pollutants and enhance air quality in urban areas. Cities worldwide are increasingly integrating green spaces, planting trees, and establishing urban forests to absorb pollutants and improve air quality. Exemplifying this, cities like Milan and London have initiated tree-planting campaigns, with innovative architectural designs incorporating vertical forests, such as the Bosco Verticale in Milan, demonstrating the efficacy of planting numerous trees on buildings to capture pollutants and generate oxygen.

4: Promoting Healthier Practices to Mitigate Smog Impact:

Recognizing the substantial contribution of vehicular emissions to smog formation, the adoption of simple preventative measures, such as walking, biking, and utilizing public transportation, stands as an effective approach. Additionally, transitioning towards eco-friendly consumer products characterized by low volatile organic compounds (VOCs) in materials such as paints, papers, plastics, and sprays can significantly contribute to the mitigation of air pollution. The significance of such individual initiatives in reducing personal health risks during smog events is undeniable. The Provincial Disaster Management Authority (PDMA) in Pakistan has issued guidelines advocating against outdoor activities during smog events (PDMA, 2017). These guidelines also promote the use of masks and

emphasize the importance of employing and maintaining indoor air filters for enhanced protection (Siddique, M.U., *et al*., 2023).

5: Elevating Public Awareness on Smog Mitigation:

A study conducted by Siddiqui A. *et al*., in 2023 demonstrated the efficacy of utilizing social media as a potent tool in addressing smog and other climate-related issues through a well-structured and target-oriented climate communication strategy. The imperative of educating the public regarding the detrimental effects of smog on both human health and the environment cannot be understated (Ahsan *et al*., 2020; Wang *et al*., 2016). The dissemination of information about the hazardous effects of smog through informative sessions and preventive programs is pivotal in fostering public understanding. Studies, such as the one by Ahsan *et al*. (2020), reveal that sociodemographic factors, particularly education levels, play a vital role in comprehending smog hazards and related policies among residents, particularly in Lahore. Leveraging online media content and mobile applications to alert the public about the severity of air pollution empowers individuals to take proactive measures such as staying indoors and minimizing physical exertion (Li, X. & Tilt, B. 2019).

6: Social and Behavioral Dynamics in Addressing Air Pollution:

The incorporation of trust in disseminated information emerges as a critical element in effecting meaningful change. A notable example is the initiative undertaken by China in 2013-2014, wherein real-time air quality assessments were provided. This initiative resulted in significant shifts in household behaviour, heightened online searches related to pollution, alterations in consumption habits to reduce pollution exposure, and an increased willingness to pay for housing in less polluted areas (Barwick *et al*., 2019). The consequential short- and long-term behavioural changes stemming from this initiative led to a substantial nearly 7% reduction in mortality attributable to air pollution. The estimated annual benefits, amounting to approximately 18 billion USD, far surpassed the associated costs of the program (Ito, K. and Zhang, S. 2020). In light of such successes, the promotion of improved public awareness and the encouragement of social and behavioural changes are strongly recommended as integral components in addressing smog episodes and their adverse effects in the context of Pakistan.

7: Alternative Approaches for Managing Crop Residues: A Sustainable Paradigm

The combustion of crop residues contributes significantly to air pollution and poses environmental challenges (Anjum M.S. *et al*., 2021). However,

there exist alternative methods that are more sustainable and environmentally friendly for dealing with crop residues. In situations where expeditious action is imperative, and the objective is to efficiently manage crop residues without resorting to burning, rapid alternatives can be implemented. Farmers can be equipped with machinery such as shredders or chippers to expediently break down crop residues into smaller fragments. This facilitates swift decomposition and seamless incorporation into the soil. Flail mowers stand out as effective tools for cutting and chopping crop residues, reducing their size and promoting accelerated decomposition. High-speed tillage equipment proves advantageous for swiftly incorporating crop residues into the soil, expediting decomposition and nutrient release. In instances where bioenergy is in demand, crop residues can be utilized as feedstock for biogas production or other bioenergy applications. The establishment of windrows for composting crop residues, while conventional composting may be time-consuming, can be accelerated through proper management. Additionally, the conversion of crop residues into biochar, a stable form of charcoal, offers a viable approach. Biochar can serve as a beneficial soil amendment, concurrently aiding in carbon sequestration. Globally, diverse practices and initiatives are being implemented to capture and mitigate air pollution not only that agricultural residues containing immense amount of biochemicals, nutraceuticals can used for the extraction of these compounds with ecofriendly techniques (Anwar, M.N. *et al*., 2021).

8: Facilitating Data Sharing and Integration at National and Regional Levels to Address Air Pollution:

Promoting the dissemination of air quality data, which is real-time and collected long-term, among regional entities, governmental agencies, and research institutions is imperative (Liu, Y. *et al*., 2020). The development of platforms or systems that enable the seamless integration of data from diverse sources is essential to generate comprehensive regional datasets. Encouraging collaborative research projects involving multiple stakeholders, including government agencies, academic institutions, and industry partners, is paramount. This approach fosters the exchange of knowledge and expertise, addressing specific regional air pollution challenges. The scientific consensus, as evident in the aforementioned studies, underscores the significant impact of air pollution on meteorological conditions, influencing various facets of the Earth's atmosphere and climate. In Pakistan, substantial research is warranted in this domain to comprehend the intricate dynamics of meteo-pollution and their mutual influence. The attainment of effective research outcomes necessitates

interdepartmental collaborations at the national level (Anwar, M.N. *et al*., 2021). Moreover, research and development activities, coupled with prompt data sharing on technological innovation and capacity building, must extend to the regional level, given the transboundary nature of pollution issues and the potential regional impacts on weather conditions. Successful collaboration on national and regional levels demands the standardization of monitoring methods, ensuring scientific data accessibility through a consolidated dashboard or website for all stakeholders. Additionally, harmonizing policies across regions and advocating for common monitoring equipment and technologies are critical for data comparability. Continuous evaluation and adaptation of prevention and control activities against pollution challenges are imperative for sustainability.

These strategies collectively contribute to a more coordinated and effective regional approach to addressing air pollution. However, the efficacy of such endeavors hinges on the commitment and collaboration of diverse stakeholders. Individual and community initiatives hold substantial potential to significantly reduce air pollution. By embracing sustainable practices and advocating for change, communities can play a pivotal role in fostering a cleaner and healthier environment. The exemplary case of Beijing provides valuable insights and guidelines for adopting similar strategies. However, the applicability of the Chinese model for environmental policies is intricate. Recent analyses by environmental economist Dr. Sanval Nasim identify China as a high-capacity, well-resourced state with a robust bureaucracy capable of taking on challenging, often costly measures to control local populations. The centralised, disciplined governance apparatus in China allows for effective enforcement, including the banning of old vehicles, sanctions against polluters, and imposition of substantial fines. Conversely, the Pakistani state is characterized as a low-capacity entity with limited infrastructural power, struggling to coordinate across multiple state and societal actors. Challenges include difficulties in implementing orders, leakages, and resource constraints that impede the effectiveness of field officers tasked with enforcing legislation and policy directives (Mir, K.A. *et al*., 2022). While navigating the limitations of the national policy framework, significant strides can be made at the community and individual levels to prevent and control air pollution (Anjum, M.S. *et al*., 2021).

Conclusion:

In conclusion, addressing air pollution requires a multifaceted and collaborative approach that encompasses scientific research, technological innovation, and coordinated efforts at both national and regional levels. The detrimental effects of air pollution on meteorological conditions and the

environment necessitate urgent action. The scientific consensus underscores the need for comprehensive research, particularly in regions such as Pakistan, to unravel the complex dynamics of meteo-pollution interactions. This involves interdepartmental collaborations at the national level and the extension of research and development activities to the regional level. Facilitating data sharing and integration is a critical aspect of effective pollution management. Developing platforms for comprehensive datasets, standardizing monitoring methods, and harmonizing policies across regions are essential components. Continuous evaluation and adaptation of prevention and control activities are imperative for sustained progress.

While international models, such as China's, offer insights, the unique challenges faced by each region require tailored strategies. The success of these efforts relies on the commitment and collaboration of diverse stakeholders, including government agencies, research institutions, industry partners, and local communities. Individual and community efforts are crucial in reducing air pollution. Advocating for sustainable practices, adopting cleaner technologies, and fostering awareness can contribute significantly to creating a cleaner and healthier environment. In essence, a concerted and sustained commitment to scientific research, data sharing, technological innovation, and community engagement is vital to mitigating the impact of air pollution on both regional meteorological conditions and the broader environment.

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