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An Integrated Assessment of Smog Formation, Environmental Impacts, and Mitigation Strategies in Pakistan

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Abstract

Smog has emerged as one of the most pressing environmental and public health challenges in Pakistan, particularly in major urban centres like Lahore, Faisalabad, and Karachi. This paper examines the various causes, impacts, and mitigation strategies associated with smog formation in the country. The study identifies key contributing factors, including vehicular emissions, industrial discharges, and agricultural practices such as crop residue burning. Meteorological phenomena, especially temperature inversions and stagnant wind conditions, further exacerbate smog concentration during the winter months. The agricultural sector is both a contributor to and a victim of smog, as pollutants degrade soil and water quality, damage crops, and disrupt livestock health and biodiversity. On the public health front, smog exposure leads to respiratory and cardiovascular illnesses, reduced lung function, and increased mortality rates, particularly among vulnerable populations. The review also evaluates existing monitoring and measurement systems, emphasising the role of continuous monitoring,



mobile sensors, and satellite-based remote sensing in assessing air quality trends. Despite ongoing mitigation initiatives such as stricter vehicular emission standards, industrial regulation, and public awareness campaigns, implementation gaps persist due to inadequate enforcement and resource limitations. The findings indicate that there is an urgent need for an integrated, multi-sectoral approach that combines technological innovation, institutional strengthening, and public engagement to effectively combat smog and safeguard environmental and human health in Pakistan.

Keywords: Smog, Air Pollution, Pakistan, Agriculture, Public Health, Environmental Monitoring, Mitigation Strategies

1. Introduction

Pakistan is known for its beautiful natural landscapes and rich cultural history, but pollution is becoming a bigger and bigger problem there. This dangerous mix of smoke and fog has turned into a serious public health problem that is affecting people all over the country, both in cities and in the country (Majeed, Zafar, & Saleem, 2024). When there are a lot of pollutants in the air, like sulphur dioxide (SO₂), nitrogen oxides (NO_x), ground-level ozone, and particle matter (PM), it makes smog. These materials can mix and react when the weather is right (Mishra, 2017; Liaqut, Raza, & Munir, 2023). When sunlight hits these pollutants, it starts a chain of complicated chemical reactions that make ground-level ozone and other dangerous chemicals. They come together to make a thick, yellowish-brown layer of smog that makes it hard to see. It is important to know the difference between haze and smog because smog is a broader term that refers to tiny particles in the air that absorb and scatter sunlight, making it harder to see. Haze can happen naturally when there are dust storms, volcanic eruptions, or wildfires. Haze can also be caused by human activities like cutting down trees, burning crops, and building things. Unlike smog, haze does not always mean that photochemical reactions or secondary pollutants are happening. It is mostly made up of very small particles that are in the air, like dust, soot, sea salt, and different types of aerosols. These particles make it harder to see by scattering and absorbing light. Haze can be bad for people who already have heart or lung problems, but its health effects are usually not as bad as those of smog. The increasing number and severity of smog events in Pakistan pose many risks to public health, biodiversity, agriculture, and the environment (Yousaf, Raza, & Ahmed, 2021).

Lahore, Karachi, and Islamabad are some of the most important cities in Pakistan that have had a lot of serious pollution over the past ten years. People are becoming more worried about how these events will affect the environment and public health in the long run (Khan, Safdar, & Hussain, 2024). Time-series data from U.S. embassy air quality monitoring sites in Lahore and other South Asian cities show that the daily average PM_{2.5} concentrations often go above the World Health Organization's (WHO) air quality standards. The PM_{2.5} levels in cities in Pakistan are always higher than the WHO acceptable 24-hour average. The first limit was set at 25 µg/m³, but it was lowered to 15 µg/m³ in 2021 (Majeed et al., 2024). Haze in Pakistan is caused by a mix of human and natural factors, such as burning biomass, industrial waste, car exhaust, and changes in the weather throughout the year (Kashif, Raza, & ul-Haq, 2019). Current data shows that haze is a big problem. IQAir reported that Lahore's AQI was over 200

(Very Unhealthy) on October 13 and 14, 2025, with PM_{2.5} levels. IQAir Plus One. Both international and local standards in Pakistan say that these values are much higher than what is recommended. This shows that air quality is still getting worse, even though laws are trying to make it better.

IQAir (2022) says that Lahore has the highest AQI in the world, with a score of 173. The AQI in Lahore reached 207 on January 31, 2024, with PM_{2.5} being the main pollutant and the air being "Very Unhealthy." According to estimates, the PM_{2.5} levels in Lahore were about 32.9 times higher than the WHO's yearly safety limit. Dhaka, Bangladesh, had the highest AQI at 245, and Hanoi, Vietnam, had the second highest at 240 (IQAir, 2024). Rapid urbanisation, emissions from factories and vehicles, and certain farming methods, like burning crop residue, are the main causes of poor air quality in these cities (Basak, Dey, & Chowdhury, 2023; Dibya, Alam, & Faruque, 2023). Even though these towns are different in terms of where they are, how much money they have, and how they are governed, they all face the same environmental and public health problems that need to be dealt with right away and as a group.

This paper seeks to conduct a comprehensive analysis of Pakistan's smog problem, highlighting its origins, contributing factors, and complex repercussions. This study aims to clarify the changing nature of smog in Pakistan through the use of empirical air quality data, peer-reviewed scientific literature, and current environmental reporting. It looks at how well current methods for reducing air pollution work and looks for new, scientifically proven ways to keep air quality good over the long term. To solve Pakistan's smog problem, the government, environmental groups, academic researchers, and the general public all need to work together. This review seeks to enhance the ongoing discourse regarding air pollution in South Asia by integrating existing knowledge and identifying essential areas for further research. It also seeks to facilitate forthcoming research and policy endeavours designed to alleviate the detrimental effects of this enduring environmental challenge.

2. Smog Impact Mechanisms

2.1. Constituents of Smog Pollutants

The harmful effects of smog are mostly caused by the way its main pollutants, which are a mix of gases and tiny particles, interact with each other. Yousaf et al. (2021) delineate the principal constituents as nitrogen oxides (NO_x), sulphur dioxide (SO₂), carbon monoxide (CO), ground-level ozone (O₃), particulate matter (PM), and volatile organic compounds (VOCs). These pollutants come from both natural and man-made sources, and each one has a different effect on how smog forms and stays in the air. Volatile organic compounds (VOCs) are gases that come from many places, such as paints, solvents, pesticides, adhesives, and petroleum products (Wu, Zhu, Yuan, Guo, & Zhang, 2024). Volatile organic compounds (VOCs) released into the atmosphere react with sunlight in photochemical reactions, creating secondary pollutants like ozone and organic aerosols.

Nitrogen oxides (NO_x), which include nitrogen dioxide (NO₂) and nitric oxide (NO), are a type of gas that is a major cause of air pollution and is very important in the formation of photochemical smog. Vehicle exhaust, industrial processes, and thermal power plants are the main sources of NO_x emissions

(Kashif et al., 2019; Harrison & Ping Shi, 1996). When these chemicals are released into the air, they react in complicated ways to make ozone and other small particles. Sulphur dioxide (SO_2) is a harmful substance that mostly comes from burning fossil fuels that contain sulphur or melting metals in factories. SO_2 directly affects health and changes the balance of radiation in the atmosphere by making aerosols that reflect sunlight, which causes climate forcing (Niaz et al., 2015). Carbon monoxide (CO) is a gas that you can not see or smell. It is made when carbon-based fuels like coal, petrol and biomass burn (ul-Haq et al., 2017). Long-term exposure to carbon monoxide makes it harder for the blood to carry oxygen, which is bad for health.

Ground-level ozone (O_3), also known as tropospheric ozone, is a major cause of smog. This process predominantly transpires when volatile organic compounds (VOCs) and nitrogen oxides (NO_x) engage in the presence of sunlight (Munir & Khayyam, 2022; Rafiq et al., 2017). NO_2 takes in ultraviolet (UV) light and breaks down into reactive atomic oxygen (O) and nitric oxide (NO). Ozone (O_3) is formed quickly when molecular oxygen (O_2) and free oxygen come together. VOCs oxidise to create reactive radicals that help turn NO back into NO_2 without using up ozone. This reaction happens over and over again as long as there are enough precursors and sunlight. It makes ozone all the time (Ibrahim, 2019; Wang et al., 2019).

So, photochemical smog is common in cities where there are a lot of NO_x and VOCs in the air, mostly from cars and factories. Particulate matter (PM) is a major cause of smog. There are a lot of different solid and liquid particles floating around in the air. Particulate matter (PM) is usually divided into two groups based on the size of the particles: PM_{10} , which includes particles that are 10 μm or smaller (like dust, pollen, and mould spores), and $\text{PM}_{2.5}$, which includes particles that are 2.5 μm or smaller (like soot, combustion byproducts, and organic aerosols). The smaller particles are the most dangerous to human health because they can get into the bloodstream through the alveolar regions of the lungs and go deep into the respiratory system (Geddes & Murphy, 2012).

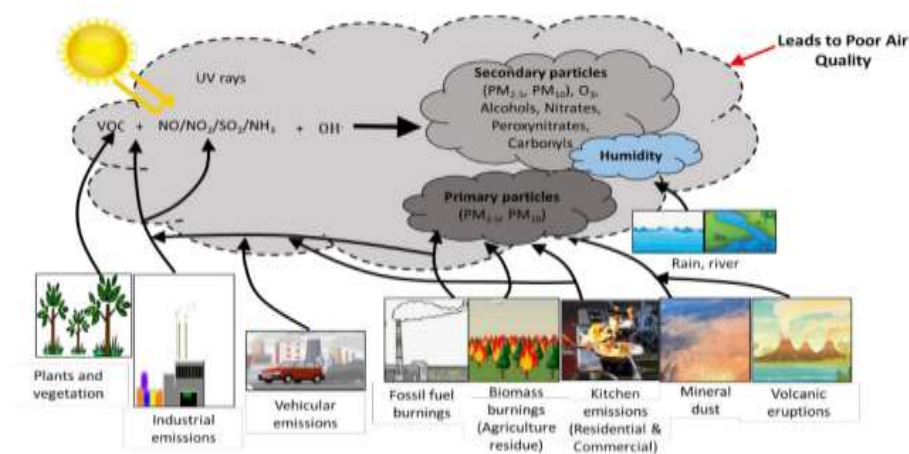
Different places have different amounts of chemicals in the particulate matter because of both natural and human-made processes. Metal oxides, ammonium salts, nitrates, sulphates, and organic aerosols are all common parts. Organic aerosols are made when volatile organic compounds (VOCs) are oxidised. Aerosols can come from plants or people. NO_x that comes out of cars and factories makes nitrates, while SO_2 that comes out of factories and power plants makes sulphates. Farmers use ammonium salts for two things: to raise animals and to fertilise plants. At the same time, metal oxides, especially iron, aluminium, and copper, are released into the air by mechanical wear and tear, vehicle wear and tear, and industrial activities (Mukherjee & Agrawal, 2017). These elements interact dynamically in the atmosphere to create and maintain the dense smog layers seen in heavily polluted cities.

2.2. Things that help make and spread smog

Lahore has high levels of air pollution all the time because of a mix of human activity and environmental factors that make smog form and keep it from spreading. This problem is mostly caused by emissions from factories. Many factories in the metropolitan area release large amounts of particulate matter (PM), sulphur dioxide (SO_2), and nitrogen oxides (NO_x), but the government does not

do much to control these emissions. The situation has gotten worse because pollution control technologies are out of date and emission rules are not being enforced well enough. This has led to a steady decline in air quality (Rashid et al., 2020; Siddique et al., 2023).

Another big problem is that Lahore relies heavily on fossil fuels for transportation, making electricity, and meeting the energy needs of homes. Old cars and machines, along with combustion processes that do not work well, release a lot of carbon monoxide, nitrogen oxides (NO_x), hydrocarbons, and fine particulate matter (Yousaf et al., 2021). Diesel engines, especially in buses, trucks, and cargo vehicles, are a major source of pollution because they release a lot of soot and black carbon when they burn (Malhi et al., 2023; Tahir et al., 2023). The problem has gotten worse because more and more people are buying cars. From 1998 to 2018, the number of registered cars in Pakistan grew from just over 2 million to 10.6 million. More than 8.5% of the average annual increase. The number of cars went up by almost 650% from 1991 to 2012, while the number of motorcycles and scooters went up by more than 450%. The growth sped up after 2003 because of urbanisation, economic growth, and not enough money spent on public transit infrastructure (see Graph 1). The rise in mobile emission sources has played a big role in the haze that has settled over cities in Pakistan, especially Lahore. Agricultural practices have a big impact on the city's seasonal pollution. In Punjab, burning agricultural waste after harvest is still common, which releases a lot of smoke and particles into the air. When these emissions mix with other pollutants in cities with the right weather, they make thick layers of smog (Yousaf et al., 2021). In the winter, temperature inversions and still air trap pollutants at the surface, making it harder to see and putting urban residents' health at risk.



The main causes of Lahore's bad smog are burning farm waste, relying on fossil fuels, industrial emissions, and too many cars on the road. Their combined effects show how important it is to have a single plan for managing air quality that focusses on both cutting down on emissions and improving city

design. The weather has a big effect on how smog forms and spreads. Figures 2–4 show that smog is more common and worse in Pakistan in the winter, especially in Lahore and nearby areas of Punjab. This seasonal occurrence results from a combination of geographical, environmental, and meteorological factors that intensify air pollution. Temperature inversions are a major cause of winter smog. An inversion stops vertical air mixing by putting a layer of warm air over a colder air mass close to the ground. The stable atmosphere stops pollutants, mostly from cars, factories, and burning biomass, from rising into the air. This causes them to build up near the ground, which could lead to higher levels (Bilal et al., 2022). Pollutants accumulate in the lower troposphere, leading to the formation of persistent, dense smog layers, particularly in the absence of wind and sunlight. Wind patterns have a big effect on the movement of pollutants both up and down and side to side. Wind patterns in the area and the region affect how smog spreads and moves. These patterns can affect both cities and rural areas that are close to places where emissions are high. Strong winds can carry smog over long distances, making air quality problems worse in areas downwind. When the wind is weak or not moving, pollutants stay where they are.

Fig. 1. Conceptual Diagram of Smog Formation Pathways Relevant to South Asian Atmospheric



Topography also has a big effect on how pollution spreads. Some landforms, like valleys or low-lying basins, tend to trap air masses. This makes it harder for pollutants to spread and makes smog episodes worse. Majeed et al. (2024) and Czarnecka and Nidzgorska-Lencewicz (2011) asserted that the presence of mountain ranges and coastal boundaries can influence the trajectory of contaminated air, leading to variations in regional air quality. These natural barriers that stop airborne pollutants from being diluted could cause smog levels to rise over time. The length, severity, and spatial extent of smog events are influenced by the interplay of topographical features and meteorological conditions, such as temperature inversions, wind patterns, and solar radiation.

Fig. 2. Vehicle Population in Punjab from 2016 To 2025. Data Derived from Punjab Development Statistics (Various Years) and Bureau of Statistics, Punjab (2025).

Rank	Major city, country/region	AQI* US
1	 Kolkata, India	165
2	 Lahore, Pakistan	152
3	 Delhi, India	133
4	 Cairo, Egypt	132
5	 Mumbai, India	121

Fig. 3. Representation of the Air Quality Index of Lahore (Pakistan) in 2025, Sep-Oct (AQI).

To protect public health and manage air quality well, you need to know how smog is made and how it affects people. By closely monitoring the factors that affect smog, such as emission sources, weather patterns, and atmospheric chemistry, environmental authorities can better predict when high-risk times will occur and take steps to avoid them. This means supporting adaptive public health programs, putting in place measures to control emissions, and quickly sending out air quality alerts when the weather is most likely to cause smog to build up. These data-driven strategies help with long-term policy planning that aims to achieve sustainable environmental resilience in addition to reducing the acute health hazards linked to poor air quality.

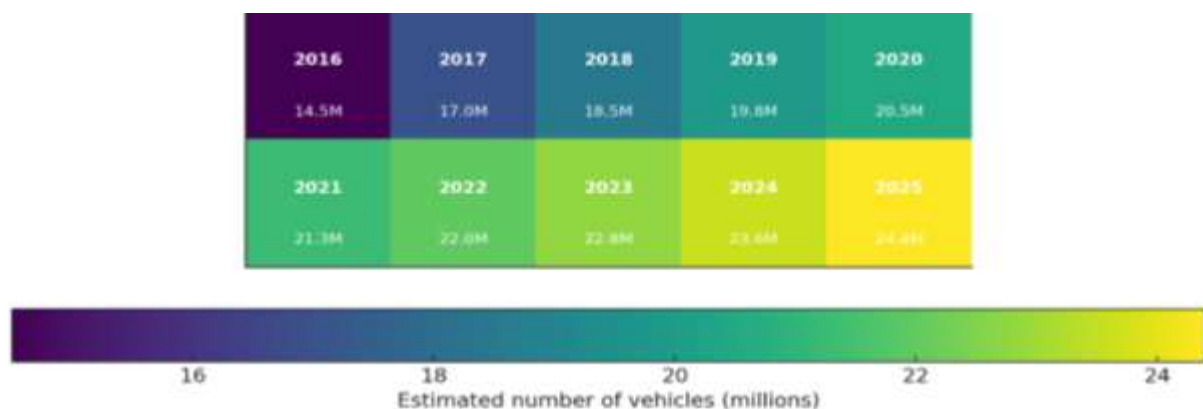


Fig. 4. Representation of the Air Quality Index of the Worst 5 Cities in the World 2025 (AQI)

3. Smog and Farming

3.1. How farming affects smog

There are many socioeconomic, environmental, and meteorological factors that make the link between Pakistan's agriculture and smog generation complicated. Agriculture is still an important part of the national economy and a major source of income for many people. It adds a lot to the country's GDP (Azam & Shafique, 2017). Even though agriculture is important to the economy, some farming methods have become major causes of air pollution, which leads to the formation of smog.

A major problem is the open burning of agricultural waste, especially in Punjab's rice-wheat area. A lot of people agree that this is one of the main causes of the haze that happens in Pakistan every year (Yousaf et al., 2021). Many farmers burn leftover straw and stalks after the harvest to get the fields ready for the next planting season in a quick and cost-effective way. This method is easy to use, but it sends a lot of harmful pollutants, like carbon monoxide (CO), particulate matter (PM), and other harmful gases, into the air. These incinerations usually happen in the months after the monsoon and before winter, when the winds are calm and the temperature changes keep pollutants near the surface, making the air quality and visibility worse (Bilal et al., 2022; Yousaf et al., 2021; Mukhtar, 2018) (see Fig. 5).

Burning trash and using a lot of chemical fertilisers and pesticides both add to air pollution. Research conducted by Abas et al. (2019), Arif and Hassan (2023), and Chaudary et al. (2021) underscores that these chemicals release reactive nitrogen species, including nitrogen oxides (NO_x) and ammonia (NH₃). These gases mix with other pollutants in the air to make fine particulate matter (PM_{2.5}), which is a big part of smog. Some herbicides release VOCs, which make photochemical haze worse. On the other hand, using too much nitrogen-based fertiliser, which is often not regulated, speeds up the process of ammonia volatilisation. Even though these inputs help crops grow, their combined effect on the atmosphere shows how important it is to use climate-smart and sustainable farming methods that protect the environment while making sure there is enough food.

3.2. How Smog Affects Farming

Smog has a big effect on farming, causing crop damage and lower yields, which makes it hard for Pakistan to feed itself (Shamsi et al., 2000). Smog exposure has an immediate effect on plant physiology; it harms foliar tissues and causes visible damage like necrosis, chlorosis, and leaf mottling. Long-term exposure to high levels of ozone, sulphur dioxide, and particulate matter breaks down chlorophyll pigments and makes stomata less effective, which lowers the efficiency of photosynthesis.

Ahmad et al. (2013) contend that this reduction in photosynthetic activity limits the energy production potential of plants. This leads to stunted growth, less biomass accumulation, and leaves that die too soon. Chronic physiological stress also makes crops less resistant and less able to reproduce, which

leads to lower yields because of pollution. Long-term exposure to air pollution can make it harder for plants to fill their grains, bloom, and take in nutrients.

All of these things can make the harvest smaller and less valuable. Pollutants can be very harmful to sensitive crops like vegetables, rice, and wheat when they are present during important biological processes. The long-term effects are more than just losing crops right away. They include changes in microclimatic conditions and a decline in soil health. If these problems are not fixed, they could hurt future productivity.



Fig. 5. Crop Burning Smoke: A Global Health Threat (AQI, 2024).

Research demonstrates that elevated smog concentrations can significantly diminish crop yields, with reductions ranging from 10% to 40%, depending on the type of pollutant, exposure duration, crop variety, and other environmental factors (Raja et al., 2018; Wahid, 2006). Air pollution can hurt plants in many ways, including by stopping photosynthesis, nutrient absorption, and the overall health of the plants. Wheat, soybeans, rice, maize, and potatoes are some of the crops that are most affected. Wheat (*Triticum aestivum*), the most important winter crop in Pakistan, has been the most affected. It is a necessary food. From 2007 to 2020, the country did not grow much more wheat. It went from 23,295 to 24,946 thousand metric tonnes. Pollution can cut crop yields by 10% to 30%, according to studies. Experimental studies conducted in proximity to Lahore demonstrated that exposure to ozone (O_3) during the wet growing season led to a 53% decrease in soybean (*Glycine max*) seed weight in suburban areas, 65% in rural regions, and up to 74% in roadside locations (Devrajani et al., 2020).

3.3. The impact of smog on soil and water pollution

Smog is a big threat to agricultural ecosystems because it pollutes soil and water. Some of the most harmful pollutants in the air are particulate matter (PM), sulphur dioxide (SO₂), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and ground-level ozone (O₃). They can change the chemical and biological properties of soil and water systems in a big way. These pollutants can stick to surfaces or dissolve in water, throwing off the balance of nutrients, making the soil less fertile, and polluting sources of irrigation. Over time, this pollution hurts plant growth, microbial activity, and the ecosystem's overall productivity. When these pollutants are deposited, they add a number of harmful substances that make the soil less healthy and fertile. For instance, heavy metals build up in the top layers of soil over time. This makes the soil less productive and raises the risk of crop contamination and food chain translocation (Hindy, 1991).

Acidic pollutants like SO₂ and NO_x make the soil more acidic, which makes it harder for plants to take up important nutrients and throws off the soil's pH balance (Soriano, 2014). Ammonium salts that fall from the sky also raise the amount of nitrogen in the soil. Ammonia (NH₃), which is naturally alkaline, turns into ammonium ions (NH₄⁺), which releases hydrogen ions (H⁺). This slowly lowers the pH of the soil. This leads to an imbalance of nitrogen and a longer period of soil acidification (Bouman et al., 1995; Krupa, 2003).

Smog changes the chemistry of the soil, which affects how easily plants can get nutrients. Changes in the pH and chemical makeup of the soil can make it harder for plants to get important macronutrients like potassium, phosphorus, and nitrogen. This could have a negative impact on plant growth and yield (Amato-Lourenço et al., 2017; Han et al., 2020). Studies show that high levels of ground-level O₃ may stop roots from growing and make it harder for plants to take in nutrients, especially in sensitive crops (Leisner & Ainsworth, 2012). The persistent presence of smog jeopardises the long-term sustainability of agricultural productivity in affected regions and degrades the quality of soil and water.

3.4. How Smog Affects Plants and Animals 3.4. How Smog Affects Plants and Animals

Smog has effects on agriculture that go beyond just the soil and crops. It harms the health of animals and the diversity of the ecosystem as a whole. Studies show that animals' health gets worse when there are high levels of air pollutants like ozone (O₃), nitrogen oxides (NO_x), sulphur dioxide (SO₂), and particulate matter (PM). Cattle and poultry are vulnerable to respiratory diseases analogous to those affecting humans. Breathing in these pollutants can cause inflammation in the respiratory tract, make the lungs work less well, and make people more likely to get sick, which lowers productivity, slows growth, and raises death rates (Beaupied et al., 2022; Nieckarz et al., 2023; Swarup & Dwivedi, 1998). The health effects cost farmers money and make the agricultural sector less efficient. Air pollution caused by smog affects not only cattle but also the way ecosystems and soil microbial communities work. Acidic deposition negatively impacts symbiotic relationships that enhance soil fertility by modifying microbial composition and nutrient dynamics within the soil (Wong, 2017). These disturbances change the arrangements of plant communities, which in turn changes the habitats of species that depend on them as they move through ecosystems. Changes in the environment can cause

problems with reproduction, strange behaviours, or a drop in the number of vulnerable species (Morgado et al., 2018). All of these things make ecological networks less stable, reduce biodiversity, and put the long-term health of agriculture at risk.

4. The Effects of Smog on Health

4.1. Issues with the Respiratory System

The main way that smog hurts health is by irritating and inflaming the respiratory system, which includes the nose, throat, bronchi, and lungs. People who are exposed to a lot of air pollution often have trouble breathing, cough, wheeze, and have sore throats. Long-term exposure could weaken the immune system, making it harder for the body to fight off respiratory diseases like bronchitis and pneumonia (Matloob & Sahkir, 2023; Grigg, 2018; Upadhyay, 2023). Fine particulate matter (PM_{2.5}) and tropospheric ozone (O₃) are two of the worst types of pollution. These pollutants can make the airways smaller and hurt the cilia, which are tiny hair-like structures that help clear mucus and other particles from the respiratory tract. This makes the lungs' natural defences less effective. Pollution can make lung function worse, which can show up as symptoms like fatigue, chest tightness, and shortness of breath after exercise (Carson et al., 1993; Misiukiewicz-Stepien & Paplinska-Goryca, 2021). Long-term or repeated exposure may result in serious lung diseases, such as lung cancer and chronic obstructive pulmonary disease (COPD), primarily due to ongoing oxidative stress and inflammation in lung tissues (Bălă et al., 2021; Brauer & Vedal, 1999; Duan et al., 2020). People who already have breathing problems, like asthma or chronic bronchitis, are more likely to get sick. Pollution makes their symptoms worse, causes asthma attacks, and makes COPD worse, which leads to more hospitalisations and a lower quality of life (Duan et al., 2020; Abdul Jabbar et al., 2022). The health effects are especially bad in Pakistan, especially in cities like Lahore, where pollution levels often go above what the World Health Organisation (WHO) says is safe. These results show that we need to do something right away to protect people's health. This includes campaigns to teach people about the dangers of smog exposure, health warnings that are sent out quickly when pollution levels are high, and real-time air quality monitoring that is easy for communities to use to help them protect themselves. s



Fig. 5. Photographic illustration of Smog in Lahore (Samaa TV, 2024)

4.2. Effect on the Heart

Smog has a big impact on heart health and the respiratory system (Mishra, 2017). Prasad and Paudel (2020) assert that extended exposure to pollutants such as PM_{2.5}, O₃, and nitrogen oxides (NO_x) may induce oxidative stress and systemic inflammation, consequently disrupting normal cardiovascular function. Air pollution considerably heightens the risk of heart disease by impairing normal endothelial function, causing vasoconstriction, and raising blood pressure. These physiological alterations increase the risk of ischaemic heart disease, myocardial infarction, and congestive heart failure (Gold & Samet, 2013; Ibalid-Mulli et al., 2001). Fine particulate matter (PM_{2.5}) can get deep into the lungs and into the blood, where it interacts with blood vessels. This interaction causes arteries to become stiff and the autonomic nervous system to become unbalanced, both of which make it harder for the heart and blood vessels to work together. Over time, these changes could speed up atherosclerosis, which is when lipids build up in the arteries and block blood flow to important organs like the heart, brain, and kidneys. This raises the risk of myocardial infarction and cerebrovascular accident (Gold & Samet, 2013). Evidence from Pakistan supports this association. A cross-sectional study conducted by Sughis et al. (2012) indicated that students attending a primary school situated in a high-traffic, polluted area exhibited significantly elevated arterial blood pressure compared to their counterparts in regions with cleaner air. This finding underscores the significant cardiovascular effects of prolonged exposure to smog and air pollution in early life.

5. Observation and Enumeration

To understand how smog affects the environment and public health and to come up with good ways to reduce its effects, it is important to keep an eye on and measure it. Reliable air quality data is the basis for strategic actions, public awareness campaigns, and laws based on evidence. Different monitoring methods are used to do this, and each has its own benefits when it comes to covering different areas and times. Facilities for Ongoing Surveillance: These fixed, automated stations measure the concentrations of important air pollutants like ground-level ozone (O₃), nitrogen oxides (NO_x), sulphur dioxide (SO₂), carbon monoxide (CO), and particle matter (PM) in real time. The data from these places is used to make the Air Quality Index (AQI). Regulatory bodies use it to set air quality standards and send out public health warnings (Huang et al., 2018). These technologies create high-frequency data that is very important for keeping an eye on pollution trends and giving people early warnings of smog events.

Passive air samplers are a cheap way to get air samples in places where resources are limited. These devices can collect air samples for long periods of time, usually between one week and one month, without needing power or complicated technical infrastructure. Even though they have worse temporal resolution, they are much better than automated systems at checking air quality in places that are hard to get to or that do not have enough resources.

Passive samplers use the natural spread of pollutants to measure long-term exposure levels in different environments (Yousaf et al., 2021; Khuriganova et al., 2019). They are good for community-based or

regional monitoring projects because they are cheap and easy to use, even though they can not be used in real time. You can put air quality sensors on cars, drones, or portable platforms to keep an eye on the air quality in real time. These sensors quickly collect high-resolution data from a variety of locations (Khan, Tariq, & Bukhari, 2023). This method makes it easier to find areas with a lot of pollution, talk about where the pollution is coming from, and improve stationary monitoring networks. It makes it possible to map pollution gradients in cities that are growing quickly, like Karachi and Lahore, where there may not be many fixed monitoring stations.

Remote Sensing: Technologies that use satellites give a complete picture of air pollution over large areas of land. Remote sensing systems can measure air pollution and look at how smog forms, moves, and disappears by looking at radiation that comes from or bounces off the Earth's surface and atmosphere (Liaqut et al., 2023; Jahan et al., 2019). This strategy works very well in places where there are not any ground-based surveillance networks. Combining satellite data with data from the ground has greatly improved the accuracy of air quality models. This has helped scholars and policymakers learn more about how pollution works and come up with better ways to deal with it. Lidar systems use laser pulses to measure and describe the concentration of particles at different altitudes all the time. These systems give us a lot of information about how aerosols are spread out vertically, which helps us understand smog layers, how the atmosphere mixes, and how these things affect the weather and climate (Mohyuddin et al., 2022). Recent developments in spatiotemporal mapping techniques, including graph neural networks and the integration of satellite and sensor data, have enabled high-resolution AQI estimation in Lahore, yielding more comprehensive insights into pollution hotspots within urban areas (Ahmad et al., 2025). The combined use of these different monitoring methods gives us a full picture of how smog changes over time. Combining data from satellites, mobile devices, and ground-based technology makes air quality forecasting models more accurate, helps policymakers make decisions based on evidence, and allows for quick public health actions.

6. Ways to Reduce Damage

Pakistan has implemented various technological and policy initiatives in recent years to combat its worsening smog crisis, acknowledging the pressing necessity to mitigate air pollution (Siddiqui et al., 2023). Reducing car emissions, which are a major cause of air pollution in cities, has been a major goal. The government has made a lot of progress in making the air in cities cleaner by setting stricter limits on car emissions, encouraging cleaner fuel technologies, and starting programs for vehicle inspection and maintenance (Bhutta, 2023; CCAC, 2022).

Changes to regulations and incentives to encourage environmentally friendly manufacturing have made it easier to cut down on industrial emissions. Also, programs that encourage the use of renewable energy and make energy use more efficient have been put in place to reduce reliance on fossil fuels and lower pollution levels. To reduce the open burning of crop leftovers, which is a major cause of summer pollution, the government has started sustainable farming programs. These programs include raising awareness and giving farmers money to help them manage their waste and protect the soil in ways that are good for the environment (Kalwar, 2023; Siddiqui et al., 2023).

Still, there is a lack of consistency when it comes to enforcing and following these rules. Progress is hindered by challenges such as insufficient participation, inadequate monitoring resources, and restricted regulatory oversight. Additionally, ongoing endeavours to mitigate pollution are hindered by interrelated socioeconomic challenges, including poverty, rapid urbanisation, and industrial growth (Tahir et al., 2023). Pakistan needs to work on better coordination between agencies, build partnerships between the public and private sectors, and strengthen the capacity of its institutions in the future (Anwar et al., 2021). To create solutions that work in specific areas, we need to spend money on new technology, research, and systems for keeping an eye on things. Moreover, educational campaigns and open reporting can help people take ownership of air quality programs by getting them more involved and aware (Siddiqui et al., 2023).

Another step is to improve cooperation between countries on managing pollution in the region, especially since haze can come from more than one country. The 2024 India-Pakistan smog is an example of how pollutants from nearby areas have made the air in Punjab worse. As a short-term solution to help with forecasting, managing emissions, and responding quickly during smog events, Punjab has set up "Smog War Rooms" (Punjab Province, 2024). Reuters. A complete mitigation plan must include behavioural, technological, regulatory, and regional approaches to make sure that smog exposure and production keep going down.

7. Conclusion

The production of smog in Pakistan is a complicated and multi-faceted process that has a big impact on public health and farming. This review shows how the problem is connected by naming the burning of agricultural waste, industrial operations, and pollution from vehicles as the main causes. Smog makes problems like not having enough water, soil degradation, and lower crop yields worse. This costs money and puts food security in the agricultural sector at risk. Burning crop residue is a common practice that harms the environment, makes the air dirtier, and threatens agricultural systems that are good for the environment. The risks are just as bad for public health. Fine particulate matter (PM_{2.5}) and other harmful substances in smog enter the lungs and blood, causing heart problems, breathing problems, and early death. People who are already sick, like kids, old people, and people with long-term illnesses, are more likely to get hurt. Lahore's air quality is still bad in 2025 (AQI >200 at times), which shows that the rules that are in place have not worked (IQAir, 2025). IQAir Plus One. The bad smog that hit in winter 2024–2025, which put millions of people at risk of pollution levels that were more than 20 times higher than safe levels, shows how important it is to act quickly (AFP, 2025). Pakistan's pollution problem needs a thorough, cross-sectoral approach that includes strict rules, new technologies, and a lot of public involvement. Setting rules for emissions, improving sustainable energy technologies, putting in place different ways to handle agricultural waste, building monitoring infrastructure, and working with other areas are some of the main goals. Implementing climate adaptation strategies, increasing green spaces, and improving healthcare infrastructure can help with health problems even more. In the end, fighting Pakistan's haze requires a long-term commitment from politicians, cooperation between institutions, and public involvement. Putting in place proactive, evidence-based policies would protect the health of the people and the environment, which would lead to a healthier and more sustainable future for everyone.

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