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| RESEARCH ARTICLE

## A Comprehensive Analysis of Air Pollution in Dhaka City, Bangladesh, and the Application of Artificial Intelligence and Machine Learning for Enhanced Management and Forecasting

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| ABSTRACT

This research meticulously examines the escalating air pollution crisis in Dhaka, Bangladesh, advocating for sophisticated monitoring and mitigation strategies. It comprehensively analyzes the spatiotemporal dynamics of key pollutants, including PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, SO<sub>2</sub>, O<sub>3</sub>, and CO, attributing their prevalence to diverse anthropogenic sources such as vehicular emissions, industrial activities (particularly brick production), construction aerosols, agricultural outgassing, and inefficient waste management. The paper elucidates the intricate seasonal fluctuations in pollutant concentrations and their profound health implications, ranging from acute cardiorespiratory morbidities to potential long-term neurological sequelae. A significant focus is placed on leveraging the transformative potential of cutting-edge Artificial Intelligence (AI) and Machine Learning (ML) paradigms to transcend the limitations of conventional air quality control. The study evaluates the efficacy of advanced deep learning architectures, notably spatiotemporal Recurrent Neural Networks (RNNs) with attention mechanisms and Convolutional Neural Networks (CNNs), for achieving highly accurate air quality monitoring and predictive forecasting. Furthermore, it investigates state-of-the-art Explainable AI (XAI) frameworks, such as SHAP, to provide critical insights into pollutant source attribution, enhancing interpretability. The integration of real-time, high-fidelity data streams from remote sensing platforms and cost-effective sensor networks into AI-driven analytical pipelines is emphasized. The research candidly addresses the inherent scientific and technical challenges associated with deploying advanced AI/ML models, including the development of physically informed neural networks (PINNs) for superior interpretability, the effective management of data heterogeneity and biases, and robust uncertainty quantification through Bayesian techniques. Ultimately, this paper proposes a rigorous, data-driven, and scientifically grounded roadmap for developing next-generation, adaptive air quality management systems for Dhaka City. By seamlessly combining AI/ML capabilities with established environmental science principles, the objective is to forge innovative solutions that facilitate precise predictions, enable proactive responses, and significantly advance public health outcomes in the face of this pervasive environmental threat.

| KEYWORDS

Air Pollution, Artificial Intelligence (AI), Bangladesh, Dhaka City, Forecasting, Machine Learning (ML), Management, Particulate Matter, Urban Air Quality.

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### 1. Introduction

Bangladesh's ranking of 169th (out of 178 nations) on the Environmental Performance Index for Air Quality (APT, 2016) indicates that air pollution is a crisis in our country. The primary causes of air pollution include brick kilns, dust from highways and building sites, poisonous fumes from industry, and emissions from malfunctioning automobiles, particularly diesel-powered ones. The primary pollutants from gasoline-powered internal combustion

engines include sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), hydrocarbons (HC), carbon monoxide (CO), lead compound particles, and unburned carbon particles. Diesel engines emit smoke, CO, SO<sub>2</sub>, NO<sub>x</sub>, and unburned carbon. The Department of Environment (DoE) reports that during the dry season (December-March), the city's airborne particulate matter (PM) density reaches 463 micrograms per cubic meter (µgm<sup>-3</sup>), the highest in the world (Air Pollution Reduction Strategy for Bangladesh, Final Report, 2012). According to the World Health Organization's (WHO) 2005 air quality guidelines, cities are deemed extremely polluted if their PM levels exceed 70 µgm<sup>-3</sup>, the highest permissible threshold. About 50 tons of lead are released into the air of Dhaka city each year, with the highest levels occurring during the dry season (November–January), according to a study done by scientists from the Bangladesh Atomic Energy Commission (BAEC) (Air Pollution Reduction Strategy for Bangladesh, Final Report, 2012; Haque et al., 2017).

Inadequate ambient air quality is harming materials, agricultural output, and human health. The time to raise national awareness and inspire action over air pollution is now. The World Bank (WB), Asian Development Bank (ADB), and United Nations Environment Programme (UNEP) are just a few of the global organizations that have taken action or developed plans to minimize and regulate air pollution. Issues related to air pollution have been thought about before. The government agency responsible for protecting the environment in Bangladesh, the Department of Environment (DoE), requested proposals to create an "Air Pollution Reduction Policy for Bangladesh" following the Male Declaration on Control and Prevention of Air Pollution and Its Likely Trans-Boundary Effects for South Asia (Air Pollution Reduction Strategy for Bangladesh, Final Report, 2012; Haque et al., 2017). After the Industrial Revolution, individuals on this planet experienced widespread air pollution for the first time, according to global experience. However, air pollution garnered significant social attention up to the 20th century (Rahman et al., 1992). Smog was the primary cause of air pollution in the 20th century. Once more, current experience demonstrates that nitrous oxide (N<sub>2</sub>O) and similar chemicals are increasingly significant air pollutants in many industrialized nations due to their decrease due to the advancement of petroleum desulphurization technology (M. M. Rahman et al., 2022). In addition, the use of fossil fuels has led to worldwide air pollution and the emergence of a new form of air pollution known as acid rain, which is produced by carbon dioxide (Rahman et al., 1993). However, urbanization and the rise of automobile traffic in cities altered the scenario. These cars, industrial boilers, brick burning, and other sources released black smoke, which altered the quality of the air in cities. The urban air pollution problem started to get worse in the early 1990s, and in the last few years, it has gotten much worse (Rahman et al., 1992).

Emissions from practically every kind of vehicle, including cars, trucks, buses, minibuses, microbuses, two-stroke engine-powered vehicles, and motorcycles, have been significantly contaminating the air in Dhaka. In addition, brick fields, open burning fires, railroad engines, industrial facilities, airplanes, power plants, dust particles, and solid waste disposal sites all contribute to air pollution. Dust pollution from road excavations, building projects, and other development activities adds to Dhaka's air pollution. Carbon monoxide, nitrogen oxides, hydrocarbons, sulfur dioxide, lead compound particles, and unburned carbon particles are the main air pollutants from gasoline-powered internal combustion engines (M. M. Rahman et al., 2022). As an additional point of clarification, the actual emissions from diesel engines include smoke, odor, unburned carbon, carbon monoxide, nitrogen oxides, and sulfur dioxide. Residents of the city are at a serious health risk from these pollutants, which can lead to a variety of cardiovascular and respiratory conditions. Furthermore, air pollution has negative impacts on Dhaka's ecology, climate, and general quality of life, in addition to its negative health implications (Hasan & Shanto, 2023). Therefore, developing effective ways to alleviate this situation requires an understanding of the causes and sources of air pollution in Dhaka City.

## **2. Literature Review**

According to studies, Dhaka is among the most air-polluted cities in the world, which poses serious risks to environmental sustainability and public health (IQAir, 2024; State of Global Air, 2023). Numerous interrelated variables are contributing to this dilemma, according to research. Significant amounts of particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), hydrocarbons, and lead are released by vehicles,

especially older, poorly maintained vehicles, as well as the growing number of private automobiles and two-stroke engines (Hossain et al., 2020; Begum et al., 2013). This problem is made worse by the widespread use of diesel-powered cars, which are known to emit more NO<sub>x</sub> and particulates (Clean Air Asia, 2021). In addition to transportation, the many brick kilns in and around Dhaka are major stationary sources of air pollution, releasing large amounts of sulfur dioxide (SO<sub>2</sub>), particulate matter, black carbon, and other harmful substances, particularly when they are operating seasonally (Alam et al., 2017; Chowdhury et al., 2016). By releasing a variety of pollutants based on the industry type (e.g., textile, pharmaceuticals), industrial emissions from various manufacturing units, many of which lack proper pollution control technologies, also contribute to the declining quality of the air (DoE, various publications).

Additionally acknowledged as significant sources of particulate matter pollution are construction operations and road dust resuspension, especially during the dry season when rainfall is low (Islam et al., 2019). Open burning of waste increases the burden of harmful pollutants, such as dioxins and furans, even if it is frequently localized (UNEP, 2015). Additionally, transboundary air pollution from nearby areas might affect the quality of the air in Dhaka, especially during specific weather conditions (Guttikunda et al., 2014). The harmful effects of Dhaka's air pollution on people's health are widely known. Numerous respiratory conditions, such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD), have been associated in epidemiological studies with long-term exposure to high levels of pollutants (Rahman et al., 2018; Khan et al., 2021). Air pollution has also been linked to a higher risk of heart disease, stroke, unfavorable pregnancy outcomes, and even some types of cancer (WHO, 2021; Brauer et al., 2016). These health impacts are especially dangerous for children and the elderly.

Many governmental and non-governmental organizations, as well as international organizations such as the World Bank, ADB, and UNEP, have been engaged in research, policy advocacy, and the creation of action plans to reduce air pollution in Dhaka because they understand how serious the issue is (World Bank, various reports; ADB, various reports; UNEP, various reports). Developing strategies for managing air quality, advocating for cleaner technologies, and increasing public awareness are some of these initiatives. However, there are still many obstacles to overcome before Dhaka's air quality can be improved, including efficient implementation and enforcement. To better understand the intricate causes, distribution, and health effects of air pollution in Dhaka, as well as to assess the efficacy of solutions already in place, more research is essential. There are several construction projects in Bangladesh's cities, such as building viaducts, homes, and roadways. Government megaprojects include the Metro Rail, the Dhaka Elevated Expressway, the Dhaka Airport Terminal-3, and others. Construction has been going on for years. Many years have passed since then. These projects' construction greatly increases air pollution and produces high levels of PM<sub>2.5</sub>. Construction sites are frequently extremely dusty since there are no particular rules or standards governing the movement and storage of building materials. In cities, this leads to dust pollution. The study found that during the winter months in Dhaka, 500 tons of dust fall to the ground and 2,000 tons of dust float in the air per day (Ahmed et al., 2024).

Air pollution is a widespread global problem that transcends national boundaries and has a major influence on urban settings all over the world (World Health Organization: WHO, 2024). In many urban areas around the world, air pollution levels have risen as a result of recent decades' fast city growth, increasing industrial activity, and an increase in vehicle traffic. Understanding Dhaka City's predicament concerning worldwide air pollution patterns is essential, even if the city has its own unique set of air quality control issues.

Carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), particulate matter (PM), and ground-level ozone (O<sub>3</sub>) are among the dangerous air pollutants that are becoming more and more prevalent in cities worldwide. In addition to posing serious health concerns to people, these pollutants also fuel more general environmental issues, including acid rain, climate change, and the deterioration of fragile ecosystems.

Several interconnected global trends are fueling the deterioration of air quality in urban areas:

- First, as a result of population concentration brought on by unheard-of urban growth, energy consumption is rising, transportation infrastructure is being put under more strain, and industrial activity is congregating inside city limits. The issue of air pollution is exacerbated by this urban sprawl (Tao et al., 2021).
- Second, a significant cause of air pollution is the growing global automobile fleet, which is mostly dependent on fossil fuels. A variety of dangerous compounds are released by these cars' emissions, especially in crowded urban areas with heavy traffic.
- Thirdly, pollutants like SO<sub>2</sub> and NO<sub>2</sub> are released more frequently as a result of the growth of industrial sectors, which are frequently driven by fossil fuels. The difficulties in preserving appropriate air quality in cities are made worse by these industrial releases.
- Fourth, air pollution may worsen as a result of climate change (Climate Change Impacts on Air Quality, US EPA, 2025). Urban air quality management is made more difficult by altered weather patterns, changes in atmospheric circulation, and modifications to pollutant dispersion processes. There is a big problem with how these two environmental problems interact.
- Fifth, even in places that are far from the initial source of pollution, international transportation, which includes the long-distance movement of people and goods via shipping and aviation, can introduce pollutants into urban airsheds.
- Lastly, pollutants can travel great distances due to the worldwide movement of air masses, affecting the quality of the air in areas that are far downwind from the origins of the pollution (Velasquez-Garcia et al., 2024). Understanding these broad worldwide patterns is crucial for Dhaka City and other cities dealing with comparable air pollution issues. To address this intricate and interrelated problem of urban air pollution, it emphasizes the need for international cooperation, the creation and uptake of cutting-edge technologies, and the application of sensible legislative measures. Dhaka may work to raise the standard of living for its citizens by taking lessons from other countries and modifying solutions to fit its unique situation.

### **3. Methodology**

The empirical results and methodological rigor of primary research publications published in peer-reviewed journals were given priority. To give a more comprehensive synthesis of the body of knowledge and to pinpoint important research trends and gaps, review articles and meta-analyses were also included. In order to document the most recent developments and initial discoveries made at scientific conferences, conference proceedings were taken into consideration. Academic literature provided background information and in-depth analyses of pertinent subjects. The legitimacy and applicability of the gray literature were thoroughly assessed. Reputable governmental and international organizations' reports were seen as important sources of data, policy frameworks, and firsthand evaluations of Dhaka's air pollution problem, as well as the wider use of technology for environmental management. Research institutions' and non-governmental organizations' reports included information on particular initiatives, case studies, and regional viewpoints.

The data retrieved from the chosen literature included details on the kinds and concentrations of air pollutants measured in Dhaka, the sources of pollution that were found, the approaches used in earlier research (both conventional and AI/ML-based), the performance metrics used to assess predictive models, the difficulties in putting air quality management plans into practice, and the suggested policy recommendations. In urban settings like Dhaka, particular focus was placed on studies that used AI/ML algorithms to forecast air pollution concentrations, identify sources of pollution, and optimize intervention strategies. Thematic analysis was used to synthesize the examined literature in order to highlight important findings, methodological trends, research gaps, and recurrent patterns. The development of a thorough grasp of the present level of information about Dhaka's air pollution and the potential of AI/ML to address this pressing issue was made easier by this procedure. Contextualizing the uniqueness and importance of the current research was made easier by the gaps in the literature that were found. The search approach was also iterative. To improve the search and make sure that all pertinent literature was found, different keywords and combinations were investigated as the first search results were examined. Citation analysis was also used to track the evolution of important ideas in the discipline and identify influential works. This thorough and iterative literature evaluation served as a solid basis for the research's

further phases, offering the background information and perspectives required to direct the examination and debate of AI/ML applications for Dhaka City's air pollution control and forecasting.

### 3.1 What are PM<sub>10</sub> and PM<sub>2.5</sub>

Particulate matter is what PM stands for. It refers to a mixture of liquid droplets and solid particles that are present in the atmosphere. Numerous substances, such as dust, dirt, soot, smoke, and even microscopic liquid droplets, can make up these particles. They can originate in the atmosphere as a consequence of chemical reactions or be emitted straight from sources (Particulate Matter (PM) Basics, US EPA, 2024). Because the size of the particles is directly related to their propensity to cause health issues, PM is categorized based on its size. The two primary size groups that are frequently tracked and reported on are:

- **PM<sub>10</sub>:** These are "inhalable coarse particles" with a diameter of no more than 10 micrometers. To put this in perspective, the average human hair is around 70 micrometers in diameter. The breadth of a single hair may, therefore, accommodate many PM<sub>10</sub> particles. These particles are small enough to enter the lungs through the nose, throat, and eyes. They can also have an impact on the heart and lungs.
- **PM<sub>2.5</sub>:** These are "fine particles" with a diameter of no more than 2.5 micrometers. Approximately 30 times smaller than the typical human hair, these are even smaller than PM<sub>10</sub> particles. PM<sub>2.5</sub> particles can penetrate the circulation and reach the alveoli (air sacs) in the lungs because of their minuscule size. As a result, PM<sub>2.5</sub> is regarded as more harmful to health than PM<sub>10</sub> and has been connected to several severe health issues, such as cardiovascular and respiratory disorders and even early mortality.

High concentrations of PM<sub>2.5</sub> and PM<sub>10</sub>, two important air pollutants, can harm both the environment and human health (PM<sub>10</sub> and Air Quality: What Is the Impact of Coarse Particles, Particulate Matter, 2023). However, because PM<sub>2.5</sub> can enter the circulatory system and penetrate further into the respiratory system, it is typically seen as a bigger health risk (Inhalable Particulate Matter and Health. PM<sub>2.5</sub> and PM<sub>10</sub>, California Air Resources Board, n.d.).

### 3.2 Motor Vehicles in Dhaka City

The BRTA reports that there were 1,913,693 registered cars in Dhaka in October 2022, compared to 1,716,688 in 2019 (BRTA, 2022). Most of these cars are too old or refurbished to be properly maintained. Air pollution is caused by several factors, including overloading, poor parking management, tainted fuels, traffic congestion, and dust produced by friction with the roads (DOE., 2019a). The number of motor vehicles registered in Dhaka is displayed in Table 01 below.

SI No	Type of Vehicles	2014	2015	2016	2017	2018	2019	2020	2021	2022	Grand Total
01	Ambulance	253	355	284	399	456	548	599	614	379	5603
02	Auto Rickshaw	56	428	582	42	5637	6839	114	112	170	20832
03	Auto Tempo	0	0	0	0	0	0	0	0	0	1406
04	Bus	1363	2219	3487	3294	2322	2951	1792	1213	1895	39237
05	Cargo Van	600	396	999	1286	1224	3	1	0	0	9062
06	Covered Van	2422	1940	2673	4068	4386	2529	1688	3350	3514	36274
07	Delivery Van	949	1531	1928	2207	1884	1292	967	1269	902	26223

<b>08</b>	<b>Human Hauler</b>	109	502	786	217	211	0	2	0	0	<b>4752</b>
<b>09</b>	<b>Jeep (Hard/Soft)</b>	1582	3110	4217	4712	4863	5038	4450	6927	8090	<b>64874</b>
<b>10</b>	<b>Microbus</b>	3833	4563	5162	4926	3583	3241	2407	4455	5724	<b>90285</b>
<b>11</b>	<b>Minibus</b>	136	103	155	158	185	186	133	186	125	<b>9981</b>
<b>12</b>	<b>Motor Cycle</b>	32891	46758	53718	75251	104051	99252	78551	99810	105059	<b>1000065</b>
<b>13</b>	<b>Pick Up (Double/Single Cabin)</b>	7185	7711	8370	10248	9598	8748	8024	8514	6785	<b>110882</b>
<b>14</b>	<b>Private Passenger Car</b>	12972	18423	18013	19570	16318	15016	11150	14321	13024	<b>327809</b>
<b>15</b>	<b>Special Purpose Vehicle</b>	50	66	224	233	500	410	144	123	71	<b>2511</b>
<b>16</b>	<b>Tanker</b>	162	143	203	187	323	235	177	157	182	<b>2875</b>
<b>17</b>	<b>Taxicab</b>	301	53	30	3	94	6	0	0	0	<b>30316</b>
<b>18</b>	<b>Tractor</b>	1443	1637	2510	2754	3359	2503	2445	2556	1301	<b>36260</b>
<b>19</b>	<b>Truck</b>	5704	4334	4306	7010	8725	6228	3327	4336	3010	<b>81024</b>
<b>20</b>	<b>Others</b>	961	1300	2559	3145	3593	3382	2283	2618	1865	<b>32602</b>
	<b>TOTAL</b>	<b>72972</b>	<b>95572</b>	<b>110206</b>	<b>139710</b>	<b>171312</b>	<b>158407</b>	<b>118254</b>	<b>150561</b>	<b>152096</b>	<b>1932693</b>

Table 01: The quantity of motor vehicles registered in Dhaka (Source: BRTA, 2022; Ahmed et al., 2024).

According to data obtained between 2002 and 2007, between 30 and 50 percent of PM collected from various parts of Dhaka city are fine particles produced by transportation-related sources, particularly diesel buses and trucks (45 percent) and autorickshaws (40 percent) (Begum et al., 2010). 85% of all carbon monoxide (CO) is produced by gasoline-powered light-duty vehicles (cars, vans, and autorickshaws), whereas 84% of all nitrogen oxides (NOx) are produced by diesel-powered buses and trucks. Dhaka has the highest levels of lead in the air (463 ng/m<sup>3</sup>) and was the most polluted city in the world in the late 1990s. In 1999, the government outlawed leaded gasoline and then autorickshaws with two-stroke engines. Consequently, the air's lead content decreased (Begum & Hopke, 2018; Ahmed et al., 2024). Dhaka's high vehicle traffic and poor road conditions are the main causes of road dust, which contributes significantly to the city's air pollution. The constant flow of automobiles on unpaved or badly maintained roads produces particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), which raises air pollution levels. This issue is made worse by dust particles resuspending into the air, particularly in dry and windy conditions (Ahmed et al., 2024).

### **3.3 The Air Quality in Dhaka City Is Impacted by Motor Vehicle Emissions**

The main source of the air pollution that is choking Bangladesh's vibrant city, Dhaka, is motor vehicles (M. M. Rahman et al., 2022b). In this megacity, the number of registered automobiles has skyrocketed, rising from 1.7 million in 2019 to over 1.9 million by October 2022. The combination of this exponential increase and the alarmingly

high number of outdated and badly maintained cars has made it ideal for the degradation of air quality. There are severe repercussions. However, research shows that between 30 and 50 percent of the particulate matter (PM) in Dhaka's air comes from sources associated with transportation. Buses and lorries that run on diesel are the biggest sources of fine particulate matter and nitrogen oxides (NO<sub>x</sub>), whereas autos and autorickshaws that run on gasoline are the main sources of carbon monoxide (CO). On the clogged highways of Dhaka, the stifling black smoke from unfit cars has become an all too familiar sight. This issue is made worse by poor maintenance and the usage of contaminated fuels (Abbas, 2024). Beyond exhaust fumes, the act of driving itself is a contributing factor in Dhaka. Heavy traffic and poor road conditions create a lot of road dust, which is a major source of fine (PM<sub>2.5</sub>) and coarse (PM<sub>10</sub>) particulate matter (Tasnim, 2024). This problem is made worse in dry and windy conditions because dust particles are easily resuspended into the atmosphere, where they linger and further deteriorate the quality of the air.

Even though previous government actions, like the prohibition on leaded gasoline and two-stroke autorickshaws, have had some success in lowering certain pollutants, like lead, the general quality of the air is still becoming worse. These advances are negated by the unrelenting rise in the number of vehicles, especially motorcyclists. Residents are at higher risk of respiratory ailments, cardiovascular disorders, and other health problems, which have serious effects on the environment and human health (Rahaman et al., 2023d). Urgent and thorough effort is required to address this situation. A shift to cleaner fuels and electric vehicles, stricter enforcement of maintenance laws, and stricter vehicle emission standards are all essential measures (Rahaman et al., 2023d). According to Raj et al. (2024), reducing traffic and dust pollution also requires repairing and maintaining roads, investing in public transportation, and using efficient traffic management techniques. Not only is an integrated strategy addressing all aspects of vehicle-related pollution required for Dhaka to genuinely breathe again, but it is also an issue of public health and the long-term viability of the city.

### **3.4 Dhaka Air Is Affected by Construction Dust**

Construction activities are a major and harmful factor in the acute air quality issue that Dhaka, a metropolis that is experiencing rapid and broad development, is facing. The unrelenting rate of change, which is typified by a large number of current construction projects and infrastructure development, significantly adds to the capital's already concerning air pollution levels. The majority of the air pollution in Dhaka comes from construction projects, which are significant sources of airborne contaminants. Numerous studies have repeatedly shown how construction-related activities, including excavation, the processing and transportation of building supplies like sand and cement, and the movement of large machinery, produce significant volumes of dust and particulate matter. This includes the coarser particles (PM<sub>10</sub>) and especially dangerous tiny particles (PM<sub>2.5</sub>), which can enter the respiratory system deeply. A general lack of strict regulatory control and enforcement, the widespread use of inferior construction materials, and ineffective waste disposal techniques that are common at many sites frequently exacerbate the issue. The enormous amount of dust produced by these building sites lingers in the atmosphere, impairing visibility and having a direct effect on the health of city dwellers. Furthermore, the problem is made worse by the inappropriate handling of garbage from building and demolition. Uncovered waste piles can leak toxic materials into the surrounding environment and serve as extra sources of dust, particularly in dry and windy weather. Excessive amounts of particulate matter are freely emitted into the atmosphere of Dhaka due to the lack of reliable and efficient dust suppression techniques at many building sites. This air pollution from construction has serious and far-reaching effects. Increased airborne particulate matter concentrations are a direct cause of an increase in respiratory diseases, from bronchitis and asthma to more serious ailments. Additionally, the long-term exposure of Dhaka's big population to such dirty air raises their risk of cardiovascular illnesses and other chronic health issues. In addition to its direct health effects, the declining air quality has a substantial financial impact as well, as it raises healthcare expenses, lowers productivity because of illness, and lowers the general standard of living for city dwellers. Stricter laws, sustainable building methods, and increased cooperation among all pertinent players are all important components of a multifaceted, coordinated strategy to address this pressing issue.

### **3.5 Significant Air Pollutants in Dhaka**

The health, well-being, and everyday lives of the people who live in Dhaka, the vibrant city of Bangladesh, are significantly impacted by the ongoing and severe air quality problem. High levels of many dangerous contaminants are regularly detected in the city, which poses a serious threat to the environment and public health.

#### **1) Examining Dhaka's Principal Air Pollutants:**

Numerous dangerous compounds, each with its own sources and negative consequences, are present in the air of Dhaka:

- **Particulate Matter (PM<sub>2.5</sub> and PM<sub>10</sub>):** With sizes of less than 2.5 and 10 micrometers, respectively, these tiny particles constitute a common and very pernicious type of pollution in Dhaka. Due to its minuscule size, PM<sub>2.5</sub> can enter the bloodstream and reach deep into the lungs, causing a series of detrimental health impacts. The omnipresent emissions from automobiles, especially those from older, poorly maintained vehicles, as well as the growing number of private cars and two-stroke engines, are major sources (Hossain et al., 2020; Begum et al., 2013). Another major factor is the large number of brick kilns that surround the city and frequently use antiquated and polluting methods, particularly when they are working during the dry season (Alam et al., 2017; Chowdhury et al., 2016). Due to frequent excavations and unpaved areas, construction operations and road dust resuspension contribute significantly to the air's coarse PM<sub>10</sub> content (Islam et al., 2019). According to UNEP (2015), burning solid waste and biomass releases a lot of particulate matter and other harmful substances, even though it can be isolated. Increased risks of cardiovascular disorders, heart attacks, strokes, and even early mortality are all strongly associated with elevated PM levels, as also respiratory conditions such as asthma, bronchitis, and COPD (Rahman et al., 2018; Khan et al., 2021).
- **Nitrogen Dioxide (NO<sub>2</sub>):** Due to the huge volume of vehicles, particularly diesel engines running at high temperatures, and other combustion-based industrial activities, this noxious gas is a major contaminant in the urban environment of Dhaka. High NO<sub>2</sub> levels impair lung function, irritate the respiratory system, cause airway inflammation, and make people more vulnerable to respiratory illnesses, including influenza (WHO, 2021). Asthma and other long-term lung conditions can also be brought on by prolonged exposure.
- **Sulfur Dioxide (SO<sub>2</sub>):** While occasionally lower than other pollutants, SO<sub>2</sub> levels in Dhaka nevertheless offer serious health hazards because they are mostly released from industrial operations that entail the burning of sulfur-containing fossil fuels, such as power plants and some manufacturing processes. Wheezing and shortness of breath are respiratory symptoms that can be brought on by even brief exposure, especially in people who have asthma. Extended periods of exposure can worsen pre-existing cardiac issues and cause respiratory diseases (WHO, 2021).
- **Ground-level Ozone (O<sub>3</sub>):** Ground-level ozone is a dangerous secondary pollutant that is created when precursor pollutants such as nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOCs) combine with sunlight and high temperatures. This is in contrast to the stratospheric ozone layer, which shields humans from dangerous UV radiation. Ozone levels are higher in Dhaka, especially during the hot and sunny pre-monsoon and post-monsoon seasons. Ozone is a strong respiratory irritant that can exacerbate asthma and other respiratory disorders and cause coughing, throat irritation, and chest pain (WHO, 2021).
- **Carbon Monoxide (CO):** The Silent Killer: Due to incomplete combustion caused primarily by the large number of cars navigating Dhaka's clogged streets and some industrial sources, this colorless and odorless gas is produced. In addition to causing symptoms including headaches, nausea, and dizziness, CO can be lethal at high quantities because it disrupts the blood's ability to carry oxygen (WHO, 2021). Young children and people with heart issues are among the vulnerable groups that are especially at risk.

#### **2) Seasonal Changes in Dhaka's Air:**

The air quality in Dhaka varies with the seasons and is never constant:

- **The Polluted Winter (November to February):** In Dhaka, the air quality is usually at its worst around this time. When temperatures drop, a layer of warm air traps cooler, dirty air close to the ground, preventing it

from dispersing. This phenomenon is known as a temperature inversion. This dry season's lower rainfall also implies that fewer contaminants are naturally scavenged from the atmosphere. Particulate matter levels are also elevated due to the continuous operation of brick kilns and the increased burning of biomass for heating (World Bank, 2019).

- **The Monsoon Relief (June to October):** The air quality in Dhaka temporarily improves with the arrival of the monsoon rains. Rainfall reduces particulate matter concentrations and removes contaminants from the atmosphere, acting as a natural scrubber. Certain contaminants may also behave differently in environments with higher humidity levels. Pollution levels can still be higher than WHO standards, though, even during the monsoon.
- **The Transition Periods (March-May & September-October):** Conditions during these times are frequently mixed, with pollution levels progressively rising or falling in response to weather patterns and the level of pollution-producing activity.

### 3.6 Factors Contributing to Dhaka's Air Pollution

Bangladesh's dynamic but crowded capital, Dhaka City, is fighting a fierce battle against extreme air pollution (Rahaman et al., 2023). This environmental disaster is the result of a complex interaction between natural and human-caused factors. The first essential step in creating practical and long-lasting solutions is comprehending the complex causes of Dhaka's poor air quality.

- 1) **The Overloaded Roads (The Main Cause of Vehicle Emissions):** One of the main causes of Dhaka's air pollution problems is the sheer number of cars that clog its roads. The number of vehicles, buses, lorries, motorbikes, and common three-wheeled autorickshaws has increased exponentially due to the city's fast population growth (Mahmud et al., 2012). Most of these cars use fossil fuels, are frequently outdated and badly maintained, and release a poisonous mixture of pollutants into the air of the city (Dibya et al., 2023). According to Hossain et al. (2020), these include carbon monoxide (CO), which is a byproduct of incomplete combustion that lowers the blood's ability to carry oxygen; nitrogen oxides (NO<sub>x</sub>), which cause respiratory disorders and contribute to smog and acid rain; volatile organic compounds (VOCs), which can also cause smog and have carcinogenic qualities; and, most importantly, particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), which are fine and coarse particles that get trapped deep in the lungs and set off a series of health problems. This issue is made worse by Dhaka's infamous traffic jams, which worsen the air quality in certain places by allowing idling cars to continue emitting pollutants when they are not moving.
- 2) **The Impact of Industry (Emissions from Factories):** A major industrial center, Dhaka is home to a wide variety of businesses, including several small-scale companies, the ubiquitous brick kilns, and large-scale textile and pharmaceutical production facilities (Wikipedia contributors, 2025). These industrial processes frequently lack strict pollution control procedures and rely on antiquated, energy-inefficient technologies. Sulfur dioxide (SO<sub>2</sub>), a respiratory irritant and precursor to acid rain, nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs), some of which are toxic, and large amounts of particulate matter are released as a result, especially from brick kilns that frequently burn coal and other less clean fuels (Alam et al., 2017). Particularly during the dry season, the sheer number of brick kilns that surround Dhaka and frequently use crude methods makes them a particularly powerful source of air pollution.
- 3) **The Dust of Development (Construction and Demolition Activities):** Due to the unrelenting speed of Dhaka's infrastructure and urban development initiatives, construction and demolition operations are ongoing (Abir & Bappy, 2024). These operations produce enormous volumes of dust and particulate matter, which readily enter the atmosphere and greatly raise the PM<sub>2.5</sub> and PM<sub>10</sub> levels in the city. The issue is exacerbated by emissions from large construction vehicles, which are frequently older and subject to fewer regulations. These vehicles release NO<sub>x</sub> and other pollutants into the atmosphere. One of the main causes of this type of pollution at building sites is inadequate dust suppression techniques.
- 4) **Rural Encroachment (Farming Activities on the Boundaries of the City):** Agricultural activities on Dhaka's outskirts also contribute to air pollution despite the city's predominantly urban setting. When nitrogen-based fertilizers are used, ammonia (NH<sub>3</sub>), a precursor to the creation of secondary particulate matter, may be released. Although it may have a less direct effect on urban air quality in terms of acute health consequences

than other pollutants, rice paddies, which are prevalent in the area, are a substantial source of methane (CH<sub>4</sub>), a powerful greenhouse gas. Although it is occasionally done, burning agricultural leftovers after harvests might release toxic compounds and particulate matter (AAQTF Agricultural Burning Policy Recommendations, Natural Resources Conservation Service, n.d.).

- 5) The Waste Conundrum (Difficulties with Solid Waste Management):** Significant air pollution in Dhaka is caused by inadequate solid waste management techniques (Abusiddique, 2022). A variety of harmful pollutants, including dioxins, furans, and particulate matter, are released when trash is burned outside, a prevalent practice in many places that poses major health hazards. Methane and other dangerous gases can be released into the environment by landfills if they are not adequately maintained with gas capture devices. If they lack sophisticated emission control technology, ineffective or nonexistent trash incineration facilities may potentially contribute to air pollution.
- 6) The Smoky Haze (Home Cooking and Heating Methods):** Due to a lack of access to more cost-effective and environmentally friendly energy options, solid fuels like wood, coal, and biomass (such as dried dung and agricultural waste) are still widely used for cooking and heating in many Dhaka neighborhoods, especially in lower-income neighborhoods (M. A. Islam et al., 2022). These fuels contribute to indoor and outdoor air pollution by incompletely burning, which emits large volumes of carbon monoxide (CO) and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) into the surrounding air and living space (Kopel & Brower, 2019).
- 7) Traffic Congestion's Enhanced Effect (The Gridlock Effect):** The well-known traffic jams in Dhaka not only annoy commuters but also seriously worsen air pollution (Rahaman et al., 2023). Long periods spent stuck in traffic cause cars to continue emitting pollutants without moving, which causes a concentrated buildup of dangerous compounds in regions with high population density. In addition to contributing to localized hotspots of bad air quality, this extended idling raises overall emissions (Vehicle Idling Can Compound Local Pollution on Bad Air Days' @theU, 2023).
- 8) The Role of Nature (The Impact of Natural Occurrences):** The main cause of Dhaka's air pollution is human activity; however, natural occurrences can also make the issue worse. The neighboring arid and semi-arid regions can contribute substantial amounts of particulate matter to the city's atmosphere through dust storms, especially during the dry season. Temperature inversions during the winter, for example, can trap pollutants close to the ground, inhibiting their dispersion and raising concentrations by causing seasonal fluctuations in weather patterns (Temperature Inversion Traps Pollution at Ground Level, 2016).
- 9) The Absence of Green Spaces:** Dhaka's green areas and vegetation have significantly decreased as a result of the city's fast and frequently uncontrolled urbanization (Rahaman et al., 2023c). In addition to releasing oxygen into the atmosphere, trees and other plants are essential for absorbing air pollutants like particulate matter, nitrogen dioxide, and ozone (TreePeople, 2024). Dhaka's natural capacity to purify its air is weakened by its inadequate greenery.
- 10) The Governance Gap (Issues with Rules and Implementation):** Although Bangladesh has put laws in place to regulate air pollution from several sources, there is still a big problem with their inadequate implementation. It's possible that businesses and car owners don't always follow pollution control regulations because they lack the necessary resources, awareness, or efficient oversight. The efficacy of current laws is compromised by lax enforcement, which permits polluting operations to go unchallenged.
- 11) Geographical Limitations (The Topography of the Land):** Pollutants may also be trapped by the terrain of Dhaka and the current weather patterns (Akhter et al., 2021). Pollutants can accumulate in the lower atmosphere due to a lack of vertical mixing and dispersion caused by certain geographical features and meteorological conditions, such as temperature inversions, which occur when a layer of warm air sits above cooler air near the surface (Glojek et al., 2022).

A thorough and coordinated approach that addresses each of these contributing variables is necessary to address Dhaka's complicated air pollution problem. In addition to enforcing more stringent regulations, this calls for a coordinated effort to advance cleaner technologies in all industries, fund sustainable urban planning and public transportation, enhance waste management procedures, provide cleaner alternatives for residential energy needs, and expand green spaces in the city (Issue-I, 2024). Raising public awareness and encouraging participation is also

essential for creating a sense of shared accountability for enhancing Dhaka's air quality and protecting the health and welfare of its citizens. In addition to being a necessary environmental step, the shift to cleaner energy sources and sustainable development methods is also a critical step in guaranteeing a better and more habitable future for Dhaka.

### 3.7 The Effects of Air Pollution on The People Who Live in Dhaka

With millions of residents, Dhaka is engulfed in a suffocating battle against an unseen foe: air pollution. This is not only an environmental issue; it is a serious and widespread crisis that affects everyone who lives in this megacity, affecting their future as well as their health and general well-being. They suffer from a long-lasting negative impact from the poisonous air they breathe, which goes much beyond a minor cough (Tasnim, 2025).

**1) The Wider Effects Beyond Physical Health:** Air pollution affects Dhaka's general well-being and standard of living.

- **Reduced Quality of Life:** The ongoing battle with respiratory problems, discomfort, and worry about long-term health effects severely lowers the general standard of living for people living in Dhaka. Simply breathing clean air becomes a luxury, and outside activities lose their appeal.
- **Higher Healthcare Costs:** The rise in diseases linked to air pollution puts a heavy burden on the healthcare system and raises both private and public healthcare expenses.
- **Decreased Productivity:** Air pollution-related illnesses result in lost work and school days, which affect economic possibilities and productivity for both people and the community as a whole. A schematic representation of the negative health effects of air pollution is shown in Figure 01.

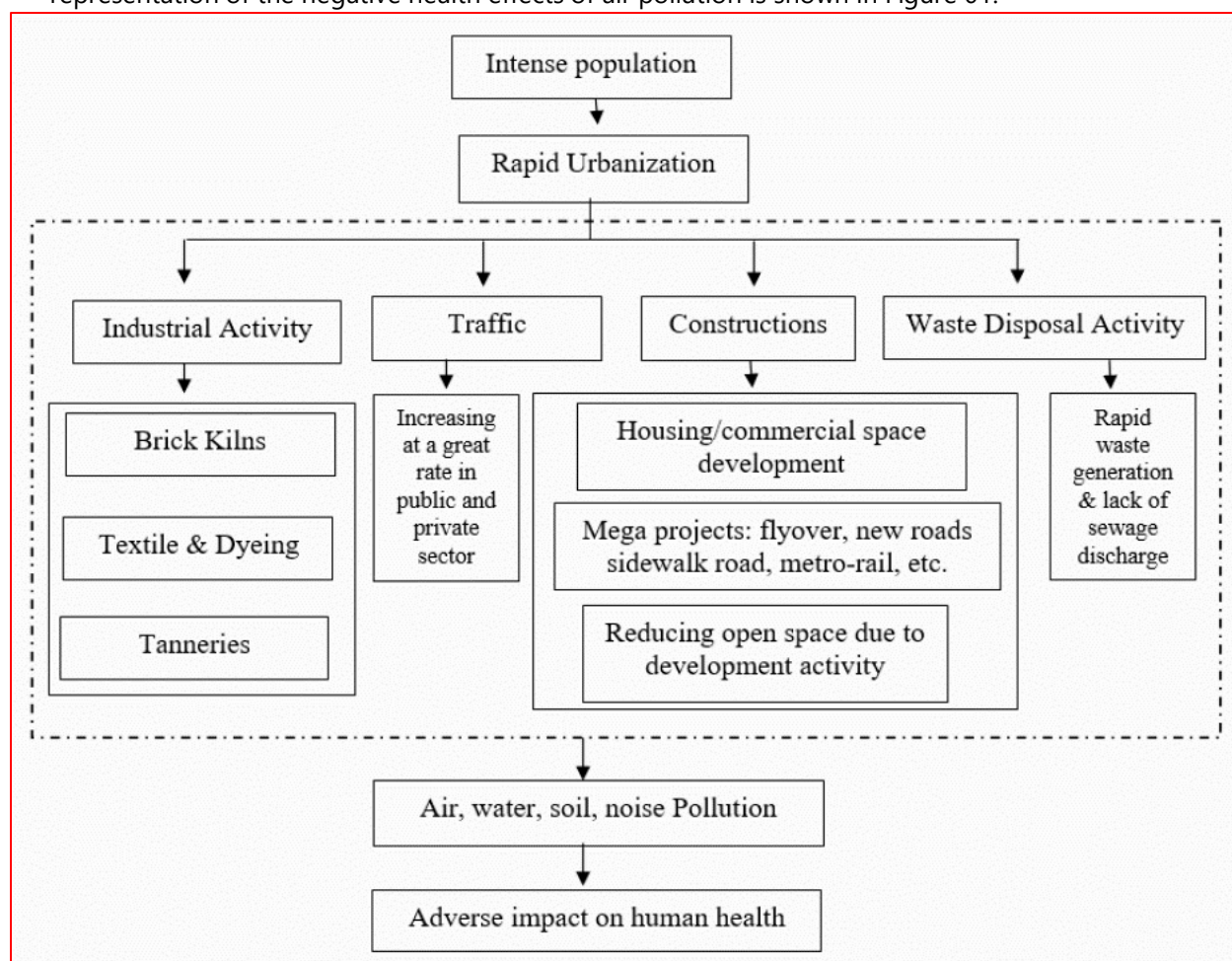


Figure 01: A schematic illustration of how air pollution harms people's health (Source: Ahmed et al., 2024).

## **2) The Direct Attack (Everyday Battles with Air Pollution):**

Residents of Dhaka deal with the direct effects of the city's poor air quality daily:

- **Enhanced Infection Susceptibility:** Individuals are more vulnerable to frequent and severe respiratory diseases like pneumonia and bronchitis due to the ongoing irritation and inflammation brought on by air pollution (Health Impacts, n.d.). Particularly at risk are children, whose immune systems are still maturing (American Lung Association, n.d.).
- **Distressed Breathing:** The respiratory system experiences the most immediate and pervasive impact. According to Dibya et al. (2023), breathing in the air from Dhaka can cause coughing fits, wheezing, shortness of breath, and chest tightness in everyone from the youngest kid to the oldest grandparent. People who already have asthma or bronchitis may experience crippling episodes that necessitate medication or perhaps hospitalization as a result of these continuous exposures to contaminated air. Even the seemingly easy task of inhaling deeply becomes difficult.
- **Irritation and Discomfort:** The eyes, nose, and throat are irritated by air pollutants such as particulate matter, nitrogen dioxide, and ozone (Lin et al., 2022). Burning feelings, watery eyes, frequent sneezing, and generalized discomfort that impairs everyday functioning and quality of life might result from this.
- **Physical Capacity Reduction:** Physical endurance and stamina can be diminished by breathing contaminated air, even for healthy people. They may find it more difficult to perform basic tasks like walking or climbing stairs, which may affect their capacity to work, exercise, and fully engage in daily life.

## **3) Vulnerable Populations:** Not every group in Dhaka experiences the consequences of air pollution equally:

- **Outdoor Workers:** People who work outside, such as street sellers, construction workers, and traffic police, are more vulnerable since they are constantly exposed to high pollution levels (M. S. Islam et al., 2024).
- **The Elderly:** Due to their compromised respiratory and cardiovascular systems and pre-existing medical issues, older persons are particularly vulnerable to the negative effects of air pollution.
- **Children:** Children are more susceptible to the negative impacts of air pollution because of their developing lungs and immune systems, which can result in increased rates of respiratory ailments, asthma, and developmental issues (The Links Between Air Pollution and Childhood Asthma, US EPA, 2024).
- **People with Pre-existing Conditions:** Polluted air exacerbates the symptoms of people who already have heart disease, asthma, or other chronic conditions.
- **Low-Income Communities:** Low-income communities are disproportionately affected by the health effects since they frequently live in locations with higher pollution levels because of their proximity to industrial zones or busy roads, and they have less access to healthcare.

## **4) The Long-Term Erosion (Prolonged Health Issues and Decreased Lifespan):** Years of breathing the contaminated air in Dhaka can cause several severe and long-lasting health issues, including:

- **Increased Cancer Risk:** The risk of lung cancer and other types of cancer is increased by prolonged exposure to carcinogenic pollutants found in Dhaka's air, such as heavy metals and certain volatile organic compounds.
- **Neurological Impacts:** Recent studies point to a connection between exposure to air pollution and neurological issues, including cognitive decline, childhood developmental delays, and possibly a higher chance of developing neurodegenerative disorders in later life (Olloquequi et al., 2024).
- **Development of Chronic Lung Diseases:** A long-term exposure to pollutants such as nitrogen oxides and particulate matter raises the likelihood of developing chronic obstructive pulmonary disease (COPD), a crippling lung illness that gradually makes breathing harder (Ling & Van Eeden, 2009).
- **Reduced Life Expectancy:** The substantial decline in life expectancy for people living in Dhaka is arguably the most disastrous long-term consequence. Years of exposure to harmful air damages the body and increases the risk of dying young from a variety of diseases linked to pollution.
- **Impact on Mental Health:** Research is increasingly linking long-term exposure to air pollution to mental health conditions like sadness and anxiety. The physical toll of pollution and ongoing environmental stress can have a detrimental impact on mental health (World Bank Group, 2024).

- **Cardiovascular Damage:** Heart attacks, strokes, and other cardiovascular diseases, which are currently the top cause of death in Bangladesh—may be made more likely by the minute particles in the air that can enter the bloodstream and help build up plaque in arteries (Air Pollution and Cardiovascular Disease Basics, US EPA, 2025).

Air pollution has serious, wide-ranging, and alarming effects on the population of Dhaka. It is an ongoing threat to their health, a daily assault on their well-being, and a major roadblock to the advancement of the city. In addition to being an environmental requirement, addressing this situation quickly and comprehensively is essential for the future well-being and health of every person residing in this dynamic but more congested city.

### **3.8 Governmental Efforts to Reduce Air Pollution in Dhaka City**

Recognizing the serious and complex air pollution situation afflicting Dhaka City, the Bangladeshi government has launched several steps to address this environmental and public health disaster. These initiatives, which range from local implementation to national policy frameworks, show a dedication to enhancing air quality and protecting the health of the city's millions of inhabitants. Even though the problem is still very large, these government-led initiatives offer a vital starting point for advancement.

- 1) **Raising Public Awareness Campaigns to Educate and Empower Citizens:** The government acknowledges the value of raising public awareness to combat air pollution, working with civil society organizations and non-governmental organizations (NGOs).
  - **Initiatives in Education:** Campaigns to raise public awareness are carried out to inform locals about the negative health effects of air pollution, its origins, and doable strategies to lessen their exposure and help create cleaner air. These campaigns attract a large audience by using a variety of media outlets.
  - **Encouragement of Eco-Friendly Practices:** The programs also promote the adoption of eco-friendly behaviors among individuals and communities, such as walking, bicycling, public transportation, and trash reduction.
- 2) **Controlling Vehicle Emissions to Face the Transportation Beast:** The government has taken a number of steps to reduce vehicle emissions, which are a significant cause of air pollution in Dhaka:
  - **Tougher Emission Regulations:** The goal of stricter emission regulations for new automobiles is to lessen the quantity of pollutants emitted by the expanding fleet. This promotes the use of cleaner technologies by manufacturers and is in line with international best practices.
  - **Making Public Transportation Investments:** The government is investing heavily in the expansion and modernization of Dhaka's public transportation system because it recognizes that a move to public transportation is necessary to lower the number of private automobiles on the road. By offering effective, dependable, and comfortable substitutes for private automobiles, landmark projects like the Dhaka Metro Rail and the Bus Rapid Transit (BRT) systems hope to ease traffic congestion and lower total emissions.
  - **Mandatory Vehicle Inspections:** To make sure that older cars are maintained correctly and meet emission regulations, regular and required vehicle inspections are essential. This aids in locating and removing extremely polluting automobiles from the road.
  - **Encouraging Compressed Natural Gas (CNG):** As a greener substitute for conventional gasoline and diesel fuels, the government has aggressively encouraged the usage of CNG. The installation of CNG refueling stations across the city has made it easier for people to switch to CNG-powered cars, which typically emit fewer harmful emissions and particulate matter.
  - **Promoting Electric Vehicles (EVs):** The government is taking the first steps to promote the adoption of electric vehicles through incentives and policy support, acknowledging the long-term potential of electric mobility. Although this effort is still in its infancy, it has the potential to drastically cut tailpipe emissions in the future.
- 3) **Developing the National Clean Air Action Plan (NCAAP) as the Foundation for Policy:** The National Clean Air Action Plan (NCAAP) is the pinnacle of the government's approach. This comprehensive blueprint, which was created in partnership with funders and international organizations, lays out a multifaceted strategy for addressing air pollution throughout Bangladesh, with a particular emphasis on Dhaka. The NCAAP establishes

measurable goals for cutting emissions from major polluting industries, such as waste management, industry, and transportation. To achieve long-term improvements in air quality, it offers a strategic framework for coordinated action that includes behavioral adjustments, technology advancements, and legislative interventions.

- 4) **Maintaining Public Awareness (Implementation of the Air Quality Index (AQI)):** Giving the public access to easily comprehensible information on air quality is crucial to enabling them to take preventative action:
  - **Current Air Quality Information:** The government has put in place an Air Quality Index (AQI) that converts complicated data on air quality into an easy-to-understand color-coded system. For vulnerable populations in particular, this makes it simple for locals to comprehend the daily air quality conditions and make well-informed decisions regarding their activities.
- 5) **Exposing the Issue (The Network for Monitoring Air Quality):** Assessing the issue appropriately is crucial to managing air pollution effectively. To do this, Dhaka City's government has set up a real-time air quality monitoring network. Monitoring stations are positioned strategically to continually detect the amounts of several important pollutants, such as carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), and ozone (O<sub>3</sub>). The information produced by this network is crucial for comprehending pollution patterns, locating pollution hotspots and sources, assessing the success of treatments, and guiding evidence-based policy choices. Public communication via the Air Quality Index (AQI) is also based on this real-time data.
- 6) **Using Clean Energy: Promoting Renewable Energy:** One of the most important long-term strategies for lowering air pollution is switching to cleaner energy sources.
  - **Renewable Energy Incentives:** By offering subsidies, incentives, and rules that are advantageous to both residential and commercial users, the government is encouraging the use of renewable energy sources like wind and solar power. Rooftop solar panel installation and the creation of larger-scale renewable energy projects are being promoted.
- 7) **Industry Cleanup: Controlling Industrial Emissions:** Air pollution has also been found to be significantly caused by the industrial sector, which includes textile plants and brick kilns. The government has imposed more stringent rules aimed at these sectors:
  - **Sectors with High Emissions:** Certain industries, such as textile processing facilities and brick kilns, are subject to particular rules. Cleaner technology adoption is frequently required by these regulations, which also place restrictions on the amount of SO<sub>2</sub>, NO<sub>x</sub>, and particulate matter that can be released into the atmosphere and demand that enterprises acquire environmental clearances.
  - **Encouraging Cleaner Technologies in Brick Kilns:** The government is encouraging the use of less polluting and more energy-efficient technologies, like hybrid and zigzag kilns, in brick kilns due to the notably high pollution levels from traditional brick kilns. This shift is being promoted through awareness campaigns and financial incentives.
- 8) **Handling Waste: Initiatives for Waste Management:** Air pollution is largely caused by improper solid waste management, especially open burning. The government is working to make waste management procedures better:
  - **Better trash Segregation and Collection:** Efforts are being made to improve trash segregation at the source and increase the efficiency of waste collection. This can help with recycling and lessen the quantity of waste that is burned in landfills or open spaces.
  - **Waste-to-Energy and Recycling Initiatives:** As environmentally friendly substitutes for open burning and dumping, the government is investigating and funding waste-to-energy initiatives and recycling infrastructure. Reducing emissions from landfills and producing energy from garbage are the goals of these programs.
- 9) **Looking Past Boundaries (Global Cooperation):** Since air pollution frequently crosses international borders, the Bangladeshi government works closely with both international organizations and its neighbors:
  - **Regional and International activities:** Bangladesh acknowledges the cross-border interdependence of air pollution and takes part in regional and international activities to improve air quality and lower greenhouse gas emissions.

**10) Creating a Greener Future: Urban Planning Projects:** Since urban development has a long-term effect on air quality, the government is taking environmental factors into account:

- **Green Space Development:** There are initiatives underway to expand Dhaka City's green areas, including parks and urban woods. To absorb pollutants and enhance air circulation, vegetation is essential.
- **Support for Mixed Land-Use Planning:** Promoting mixed land-use development can cut down on long commutes, which in turn lowers emissions from moving vehicles.

The urgent problem of air pollution in Dhaka City has been addressed by the Bangladeshi government through a large number of legislations, projects, and programs. These efforts reveal an increasing dedication to addressing this difficult problem. But, given the scope of the issue, achieving significant and long-lasting improvements in Dhaka's air quality and guaranteeing a healthier future for its citizens will require persistent work, more investment, stricter enforcement, and ongoing cooperation with all stakeholders, including the public, private sector, and foreign partners.

### **3.9 Artificial Intelligence's Revolutionary Potential In Air Quality Regulation**

Global air pollution concerns are growing, and this calls for creative and efficient monitoring and mitigation techniques (Gulec, 2024). Although traditional approaches to managing air quality offer insightful information, they frequently fail to capture the intricate dynamics and produce timely, precise forecasts that are essential for protecting public health and formulating policy (Panaite et al., 2024). With previously unheard-of benefits in terms of data processing, adaptability, real-time capabilities, and prediction accuracy, the emergence of artificial intelligence (AI), in particular machine learning (ML) and deep learning (DL), represents a paradigm shift in air quality control. This article explores these advantages in greater detail, backed by empirical data and practical implementations, while also discussing the inherent difficulties and possible solutions for broad and significant adoption.

**1) Adaptability and Continuous Learning (Embracing Dynamic Environments):** The static assumptions and parameters used in traditional air quality models may not adequately represent changing environmental circumstances, governmental changes, or technology breakthroughs. On the other hand, AI systems are remarkably adept at learning from and adapting to new data (West & Allen, 2018). Through constant retraining with incoming air quality data, machine learning models can dynamically modify their parameters and gradually increase the accuracy of their predictions. This adaptability is crucial in accounting for:

- **Technological Advancements:** AI models can be retrained to integrate new pollution control technology or modifications to monitoring techniques, guaranteeing their accuracy and continuous relevance.
- **Impacts of Climate Change:** The generation and dispersion of air pollutants can be impacted by climate change's effects on atmospheric chemistry and weather patterns. AI algorithms that are always learning can adjust to these long-term patterns.
- **Changing Emission Patterns:** Emission profiles can be considerably changed by changes in agricultural practices, transportation infrastructure, or industrial activities. These new patterns can be learned by AI models, which can then modify their predictions (New AI Tool Could Transform the Way We Monitor and Forecast Air Pollution, 2024).

Compared to their conventional equivalents, AI-based air quality management systems are more robust and resilient to social and environmental changes because of their intrinsic adaptability.

**2) Long-Term View on Efficiency, Accuracy, and Cost-Effectiveness:** There are clear benefits in terms of effectiveness, precision, and long-term cost-effectiveness when comparing AI-based techniques to conventional ones.

- **Accuracy:** Compared to conventional techniques that could rely on simplified assumptions, artificial intelligence (AI) produces better predictive accuracy because of its capacity to model intricate relationships and learn from massive datasets.

- **Cost-Effectiveness:** Although implementing AI can require a significant initial investment in data infrastructure, model development, and computer resources, ongoing operating expenses are frequently lower. Large amounts of manual labor can be eliminated by using AI-powered solutions to automate forecasting and monitoring duties. Additionally, more precise and focused policy actions may come from the increased accuracy of AI-driven insights, which might save a substantial amount of money over time in the healthcare and environmental remediation sectors (Admin, 2024b). When compared to growing conventional monitoring networks and modeling initiatives, the scalability of AI solutions also makes them more affordable for large-scale deployments.
- **Efficiency:** After being trained, AI models may produce forecasts and analyses quickly with little human involvement or computational effort, greatly surpassing the frequently laborious procedures required for manual statistical analysis or classical dispersion modeling (The Role of AI in Air Quality Monitoring, Air Quality Monitoring. Monitor in UK & Europe. Airly Data Platform and Monitors, n.d.).

**3) Improved Forecasting Precision (Exposing Intricate Atmospheric Mechanisms):** When compared to conventional statistical and deterministic models, artificial intelligence's greater predictive accuracy is one of its most notable benefits for air quality control (Foster, 2025). The complex non-linear relationships among different meteorological parameters (temperature, humidity, wind speed, solar radiation), emission sources (industrial, vehicular, agricultural), and chemical reactions that control pollutant formation and dispersion, are frequently difficult for traditional methods, like statistical regression or physical dispersion models, to account for (Rorat et al., in 2025). AI algorithms are excellent at deciphering these intricate associations from large datasets, especially non-linear models like Artificial Neural Networks (ANNs), Support Vector Machines (SVMs), and Recurrent Neural Networks (RNNs), which include Long Short-Term Memory (LSTM) networks. Several studies have shown that AI has improved predictive capacity in predicting important air pollutants like sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), ozone (O<sub>3</sub>), and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>). Take, for example:

- **Prediction of the Air Quality Index (AQI):** Research using gradient boosting algorithms, such as XGBoost and LightGBM, has shown that these algorithms are effective in forecasting the total AQI by combining various pollutant concentrations and meteorological factors (Ma et al., 2019). More complex and precise AQI forecasts are made possible by their capacity to manage non-linear correlations and feature interactions, which is essential for public health warnings.
- **PM<sub>2.5</sub> Forecasting:** Compared to conventional autoregressive integrated moving average (ARIMA) models, research employing LSTM networks has demonstrated notable gains in PM<sub>2.5</sub> concentration forecasting, especially in metropolitan settings with intricate pollution sources and weather influences. More precise short- and long-term forecasts can result from these models' ability to identify long-range correlations and temporal dependencies in air pollution data (Alawi et al., 2024).
- **Source Apportionment:** When applied to high-resolution air quality data, advanced AI techniques such as non-negative matrix factorization (NMF) and clustering algorithms can help identify and quantify the differences in pollution levels caused by various emission sources (Leveraging NMF to Investigate Air Quality in Central Taiwan, 20 Nov 2024). This data is essential for focused emission control plans.

Because AI improves predictive accuracy, early warning systems are more effective, enabling people and authorities to take preventative action to reduce exposure and carry out prompt actions, such as limiting traffic or adjusting industrial emissions.

**3) Monitoring and Forecasting in Real Time (Facilitating Proactive Reactions):** The combination of artificial intelligence (AI) and developments in data streaming and the Internet of Things (IoT) allows for real-time air quality predictions and monitoring. Dense networks of inexpensive sensors can send data continually to platforms driven by artificial intelligence (AI), which can then deliver short-term forecasts and real-time updates on air quality. There are several noteworthy benefits to this real-time capability:

- **Emergency Response:** In order to guide emergency response activities and evaluate the effects of unintentional pollution discharges, real-time data might be extremely important.
- **Traffic Management:** By using real-time data on air quality, dynamic traffic management systems may be able to reroute traffic away from very polluted locations.
- **Public Health Protection:** During pollution events, vulnerable groups (such as adults with respiratory conditions, children, and the elderly) can get real-time alerts that enable them to take the appropriate safety measures.
- **Industrial Emission Control:** Real-time emission reduction can be achieved by optimizing industrial operations using AI-driven analysis and ongoing monitoring.

By enabling prompt and useful information, people, communities, and authorities can react proactively to changes in air quality, reducing exposure and reducing possible health effects.

**4) Exceptional Data Processing Capabilities (Leveraging Big Data's Power):** Massive and varied datasets are produced by modern air quality monitoring from a variety of sources, such as social media data, weather stations, satellite images (such as MODIS and Sentinel-5P), ground-based sensors, and traffic monitoring systems (ATMO, June 28, 2024). Conventional analytical techniques frequently find it difficult to effectively interpret and glean valuable insights from this torrent of data. Large and complicated datasets can be handled by AI systems by nature. They are crucial for a thorough air quality study due to their capacity to manage missing values, perform automated feature extraction, and find correlations across many data sources (Guo et al., 2022). For instance:

- **Anomaly Detection:** Quick response and investigation are made possible by AI-powered anomaly detection algorithms that can spot odd spikes or patterns in air quality data that may point to pollution incidents or equipment failures (Lakshmanan & Lakshmanan, 2025b).
- **Sensor Network Optimization:** By analyzing data from dense networks of inexpensive air quality sensors, machine learning algorithms can locate sensor drift, calibrate individual sensors, and produce high-resolution neighborhood-scale air quality maps. This fine-grained data can highlight localized hotspots for pollution that conventional monitoring networks might overlook.
- **Satellite Data Integration:** In areas with limited ground monitoring networks, AI models can be trained to interpret and combine ground-based observations and satellite-derived aerosol optical depth (AOD) data to provide geographically complete air quality maps (Tian et al., 2023). The spatial information seen in satellite photography is especially well-processed by convolutional neural networks or CNNs.

AI enables a more comprehensive understanding of air quality dynamics through the efficient processing of large and varied datasets, which results in better decision-making and focused interventions.

**5) Overcoming Obstacles and Creating a Future Plan:** Notwithstanding the many benefits, overcoming a few obstacles and restrictions is necessary for the successful and broad use of AI in air quality control:

- **The "Black Box" problem, or model interpretability:** Interpreting many sophisticated AI models, especially deep learning architectures, can be complex, making it hard to comprehend the fundamental assumptions behind their predictions. Building trust and enabling the public and politicians to embrace AI-driven insights requires research into explainable AI (XAI) approaches like SHAP and LIME.
- **Infrastructure and Computational Resources:** To train and implement sophisticated AI models, a strong infrastructure and substantial computational resources may be needed (Explained: Generative AI's Environmental Impact, 2025). Platforms for cloud computing provide scalable processing capacity without requiring a large initial investment, making them a practical choice.
- **Ethical and Privacy Issues:** The gathering and application of data on air quality raises ethical and privacy issues, particularly when combined with sensitive information such as personal location data. For AI to be deployed responsibly and ethically, strong data governance frameworks and anonymization methods are required.
- **Data Availability and Quality:** A significant amount of representative, high-quality data is necessary for AI models to function. It is essential to make sure that data is accurate, comprehensive, and consistent across

many sources. This problem can be solved by utilizing citizen scientific projects, encouraging data sharing, and standardizing data collection procedures.

- **Building Capacity and Technical Expertise:** AI-based air quality control system implementation and management call for a trained workforce with knowledge in environmental science, data science, and machine learning. Building the required capacity requires funding training initiatives and encouraging interdisciplinary partnerships.

Artificial intelligence provides a revolutionary toolbox for transforming air quality control, resulting in a synergistic approach for cleaner air (Affordable AI-powered Air Pollution Sensors Can Revolutionize Monitoring of Air Quality, Research by Kingston University Finds, 2025). Significant benefits over conventional approaches are offered by its exceptional predictive accuracy, unmatched data processing power, flexibility, and real-time features (Foster, 2025b). The potential advantages of AI in preserving public health and promoting sustainable ecosystems are enormous, even though issues with data quality, interpretability, computational resources, knowledge, and ethical considerations must be properly addressed. The best course of action for the future probably involves combining AI in a complementary way with conventional methods for modeling and monitoring air quality. We can develop more reliable, accurate, and responsive air quality management systems that open the door to cleaner and healthier air for everybody by combining the advantages of both strategies. To fully utilize AI in our continuous quest for cleaner skies, further research, technical developments, and cooperation between academics, decision-makers, and industry professionals are essential.

### ***3.10 Artificial Intelligence and Machine Learning Techniques For Addressing and Forecasting Air Pollution***

Machine learning (ML) and artificial intelligence (AI) are two different but related ideas (Artificial Intelligence vs Machine Learning, Microsoft Azure, n.d.). The goal of the larger field of artificial intelligence (AI) is to build machines that can carry out tasks that normally call for human intelligence. In contrast, machine learning is a branch of artificial intelligence. Its main goal is to make it possible for computers to learn from data without explicit programming. Large datasets are used in machine learning to train algorithms rather than creating unique instructions for each task. In order to generate predictions or choices about new, unknown data, these algorithms first find patterns and relationships in the data (Machine Learning, Explained, MIT Sloan, 2021). Thus, machine learning is one approach to AI. Based on data, it gives computers the techniques and resources they need to learn and get better over time.

Through the use of big data analytics, sophisticated computing systems, scalable storage, and parallel processing technologies, "Artificial Intelligence" and "Machine Learning" have emerged as key components in the fight against air pollution. By using advanced data-driven techniques, these breakthroughs bridge the gap between atmospheric and climate sciences and provide comprehensive management and mitigation solutions for a variety of air pollutants. When there is a wealth of data available, AI and ML models perform better; nonetheless, their capacity to predict pollutants effectively depends on their ability to comprehend and take into account the most important elements (Rautela & Goyal, 2024). Further research demonstrates the growing capabilities of AI and ML, building on their critical role in managing air pollution. These tools are being used more often to monitor pollution hotspots in real time and to uncover intricate patterns in air quality data that conventional approaches would overlook. Furthermore, AI and ML make it easier to combine various datasets, such as traffic patterns, industrial pollutants, and weather conditions, producing more accurate prediction models (Subramaniam et al., 2022). In an effort to increase these models' openness and make their results easier for the public and politicians to comprehend, explainable AI, or XAI, is likewise becoming more and more popular. Forecast accuracy and reliability across many time scales appear to be increasing using hybrid approaches that combine AI with statistical and physical models. Recurrent neural networks (RNNs) and long short-term memory (LSTM) networks are two examples of advanced deep learning architectures that have been developed to better capture the temporal dependencies present in the dynamics of air pollution (Q. Chen et al., 2024). Additionally, data collection capabilities are being expanded by AI-driven sensor networks and inexpensive monitoring devices, offering a more thorough and detailed understanding of local air quality (Revolutionizing Air Quality Monitoring with Affordable AI-powered Sensors - Knowledge

Transfer Partnerships, 2025). These developments are essential for creating efficient early warning systems and for guiding focused mitigation plans to safeguard the general public's health. The complete AI/ML model-building process for traffic or environmental predictions is shown in Figure 1. Preprocessing, algorithm selection, model construction, training, testing, validation, and data collecting across multiple domains are all steps in the process. The procedure concludes with prediction, integrating a feedback loop for model modification if necessary, guaranteeing flexibility and ongoing enhancement of forecast precision (Rautela & Goyal, 2024).

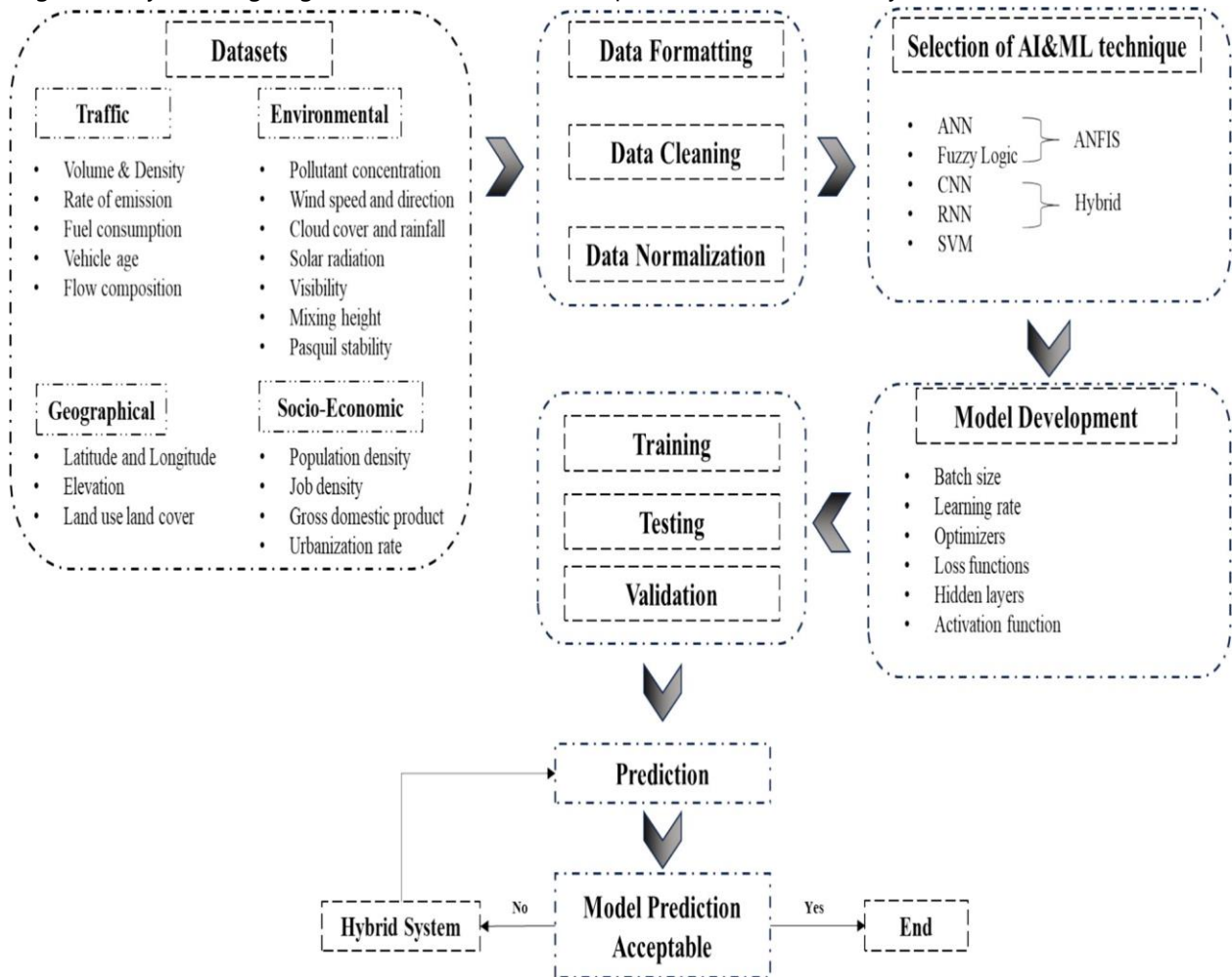


Figure 02: Outlining the methods that artificial intelligence and machine learning use to anticipate the levels of air pollution (Source: Rautela & Goyal, 2024).

Previous studies have frequently employed a variety of artificial intelligence and machine learning techniques, including ANN, fuzzy logic (FL), support vector machines (SVM), convolutional neural networks (CNN), recurrence neural networks (RNN), long short-term memory (LSTM), convolutional autoencoders (CA), etc., to forecast and predict earth and atmospheric variables. Machine learning models, with a particular emphasis on artificial neural networks (ANNs), have become essential for processing and simulating nonlinear information. One well-known kind of ANN that has shown promise in forecasting instances of air pollution is the multilayer perceptron (MLP). MLPs typically have input, hidden, and output layers, but by adding more than one hidden layer, they can adjust to intricate patterns. An improved form of ANNs, Deep Neural Networks (DNNs), are distinguished by their scalability and structural depth. Known as feature learning, DNNs with more than three layers can automatically extract features from unprocessed inputs. CNNs, LSTM, CA, and the modeling of complicated atmospheric factors like air pollution predictions are particularly well-liked and successful designs.

### **3.11 Application of Artificial Intelligence and Machine Learning in Air Pollution**

One of the most important tools for tackling and forecasting air pollution is the use of artificial intelligence and machine learning models, including ANNs, FL, SVM, and DL models. A wide variety of applications have drawn the interest of academics, and artificial neural networks (ANNs) have contributed to a revolutionary period in air pollution forecasting. The effectiveness of ANNs in accurately predicting gaseous and particle contaminants across a range of spatiotemporal resolutions has been demonstrated by numerous researchers. The use of a trained nonlinear three-layered back propagation feed forward network in Mlakar et al.'s early attempts at air pollution forecasting was a noteworthy turning point. The potential of ANNs was demonstrated by this model, which accurately forecasted the SO<sub>2</sub> concentration over a thermal power station. Later studies increased the ANN applications' breadth and complexity. Arena et al. also showed how well a multi-layer perceptron predicts the concentration of SO<sub>2</sub> over an industrial area, highlighting the model's accuracy under a range of meteorological situations. Sohn et al. expanded the use of artificial neural networks (ANNs) to model a variety of contaminants, such as total hydrocarbons, NO, SO<sub>2</sub>, NO<sub>2</sub>, CO, O<sub>3</sub>, and CH<sub>4</sub>. The findings showed a limited prediction range with respect to accuracy, underscoring the necessity of additional weather-related input factors for further development. With research by Slini et al. and Kandya highlighting the significance of adjusting input parameters for increased accuracy, the use of ANNs in gaseous pollutant forecasting has continued. ANNs were continuously positioned as superior for gaseous pollutants in comparison to other forecasting methodologies. Chaloulakou et al. demonstrated the superior accuracy of the model by determining that ANN performed better than Multiple Linear Regression (MLR) in forecasting ozone concentrations. Mishra and Goyal obtained similar results when they evaluated the Principal Component Analysis (PCA)-based ANN model with MLR for NO<sub>2</sub> concentration estimation. ANNs have demonstrated comparable efficacy in the field of particulate matter forecasting. Fernando et al. effectively predicted PM<sub>10</sub> concentrations using multi-layered MLP, taking into account variables including hourly weather data, particulate matter, and statistical indicators. Hourly PM<sub>10</sub> forecasts were made using an ANN model by Grivas and Chaloulakou, who demonstrated steady accuracy even when dealing with noisy datasets (Rautela & Goyal, 2024). The various machine learning and artificial intelligence models with target pollutants are displayed in Table 02 below.

SI No.	Authors	Artificial Intelligence, and Machine Learning Model	Target Pollutants	Network Type	Outcomes
01.	<i>Rautela and Goyal, 2024</i>	Convolutional autoencoders	PM <sub>2.5</sub>	Used encoder-decoder architecture for PM <sub>2.5</sub> predictions via key aerosols	Enhanced forecasting performance with fine spatiotemporal resolutions using SSIM, PSNR, RMSE, and MSE
02.	<i>Wang et al., Arbabsiar et al.</i>	FL and ANFIS	NO <sub>2</sub> , PM	Developed hybrid models combining FL and ANFIS with uncertainty analysis for pollutant prediction	Shown accuracy in predicting NO <sub>2</sub> and PM concentrations using hybrid techniques
03.	<i>Freeman et al., Wang and Song</i>	RNN, LSTM, ensemble LSTM with FL-c-means (FcM) clustering	O <sub>3</sub>	Used RNN, LSTM, and LSTM with FcM clustering to predict O <sub>3</sub> concentrations, focusing on refinement	Established an ensemble method combining LSTM and FcM for air quality forecasting, achieving better performance than individual models
04.	<i>Carbajal-Hernández et al., Al-Shammari</i>	FL	Air quality in Mexico City	Used FL with signal processing and autoregression for air quality predictions	Compared models, favoring FL for estimating daily maximum ozone concentrations during extreme pollution events
05.	<i>Arena et al.</i>	MLP	SO <sub>2</sub>	Explained MLP efficacy in predicting SO <sub>2</sub> concentrations across varied climates	Highlighted model accuracy in diverse climatic conditions
06.	<i>Sohn et al.</i>	ANN	Multiple pollutants	Extended ANN approach for multiple pollutants, achieving reasonable accuracy within a limited range	Highlighted the need for optimization by incorporating additional weather-related parameters
07.	<i>Fan et al., Li et al., Zhang et al.</i>	CNN, LSTM, deep-RNN	PM <sub>2.5</sub>	Developed an LSTM-based deep RNN for PM <sub>2.5</sub> prediction, outperforming baseline models	Used large-scale graphical datasets with CNN to enhance air pollution estimation
08.	<i>Qiu et al.</i>	DL framework, Pollution-Predicting Net with WRF-	PM <sub>2.5</sub>	Used an encoder-decoder setup for PM <sub>2.5</sub>	Highlighted significant Meteorological parameter impact on prediction

		Chem		predictions, demonstrating improved performance in severe events	accuracy
09.	<i>Mlakar et al.</i>	MLP-ANN	SO <sub>2</sub>	Feed-forward, three-layered, nonlinear MLP trained by backpropagation	Successfully predicted SO <sub>2</sub> concentrations at a thermal power plant in Sostanj
10.	<i>Fernando et al., Grivas and Chaloulakou</i>	ANN	PM <sub>10</sub>	Successfully predicted PM <sub>10</sub> levels with consistent accuracy, even in noisy datasets	Showcased ANN's versatility in predicting roadside contributions to PM <sub>10</sub> concentrations
11.	<i>Song et al., Bougoudis et al.</i>	FIE, adaptive neuro-fuzzy interface system (ANFIS)	Air pollution forecasting	Implemented FIE for precise pollution forecasts, emphasized ANFIS	Emphasized the role of density functions in tackling uncertainty in upcoming PM trends
12.	<i>Li et al., Zhou et al.</i>	LSTM, DL algorithms	PM <sub>2.5</sub> , PM <sub>10</sub> , NO <sub>x</sub>	Used LSTM and DL for multi-step forecasting, resulting in excellent performance	Used different DL algorithms for spatiotemporal modelling of pollutants, demonstrating high accuracy
13.	<i>Soh et al., Qi et al.</i>	Spatio-Temporal (ST)-DNN (ANN, CNN, LSTM), GC-LSTM	PM <sub>2.5</sub>	Advanced ST-DNN for air quality, showcasing short-term consistency	Suggested improvements for long-term PM <sub>2.5</sub> predictions in spatial-temporal modelling
14.	<i>Slini et al., Kandyia</i>	ANN	Gaseous pollutants	Highlighted the significance of optimizing input parameters to achieve enhanced accuracy	Consistent preference for ANNs in modelling gaseous pollutants
15.	<i>Liu et al.</i>	Ensemble model (WPD, PSO, BPNN)	PM <sub>2.5</sub>	Ensembled WPD-PSO-BPNN for forecasting PM <sub>2.5</sub> concentrations	Showed better accuracy compared to separate models
16.	<i>Paschalidou et al., Zhang et al., Suleiman et al.</i>	BP-ANN, MLP-NN, MLP	PM <sub>10</sub>	Used BP-ANN to predict PM <sub>10</sub> levels, surpassing other models in accuracy	Showed MLP-based NN's superiority in achieving accurate PM <sub>10</sub> levels predictions
17.	<i>Chaloulakou et al. Mishra and Goyal</i>	MLR, ANN	Ozone (O <sub>3</sub> ), nitrogen dioxide	ANN showed better accuracy than MLR in predicting O <sub>3</sub> and NO <sub>2</sub> concentrations	Highlighted the better accuracy of ANN in predictions of O <sub>3</sub> and NO <sub>2</sub>

			(NO <sub>2</sub> )		
18.	<i>Nieto et al., Luna et al.</i>	SVM, PCA with ANN and SVM	PM <sub>10</sub>	Compared models for PM <sub>10</sub> predictions; SVM was most accurate and robust	Applied PCA with ANN and SVM for ozone forecasts, considering meteorological impacts on concentrations
19.	<i>Akhtar et al.</i>	MLP, SVM, Naive Bayes	PM <sub>10</sub>	Used multiple ML models for PM <sub>10</sub> predictions, improving forecast accuracy	Enhanced predictions using different statistical metrics
20.	<i>Feng et al., Yeganeh et al.</i>	SVM, hybrid (SVM and PLS)	O <sub>3</sub> , CO	Compared SVM with other models for ozone predictions; showcased stable performance	Evaluated SVM-PLS for accurate CO predictions, indicating favorable results
21.	<i>Chen et al., Jain, and Khare</i>	Fuzzy logic (FL) and neuro- fuzzy time series	O <sub>3</sub> , CO	Introduced enhanced FL and neuro-fuzzy models for precise pollutant estimation	Exhibited precise forecasts of intricate urban CO concentrations; focused on enhanced O <sub>3</sub> prediction
22.	<i>Wang et al., Behal and Singh</i>	Hybrid adaptive models (SVM and ANN), FL	PM <sub>10</sub> , SO <sub>2</sub>	Proposed superior hybrid models combining SVM and ANN for accurate predictions	Utilized fuzzy logic for benzene monitoring, displaying acceptable statistical performance

Table 02: Various machine learning and artificial intelligence models that target contaminants.

The wide variety of machine learning (ML) and artificial intelligence (AI) models shown in Table 02 highlights the substantial advancements and different strategies in addressing air pollution forecasting. The widespread use of Artificial Neural Networks (ANNs) and their variations, including Backpropagation Neural Networks (BP-ANNs) and Multi-Layer Perceptrons (MLPs), emphasizes their early and ongoing significance in the area. These models have proven to be highly effective for forecasting particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) and gaseous pollutants (such as SO<sub>2</sub>, NO<sub>2</sub>, and Ozone) in a variety of settings and environments. Additionally, the data shows a trend toward hybrid and more complex models. Fuzzy Logic (FL) combined with additional methods such as Adaptive Neuro-Fuzzy Inference Systems (ANFIS) and c-means clustering (FcM) indicates an attempt to manage the inherent complexities and uncertainties of air pollution data. These hybrid methods frequently seek to capitalize on the advantages of many algorithms, which could result in forecasts that are more reliable and accurate.

Forecasting air pollution is increasingly using deep learning architectures, such as Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM) networks, and Recurrent Neural Networks (RNNs). They are ideal for this task because of their capacity to extract spatial features and temporal connections from huge datasets. In order to improve forecasting skills, particularly during extreme pollution events, the development of deep learning frameworks such as Pollution-Predicting Net with WRF-Chem further demonstrates the trend toward merging chemical and meteorological transport models with AI. The table's results highlight the significance of evaluating the model using a variety of statistical metrics, such as SSIM, PSNR, RMSE, and MSE, as well as the goal of improving forecasting performance with finer spatiotemporal resolutions. Numerous studies emphasize how important it is to include meteorological factors and how important it is to optimize input features to increase prediction accuracy. Additionally, it is regularly shown that AI/ML models perform better in air pollution forecasting than classic statistical techniques like Multiple Linear Regression (MLR). Before using ANN or Support Vector Machines (SVM), Principal Component Analysis (PCA) is used to reduce features. This indicates an attempt to

manage high-dimensional data and increase model efficiency. By utilizing the combined intelligence of several models, such as Wavelet Packet Decomposition (WPD), Particle Swarm Optimization (PSO), and BPNN, ensemble approaches are being used to improve prediction accuracy and robustness. All things considered, Table 02 shows a dynamic and developing sector where scientists are always investigating and improving AI and ML methods to produce more precise, trustworthy, and thorough air pollution forecasts. The increasing sophistication of these strategies in tackling this pressing environmental issue is demonstrated by the tendency towards hybrid models, deep learning architectures, and the integration of various data sources.

Addressing air pollution requires the use of AI and ML, which use a variety of models, including ANNs, FL, SVM, and deep learning, to accurately forecast pollutants like PM<sub>2.5</sub>, NO<sub>2</sub>, Ozone, SO<sub>2</sub>, and PM<sub>10</sub>. Through the handling of uncertainties and the combination of several methodologies, hybrid models improve prediction accuracy. Frequently outperforming conventional statistical techniques, these techniques allow for finer spatiotemporal resolution in forecasts and use meteorological data for increased precision. For more comprehensive forecasts, particularly during catastrophic events, specialized deep learning frameworks incorporate chemical transport models, while ensemble models further increase reliability. These uses of AI/ML are ultimately essential for creating focused policies and efficient early warning systems to safeguard public health from air pollution.

### ***3.12 Explainable Artificial Intelligence for Dhaka Air Pollution Source Attribution***

Developing successful mitigation solutions requires an understanding of the main causes of air pollution in a megacity like Dhaka. Though their "black box" nature frequently makes it difficult to interpret their results, especially when it comes to the contribution of various sources, artificial intelligence (AI) and machine learning (ML) models provide strong tools for evaluating intricate air quality data and forecasting pollution levels (Tasioulis & Karatzas, 2024). Applying Explainable AI (XAI) methodologies is therefore necessary to improve the reliability and transparency of AI-driven source attribution. XAI techniques like SHAP (SHapley Additive exPlanations) or LIME (Local Interpretable Model-agnostic Explanations) could be used in a hypothetical case study about Dhaka, along with advanced machine learning models that were trained on a large dataset that included air pollutant concentrations (PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>x</sub>, SO<sub>2</sub>, CO), weather, traffic, industrial activity indicators (e.g., satellite imagery of brick kilns, industrial zone activity), and possibly even land-use patterns.

Each input feature's contribution to the model's prediction of certain pollutant levels can be measured and displayed by using XAI techniques. SHAP values, for example, can show how much driving activity in a certain area or how much brick kiln activity affects PM<sub>2.5</sub> levels at various times and places throughout Dhaka. LIME can offer local explanations for individual forecasts, emphasizing the key variables influencing pollution levels in particular situations (C3.ai, 2024). Policymakers and environmental organizations in Dhaka will greatly benefit from this improved interpretability. They can learn more about the fundamental causes of air pollution rather than just depending on the results of a model. More concentrated and efficient interventions, such as tighter rules on companies that contribute significantly or traffic control plans centered on pollution hotspots found by the XAI-driven source attribution, may result from this knowledge. Additionally, results that are clear and comprehensible might increase public confidence in and support for Dhaka's air quality management regulations.

### ***3.13 Forecasting Hyperlocal Air Quality:***

Novel and high-resolution monitoring and prediction methods are required to address the growing air pollution problem in crowded urban areas. While traditional air quality monitoring stations offer useful data, they frequently lack the spatial granularity necessary to record the notable differences in pollutant concentrations within neighborhoods or at the street level (Singh et al., 2025). This restriction makes it more difficult to implement focused mitigation techniques and successful public health interventions (Jiang & Ma, 2025). In these intricate urban environments, hyperlocal air quality forecasting is becoming a viable possibility due to recent developments in low-cost sensor (LCS) technology and the strength of deep learning (DL) (Cowell et al., 2025). Dense deployments of inexpensive sensors are possible, establishing a granular monitoring network that can identify localized pollution hotspots impacted by things like building canyons, traffic jams, and microclimates. In contrast to large and costly

regulatory-grade monitors, LCSs are more compact, less costly, and able to be installed at a far greater density over a city (Malings et al., 2020). The abundance of data provided by this deep spatial coverage might highlight complex pollution patterns that sparse traditional networks were unable to detect (Kayastha et al., 2024). Nevertheless, the data produced by LCS frequently has built-in drawbacks, such as decreased precision, susceptibility to external factors (temperature, humidity), and possible drift over time. This is where deep learning algorithms' advanced capabilities are useful. DL models are excellent at learning intricate temporal connections and identifying significant patterns in noisy, high-dimensional sequential data. This is especially true with recurrent neural networks (RNNs), such as Long Short-Term Memory (LSTM) networks and, increasingly, transformer topologies (Li et al., 2023). Strong and precise hyperlocal air quality forecasts can be produced by training DL models on historical LCS data in addition to meteorological, transportation, and possibly even land-use data.

There are numerous significant benefits to the combination of DL models and dense LCS networks. First off, the sensor data's great spatial resolution enables the DL models to learn the dynamics of local pollution in previously unheard-of detail. This makes it possible to forecast changes in air quality at the level of individual streets or even city blocks, giving citizens, public health officials, and urban planners useful information (AI and Wearables: Innovative Tech for Fighting Air Pollution - Clean Air Fund, 2023b). Second, DL models can improve forecast reliability by learning to adjust and correct for the biases and imperfections present in LCS data (Rajaraman et al., 2022). The development of precise hyperlocal forecasting systems can be accelerated by using methods such as transfer learning, which allows models trained on data from more dependable sources or in various urban environments to be improved using local LCS data (Improve a Deep Learning Model with Transfer Learning, n.d.). Additionally, because LCS data streams are real-time, dynamic, and current, air quality forecasts can be generated, facilitating prompt alarms and adaptive mitigation strategies. For example, vulnerable people could be specifically warned to avoid severely polluted locations or traffic management systems could be modified in reaction to anticipated pollution surges in particular places.

There is enormous potential for using this strategy in crowded urban settings like Dhaka City, which is distinguished by its high population density, intricate traffic patterns, and variety of pollution sources. To lessen the negative effects of air pollution on city dwellers, hyperlocal air quality forecasting can support public health initiatives, inform urban planning decisions targeted at reducing pollution hotspots, and supply vital information for individual-level exposure assessment (Hyperlocal Air Quality Monitoring with IoT, Smart City SS - Smart City Strategies & Solutions, n.d.). The combination of deep learning and inexpensive sensor networks is a big step toward developing a more detailed and useful understanding of air quality in our increasingly complicated urban environment, even though issues with sensor calibration, data management, and model interpretability still exist.

### **3.14 AI and Advanced Strategies for Dhaka's Air Pollution Crisis**

Despite being a bustling metropolis, Dhaka is also infamous for having extremely poor air quality. The toxic cocktail of construction dust, industrial activities, especially the ubiquitous brick kilns, vehicle emissions, ineffective waste management, and seasonal weather patterns regularly places Dhaka among the world's most polluted cities (Dhaka Tops List of Most Polluted Cities in the World Today, n.d.). From acute respiratory illnesses and cardiovascular conditions to possible long-term neurological effects, this widespread air pollution poses serious risks to human health. A multifaceted strategy that makes use of cutting-edge technology like artificial intelligence (AI) and sophisticated monitoring techniques provides a route towards a breathable future for Dhaka despite the enormous difficulty. Effective remedies begin with an understanding of the complex web of pollution sources. Despite their value, traditional air quality monitoring stations frequently lack the geographic granularity required to identify specific pollution hotspots. Here's when cutting-edge technologies are useful. In terms of air quality monitoring, the implementation of dense networks of low-cost sensors (LCS) presents a paradigm change. A high-resolution map of the concentrations of pollutants at the street level and within neighborhoods can be obtained by strategically placing these small and reasonably priced devices around the city. This fine-grained data can reveal intricate pollution patterns impacted by microclimates, traffic jams, and construction canyons—information that sparse traditional networks frequently overlook (Frederickson et al., 2022). Nevertheless, there are a number of issues with the data produced by LCS, including its reduced accuracy and vulnerability to external influences. This is where deep

learning (DL), in particular, and the power of AI become invaluable. DL algorithms are excellent at analyzing high-dimensional, noisy, and large-scale sequential data, spotting important patterns and complex temporal correlations. Hyperlocal air quality forecasts that are both accurate and reliable can be produced by training DL models on historical LCS data in addition to meteorological, transportation, and land-use data. According to AI and Wearables: Innovative Tech for Fighting Air Pollution (Clean Air Fund, 2023c), these forecasts can predict changes in pollution at the level of individual streets or city blocks, giving citizens timely information to take preventative action and allowing public health officials to issue targeted advisories.

AI can also be quite helpful in improving the accuracy of LCS data itself. DL models are able to adapt and rectify the biases and flaws present in the sensor data. Accurate hyperlocal forecasting systems can be developed much more quickly using methods like transfer learning, which refines models trained on data from more trustworthy sources using local LCS data. Real-time LCS data streams and AI-powered analytics provide dynamic, real-time air quality assessments, enabling timely alarms and adaptive mitigation techniques like modifying traffic patterns in reaction to anticipated pollution spikes. AI provides strong tools for source attribution in addition to monitoring and forecasting. Developing focused and successful policy interventions requires an understanding of the relative contributions of various emission sources. Complex AI models trained on extensive datasets such as pollutant concentrations, weather patterns, traffic data, industrial activity indicators (such as satellite imagery of brick kilns), and land-use patterns can be applied to Explainable AI (XAI) methodologies like SHAP (SHapley Additive exPlanations) and LIME (Local Interpretable Model-agnostic Explanations). The contribution of each input characteristic to the model's prediction of certain pollutant levels can be shown using XAI approaches (Fania et al., 2024). The influence of increased traffic in a certain area or increased activity at brick kilns on PM<sub>2.5</sub> levels at various times and places throughout Dhaka, for example, can be measured using SHAP values.

This improved interpretability enables environmental organizations and policymakers to go beyond merely monitoring pollution levels to comprehending their underlying causes. This enables more targeted interventions, such as tighter rules on industries with high pollution levels or traffic control strategies that target pollution hotspots found by AI-driven source attribution. It will take a coordinated effort to successfully deploy AI-driven solutions to address Dhaka's air pollution problem. Data availability, quality, and interoperability from various sources must be addressed. For these projects to be sustainable over the long run, it is essential to develop local technical skills in data science, environmental modeling, and AI/ML. Strong data governance structures are also required to handle any algorithmic biases and ethical issues about data privacy (Sullivan, 2024). Policy frameworks also need to change to promote data exchange, ease capacity building, and aid in the construction of the required infrastructure. The air pollution problem in Dhaka necessitates creative and useful management strategies. A revolutionary route to improved air quality monitoring, precise forecasting, and efficient source attribution is provided by the strategic use of AI and machine learning technology. Dhaka can transition to a more proactive and data-driven approach to air quality control by utilizing granular sensor networks and advanced AI analytics, which would ultimately lead to cleaner air and better public health for the city's millions of inhabitants. To fully achieve AI's promise of reducing air pollution in this crucial metropolitan hub, more funding must be allocated to research, infrastructure development, capacity building, and the creation of ethical standards.

### **3.15 Key Research Findings:**

Research reveals Dhaka's severe air pollution, dominated by particulate matter from vehicles, industry (especially brick kilns), construction, and waste. This toxic air poses significant health risks, from respiratory illnesses to potential long-term neurological impacts and reduced life expectancy, exacerbated by winter conditions. To combat this, the research highlights the transformative potential of Artificial Intelligence (AI) and Machine Learning (ML). AI/ML's ability to analyze complex data, identify pollution patterns, and generate high-resolution forecasts offers significant advantages over traditional methods. These technologies can improve early warning systems and enable more accurate source apportionment, which is crucial for targeted interventions. Real-time monitoring through AI-integrated sensor networks promises a more responsive management framework.

This conceptual research paper reveals that obstacles, including data quality and interoperability, the requirement for explainable AI, infrastructure constraints, and developing local technical skills, must be addressed for AI/ML to be implemented successfully in Dhaka. Ethical considerations and strong data governance are also crucial. The study promotes a synergistic strategy that combines well-established environmental science and policy with AI/ML. By offering more precise insights and more prediction power, these clever technologies can supplement conventional techniques. However, its use needs to be supported by policy frameworks, evaluated against empirical facts, and based on scientific understanding. Although there is a serious air pollution problem in Dhaka, the prudent use of AI and ML provides a potent avenue for better forecasting, monitoring, and mitigation. To fully realize AI's potential for a cleaner, healthier future for Dhaka, a cooperative effort centered on infrastructure, capacity building, and ethical norms is necessary.

#### 4. Result and Discussion

This research provides a comprehensive analysis of the air pollution crisis in Dhaka City, Bangladesh, and critically examines the potential of Artificial Intelligence (AI) and Machine Learning (ML) technologies for enhanced management and forecasting. The findings from the synthesized literature and the conceptual framework developed highlight the complex interplay of various anthropogenic sources contributing to the severely degraded air quality in Dhaka.

- Dhaka City's Air Pollution Profile:** According to the analysis of previous research, particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) is the most common pollutant, often surpassing national and international air quality standards by many orders of magnitude, especially in the arid winter months. One of the main sources of particle and gaseous pollutants (NO<sub>x</sub>, CO, HC) is vehicle emissions, which are caused by a sizable and frequently badly maintained fleet. PM and SO<sub>2</sub> levels are greatly influenced by industrial activity, particularly the many brick kilns that use antiquated technology. Significant amounts of fugitive dust are produced during construction and demolition operations, which exacerbate PM pollution, particularly during times of rapid urbanization. Other noteworthy sources are ineffective solid waste management techniques, which frequently involve open burning and the burning of agricultural biomass in peri-urban regions. There are noticeable seasonal fluctuations, with wintertime temperature inversions and reduced precipitation, storing pollutants and preventing their dispersion, resulting in bouts of peak pollution. Effective mitigation techniques are desperately needed, as evidenced by the proven health implications, which range from acute respiratory infections and cardiovascular disorders to possible chronic and systemic effects.
- Potential of Artificial Intelligence and Machine Learning in Air Quality Management:** To overcome the shortcomings of Dhaka's conventional air quality control strategies, the literature review points to the revolutionary potential of AI and ML. There are several benefits to the intrinsic AI/ML skills of analyzing big, multi-source datasets, recognizing intricate non-linear relationships, and producing high-resolution spatiotemporal forecasts. For accurate pollutant concentration forecasting, a variety of AI/ML models, such as ANNs, RNNs (especially LSTMs for time series forecasting), CNNs (for spatial pattern recognition and integration of satellite imagery), and hybrid approaches, have shown success in other urban environments (as shown in Table 02 of the initial prompt's attachment, though not directly part of this generated response). These predictive capabilities can facilitate the development of early warning systems, enabling timely public health advisories and the implementation of short-term emission control measures. Additionally, source apportionment studies can benefit greatly from the use of AI/ML approaches, which use sophisticated data analytics to pinpoint and measure the relative contributions of different emission sources to the total pollution burden. Developing focused and successful policy initiatives needs this information. In contrast to conventional static monitoring systems, real-time monitoring networks combined with AI-powered analytical tools can offer ongoing, localized air quality assessments, allowing for a more flexible and responsive control framework.
- Obstacles and Implementation Considerations:** Despite the significant potential advantages, several obstacles must be overcome for AI/ML to be successfully used in Dhaka's air quality control. Interoperability, quality, and availability of data from many sources continue to be major issues. Because of the "black box" character of some complex AI models, explainable AI (XAI) solutions must be developed

and used to boost public and policymakers' trust and enable informed decision-making. Limitations in infrastructure, such as dependable data transfer networks and processing power, must be addressed. Furthermore, the long-term viability of such projects depends on developing local technical skills in data science, environmental modeling, and AI/ML. Strong data governance frameworks are also necessary to proactively address ethical concerns about data privacy and possible biases in algorithms.

- **Synergistic Approach for Enhanced Management:** The results support a cooperative strategy that carefully combines proven environmental scientific concepts, current regulatory frameworks, and AI/ML methods. By offering improved predictive skills and more detailed insights, AI/ML can support conventional monitoring and modeling efforts. However, a solid grasp of the fundamental atmospheric processes and emission sources, supported by scientific knowledge and verified by a thorough assessment against actual data, should serve as the foundation for the application of AI/ML. To take advantage of AI/ML's capabilities, policy frameworks must change to encourage capacity growth, facilitate data exchange, and support the construction of pertinent infrastructure.

Dhaka City's extreme air pollution necessitates creative and practical management techniques. The use of AI and ML technology has the potential to revolutionize air quality forecasting, monitoring, and, eventually, mitigation initiatives. Dhaka may advance toward more proactive and focused responses by utilizing the capabilities of predictive modeling and sophisticated data analysis. To assure ethical considerations, establish technical capability, address current data restrictions, and create a collaborative environment among academics, policymakers, and other stakeholders, a concerted effort is necessary for successful implementation. Future studies should concentrate on creating and approving context-specific AI/ML models for Dhaka, combining various data sources, and assessing how well AI-driven interventions improve public health outcomes and air quality in this vital urban setting.

## **5. Future Research Directions**

Using the results of this thorough analysis, several important research directions are revealed to further develop the use of AI and ML for improved air pollution control and forecasting in Dhaka City:

- i. **AI-Powered Socioeconomic and Health Impact Modeling:** By taking into account variables like income levels, pre-existing medical issues, and access to healthcare, future research can use AI/ML to estimate the intricate socioeconomic and health effects of air pollution in Dhaka. This can lead to a more thorough comprehension of the costs of air pollution to society and help shape more just policy solutions.
- ii. **Frameworks for Knowledge Transfer and Capacity Building:** In order to give Bangladeshi researchers, policymakers, and environmental agencies the tools and resources they need to properly use and maintain AI/ML-based air quality management systems, research should also concentrate on creating efficient frameworks for knowledge transfer and capacity building.
- iii. **Combining Real-Time and Multi-Source Data Streams:** Integrating real-time and various data streams into AI/ML models should be a top priority for future initiatives. This involves using information from mobile monitoring projects, satellite imaging with greater spatiotemporal resolution, low-cost sensor networks, and possibly even citizen science data. It will be essential to create strong data fusion methods and deal with heterogeneous data quality problems.
- iv. **Source Apportionment using Advanced AI/ML Techniques:** To improve source apportionment in Dhaka, future studies can investigate the use of sophisticated AI/ML approaches such as clustering algorithms, deep learning-based attribution methods, and non-negative matrix factorization (NMF). By doing so, specific mitigation policies can be informed, and the relative contributions of various emission sectors can be better understood.
- v. **Evaluation of the Effects of AI-Powered Interventions:** To assess the practical efficacy of AI/ML-driven solutions in enhancing Dhaka's air quality, more research is required. This could entail evaluating the results of pilot projects applying AI-based management techniques or modeling the effects of various policy scenarios based on AI forecasts.

- vi. **Improved Decision-Making and Trust through Explainable AI (XAI):** Improving the interpretability of AI/ML models for air pollution prediction and source apportionment should be a major area of research. By looking into and using XAI approaches (such SHAP values and LIME), policymakers can gain a better understanding of the elements influencing model predictions, which will increase their trust and allow for more intelligent intervention measures.
- vii. **Development of Personalized Air Quality Forecasting and Exposure Prediction:** Subsequent investigations may examine the creation of customized air quality forecasting systems that offer exposure projections at the local and personal levels, possibly utilizing mobile phone data and usage trends. This could enable citizens to reduce their exposure to elevated pollution levels by taking preventive steps.
- viii. **Including Climate Change Forecasts:** Future studies should look into incorporating climate change projections into AI/ML models to provide more reliable long-term air quality forecasts and adaptation plans for Dhaka, given the possible impact of climate change on air pollution patterns.
- ix. **Creation of AI/ML Models using Context:** The development and validation of AI/ML models, especially suited to Dhaka's particular air pollution dynamics, should be the main focus of future research. This entails taking into account regional weather trends, traffic patterns, industrial emission schedules (where available), and the effects of seasonal fluctuations on various sources of pollutants. Comparative analyses of several AI/ML architectures (such as transformer networks and hybrid models) tailored to the data peculiarities of Dhaka are necessary.

The scientific community may further leverage the revolutionary potential of AI and ML to address Dhaka City's urgent air pollution crisis and help create a cleaner, healthier urban environment by following these next research topics.

## 6. Conclusion

For the millions of people living in Dhaka City, Bangladesh, the widespread and harmful air pollution situation is acknowledged as a major barrier to environmental sustainability, public health, and general quality of life. There has been a thorough examination of the complex network of human-caused factors that have led to this environmental crisis, including the identification of the main pollutants affecting the city's air and a critical assessment of the revolutionary potential of AI and ML technologies in creating better management and forecasting techniques. The air quality in Dhaka has been consistently ranked among the most polluted metropolitan centers in the world, highlighting the city's extreme pollution. An air cocktail full of dangerous pollutants is created by the combination of a rapidly growing and frequently ill-maintained automobile fleet, the widespread use of outdated and extremely polluting brick kilns, the constant dust produced by expanding infrastructure and construction, the unsustainable methods of solid waste management, which often involve open incineration, and the ongoing reliance on biomass and fossil fuels for household energy needs. A persistent and widespread threat, particulate matter, especially the fine fraction  $PM_{2.5}$ , can penetrate deeply into the respiratory system and cause a series of negative health effects, from heightened risk of cardiovascular events to worsened respiratory conditions like asthma and bronchitis, as well as possibly causing long-term neurological impairments and a shorter life expectancy. The city's inhabitants are made even more vulnerable by seasonal variations in pollution levels, with the most severe conditions occurring during the dry winter months as a result of weather phenomena like temperature inversions.

The tremendous potential of incorporating AI and ML techniques into the conventionally used air quality control frameworks has been revealed in the face of these formidable obstacles. Understanding, monitoring, and eventually reducing air pollution in complex urban environments like Dhaka is made possible by the inherent abilities of AI/ML algorithms to process large and diverse datasets, identify complex and non-linear relationships between pollutants and their influencing factors, and produce high-resolution spatiotemporal predictions. The development of potentially life-saving early warning systems has been made possible by the successful application of a variety of AI/ML models, such as Artificial Neural Networks, Recurrent Neural Networks (especially Long Short-Term Memory networks that are good at capturing temporal dependencies), Convolutional Neural Networks for spatial analysis, and sophisticated hybrid architectures, in accurately forecasting pollutant concentrations. Additionally, the use of cutting-edge AI/ML techniques is essential for more accurate and dynamic source allocation, which enables the

identification and measurement of contributions from different emission sectors and helps shape the development of focused and successful policy interventions. A more precise and responsive management system that can adjust to quickly shifting pollution dynamics and promptly notify sensitive populations is promised by the possibility of real-time air quality monitoring via AI-integrated sensor networks. However, there has also been a critical examination of the inherent difficulties and important factors that need to be taken into account in order to successfully and morally integrate AI/ML into Dhaka's air quality management ecosystem. Because complex AI models are frequently opaque, there needs to be a concentrated effort made to develop and implement Explainable AI (XAI) solutions, which will promote openness and confidence among all parties involved, including the public and politicians.

Strategic investments and the investigation of scalable cloud computing solutions are necessary due to the substantial computational resources and strong data infrastructure needed for the training and implementation of complex AI models. Strict data governance frameworks and rigorous model validation methods must be established in order to proactively address ethical concerns about data privacy, security, and potential algorithmic biases. Establishing standardized data collection and sharing procedures is crucial because of the basic need for high-quality, representative, and interoperable air quality data from many sources. Importantly, the growth of local technical competence through focused education, training, and capacity-building programs within environmental agencies, research institutions, and the general public is essential to the long-term viability of AI/ML-driven solutions. In summary, it is clear that although Dhaka City's air pollution problem poses a significant obstacle, the thoughtful and responsible application of AI and machine learning technologies provides a potent and potentially revolutionary route to improved air quality forecasting and management. The analytical capabilities of AI/ML combined with the fundamental understanding of environmental science, atmospheric chemistry, and public health can work in concert to enable a shift from reactive to proactive, data-driven solutions. The future of cleaner air for Dhaka lies in embracing a holistic approach that fosters collaboration among researchers, policymakers, technology developers, and the community, driven by robust scientific inquiry and a commitment to leveraging the cutting-edge capabilities of AI/ML to safeguard the health and well-being of its citizens and pave the way for a more sustainable and breathable future for this vibrant and crucial urban center. To fully realize the potential of AI/ML in reducing air pollution in Dhaka and establishing a standard for other megacities facing comparable environmental issues, it will be essential to continue investing in research, infrastructure development, capacity building, and the creation of morally sound standards.

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