

Beyond the Lungs: The Multisystem Impact of Air Pollution on the Rising Burden of Diabetes, Cardiovascular Diseases, and Mental Disorders in Bangladesh

Kallol Debnath ^{1*}, Fatema Zannat ², Muhammad Waliulla ³, Nafisa Imtiaz Parmila ⁴, Al Amin ⁵, Sumiya Ahammed ⁶, Kazi Jubayer ⁷

^{1, 3, 4, 5, 6, 7} Department of Pharmacy, Faculty of Life Sciences,

University of Development Alternative, Dhaka-1209, Bangladesh

² Department of Pharmacy, University of Asia Pacific, Dhaka-1205, Bangladesh

ORCID iD: ¹ 0000-0003-0429-829X, ² 0009-0001-8366-1036, ³ 0009-0009-1301-9441,

⁴ 0009-0001-6148-5764, ⁵ 0009-0005-7272-2234, ⁶ 0009-0003-4533-9585, ⁷ 0009-0000-2825-9557

* **Corresponding Author:** Professor Dr. Kallol Debnath, Department of Pharmacy, Faculty of Life Sciences, University of Development Alternative (UODA), Dhaka-1209, Bangladesh
kalloldebnath@pharmacy.uoda.edu.bd

ORIGINAL ARTICLE

Abstract

Almost the entire global population (99%) breathes air that exceeds the World Health Organization (WHO) air quality guidelines (WHO, 2022), contributing to an ~6.7 million premature deaths annually (Types of Pollutants, n.d.). Once regarded primarily as an environmental concern, air pollution is now recognized as a major multisystem determinant of non-communicable diseases (NCDs). Beyond its well-established respiratory effects, accumulating epidemiological and clinical evidence has linked air pollution to cardiovascular, metabolic, immune, and neurological disorders (Brook et al., 2010; Rajagopalan et al., 2018; Schraufnagel et al., 2019).

This burden is particularly severe in low- and middle-income countries (LMICs) such as Bangladesh, where rapid urbanization, industrialization, and weak environmental governance have resulted in chronic exposure to hazardous air pollutants. Fine particulate matter (PM_{2.5}), the most harmful ambient air pollutant, consistently exceeds WHO guideline values. According to an analysis by the Centre for Atmospheric Pollution Studies (CAPS), Dhaka (the capital city of Bangladesh) experienced clean air on only 31 of 3,114 days between 2017 and 2025, while air quality was classified as unhealthy on 853 days, very unhealthy on 635 days, and hazardous on 93 days. The highest monthly average Air Quality Index (AQI) recorded during this period was 300 in January 2024, whereas the lowest was 97 in July

2021. These findings are consistent with IQAir reports showing that Bangladesh has remained among the world's most polluted countries, ranking 1st in 2021 & 2023 and 2nd in 2024, with Dhaka ranking as the 3rd most polluted city globally in 2024. Major sources include vehicle emissions, brick kilns, industrial activities, construction dust, and transboundary air pollution, compounded by unfavorable meteorological conditions (World Bank, 2022; IQAir, 2024).

Unlike episodic environmental hazards, chronic exposure to PM_{2.5} causes sustained biological damage through systemic inflammation, oxidative stress, endocrine disruption, and vascular dysfunction (Pope et al., 2004; Rajagopalan et al., 2018). Emerging evidence also implicates neuroinflammation and blood-brain barrier disruption in depression, anxiety, and cognitive decline (Block & Calderón-Garcidueñas, 2009; Braithwaite et al., 2019). Consequently, long-term PM_{2.5} exposure has been associated with an increased risk of insulin resistance and Type 2 diabetes (T2D), cardiovascular disease, premature mortality, and adverse mental health outcomes (Eze et al., 2015; Liu et al., 2019). Studies from Bangladesh similarly report a higher prevalence of NCDs in densely populated and industrialized urban areas, highlighting air pollution as an important contributor to the country's changing disease profile.

The health impacts of air pollution are further amplified by climate variability, socioeconomic inequalities, and

weak environmental governance. Reduced rainfall and altered seasonal patterns limit the atmospheric dispersion of pollutants, while disadvantaged populations often experience greater exposure and reduced access to healthcare (World Bank, 2019). These interconnected challenges underscore the need to recognize air pollution as a multisystem health determinant requiring coordinated action across environmental protection, public health, urban planning, and climate adaptation. Without such integrated interventions, air pollution will continue to intensify Bangladesh's growing burden of NCDs and undermine population health, economic productivity, and sustainable development.

Keywords: Air pollution, Diabetes, Heart disease, Mental disorders, Multisystem, Prevalence, Bangladesh.

Introduction:

According to the WHO, ~99% of the global population breathes polluted air that threatens human health. Consequently, air pollution is recognized as one of the greatest environmental risk factors contributing to the global burden of disease. The cumulative impact of air pollution is estimated to have caused ~135 million premature deaths between 1980 and 2020. Among these deaths, stroke accounted for 33.3%, ischemic heart disease (IHD) for 32.7%, chronic obstructive pulmonary disease (COPD) for 15.5%, lower respiratory infections (LRIs) for 11.9%, and lung cancer for 6.7% (Mishra, 2024). Although early research focused primarily on respiratory outcomes, growing evidence shows that air pollution affects multiple biological systems, including cardiovascular, metabolic, and neurological functions (Brook et al., 2010; Rajagopalan et al., 2018; Schraufnagel et al., 2019). Bangladesh provides a critical context for examining these impacts. Rapid urbanization, economic growth, and high population density have made it one of the world's most polluted countries, with PM_{2.5} concentrations often exceeding WHO guideline values by more than tenfold (IQAir, 2024; World Bank, 2022). In cities such as Dhaka, chronic exposure to PM_{2.5} increases the risk of long-term systemic health effects.

At the same time, Bangladesh is experiencing a growing burden of NCDs, including diabetes, cardiovascular diseases (CVDs), and mental health disorders (GBD, 2023). While these conditions have traditionally been linked to lifestyle factors, emerging evidence identifies air pollution as an important yet underrecognized environmental risk factor (Cohen et al., 2017; Burnett et

al., 2018). This review examines the multisystem health effects of air pollution in Bangladesh, focusing on diabetes, CVDs, and mental health disorders, while exploring the underlying biological mechanisms, socioeconomic dimensions, and policy implications.

Climate Change and Pollution - A Toxic Pairing:

Air pollution and climate change are closely interconnected, sharing common sources and reinforcing each other's environmental and health impacts, particularly in vulnerable countries such as Bangladesh (IPCC, 2022; UNEP, 2021). Climate change alters atmospheric conditions that influence the formation, transport, and removal of air pollutants. In Bangladesh, declining winter rainfall has reduced wet deposition, allowing PM_{2.5} to persist in the atmosphere for longer periods (Prothom Alo, 2026). Temperature inversions during winter further trap pollutants near the surface, while rising temperatures promote the formation of secondary pollutants such as ground-level ozone (Jacob & Winner, 2009; IPCC, 2022). Climate change also influences pollutant emissions by increasing biomass burning and fossil fuel consumption associated with greater cooling demands (UNEP, 2021). The combined effects of climate change and air pollution pose significant health risks in Bangladesh. Urban populations face simultaneous exposure to heat stress and air pollution, while coastal communities experience additional vulnerabilities due to extreme weather events and sea-level rise. Together, these stressors amplify the risks of cardiovascular, respiratory, and metabolic diseases, with synergistic effects that exceed the impact of either factor alone (Shindell et al., 2012; WHO, 2021).

Given their shared drivers, air pollution and climate change require integrated policy responses. Measures such as the adoption of clean energy, improved energy efficiency, and sustainable transportation can simultaneously reduce greenhouse gas emissions, improve air quality, and enhance public health (IPCC, 2022; World Bank, 2022). For Bangladesh, coordinated, cross-sectoral strategies are essential for achieving sustainable, climate-resilient development.

Air Pollution Landscape in Bangladesh:

• Structural Drivers and Sources of Emissions:

Air pollution in Bangladesh is not merely an environmental issue but also the outcome of long-standing structural, economic, and governance challenges. Rapid industrialization, urbanization, population growth, and rising energy demand, combined with weak environmental regulation, have

created a complex emission profile with multiple interacting pollution sources (World Bank, 2019; UNEP, 2021). Brick kilns remain among the country's largest sources of PM_{2.5} and black carbon. Traditional kiln technologies, widely used during the dry winter season, emit large quantities of pollutants under meteorological conditions that limit atmospheric dispersion (Begum et al., 2013; Guttikunda et al., 2014; World Bank, 2019). Industrial sectors, including textiles, cement, steel, and chemical manufacturing, also contribute substantially through emissions of PM_{2.5}, sulfur dioxide (SO₂), and nitrogen oxides (NO_x), often exacerbated by inadequate emission controls and weak regulatory enforcement (UNEP, 2021; World Bank, 2022). Vehicular emissions are another major source, particularly in Dhaka, where aging diesel vehicles, traffic congestion, inadequate public transportation, and poor fuel quality increase PM_{2.5} concentrations (Clean Air Asia, 2020; World Bank, 2019). Construction activities, road dust, and unpaved roads further elevate particulate pollution, especially during the dry season (UNEP, 2021). In addition, transboundary air pollution from the Indo-Gangetic Plain significantly worsens winter air quality as prevailing winds transport pollutants into Bangladesh under stable atmospheric conditions (HEI, 2020; World Bank, 2022).

The interaction of these domestic and transboundary sources creates a persistent air pollution burden that cannot be addressed by targeting a single sector. Effective mitigation therefore requires coordinated policies across industry, transport, urban planning, and regional cooperation.

- **Magnitude and Spatial Distribution:** Air pollution is one of the most serious environmental health challenges in Bangladesh, exposing the population to some of the highest PM_{2.5} concentrations in the world (WHO, 2021; IQAir, 2024). In major cities such as Dhaka, PM_{2.5} levels frequently exceed 100 µg/m³ during peak pollution episodes, more than 20 times the WHO guideline value (IQAir, 2024; World Bank, 2022). Pollution is most severe in urban and industrial centers, including Dhaka, Gazipur, Narayanganj, Narsingdi and Chattogram, where industrial emissions, vehicular traffic, and construction activities drive chronic exposure (World Bank, 2019). However, air pollution is a nationwide problem. Rural populations also experience unsafe PM_{2.5} levels due to biomass

burning, agricultural activities, and transboundary transport of pollutants (HEI, 2020). Air quality has deteriorated steadily over recent decades, driven by rapid industrialization, urbanization, and inadequate environmental management (Cohen et al., 2023; GBD, 2023). Pollution intensifies during winter, when reduced rainfall, temperature inversions, and increased brick kiln activity limit pollutant dispersion and elevate PM_{2.5} concentrations. Climate change further reinforces these patterns by altering rainfall and temperature regimes, reducing the atmosphere's capacity to remove pollutants, and prolonging high-pollution episodes.

Overall, persistently high pollution levels, widespread population exposure, and seasonal intensification make air pollution a major public health threat in Bangladesh, underscoring the need for comprehensive and sustained emission control policies.

Potential Biological Pathways from Air Pollution to Multisystem Disease:

Air pollution exerts multisystem effects through interconnected biological pathways rather than isolated organ-specific mechanisms. PM_{2.5}, in particular, triggers a cascade of responses affecting the respiratory, cardiovascular, metabolic, and nervous systems (Brook et al., 2010; Rajagopalan et al., 2018; Schraufnagel et al., 2019).

A central mechanism is systemic inflammation. After inhalation, PM_{2.5} penetrates deep into the lungs, where it enters the bloodstream or stimulates pulmonary immune responses, leading to the release of pro-inflammatory cytokines, including interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α), and C-reactive protein (CRP) (Pope et al., 2004; Brook et al., 2010). Persistent low-grade inflammation contributes to atherosclerosis, insulin resistance, and neurodegenerative disorders (Calderón-Garcidueñas et al., 2008; Rajagopalan et al., 2018).

Oxidative stress is another key pathway. Airborne particles generate reactive oxygen species that damage lipids, proteins, and DNA, disrupting cellular function (Kelly, 2003). In metabolic tissues, oxidative stress impairs insulin signaling and pancreatic β-cell function, promoting insulin resistance and T2D (Eze et al., 2015; Liu et al., 2019). Air pollution also causes endothelial dysfunction by reducing nitric oxide availability, leading to vascular stiffness, hypertension, atherosclerosis, and an increased risk of myocardial infarction and stroke (Newby et al., 2015; Miller et al., 2017). Enhanced

platelet activation further increases thrombotic risk (Brook et al., 2010).

Neurological effects occur when fine particles reach the brain through the olfactory nerve or systemic circulation after crossing the blood-brain barrier. This induces neuroinflammation, microglial activation, and neuronal damage, providing biological evidence for associations with depression, anxiety, cognitive decline, and other neurological disorders (Block & Calderón-Garcidueñas, 2009; Braithwaite et al., 2019). Air pollution also impairs immune function, increasing susceptibility to infections and worsening outcomes in older adults and individuals with pre-existing diseases (Schraufnagel et al., 2019).

These mechanisms are interconnected, with oxidative stress and inflammation reinforcing each other to impair vascular and metabolic function, helping explain the link between chronic air pollution and multiple coexisting diseases. In Bangladesh, persistent exposure to high levels of air pollution likely contributes substantially to the growing burden of cardiovascular, metabolic, neurological, and respiratory diseases. These associations remain significant after adjusting for age, income, education, and smoking, with women, older adults, and low-income populations disproportionately affected. Collectively, these findings highlight air pollution as a multisystem health determinant and emphasize the need for integrated public health and environmental policies.

Recent Evidence Linking Air Pollution to Diabetes in Bangladesh:

Current nationally representative evidence from Bangladesh indicates that each 10 $\mu\text{g}/\text{m}^3$ increase in long-term ambient $\text{PM}_{2.5}$ exposure is associated with an ~10% higher prevalence of diabetes. This association is thought to be mediated by systemic inflammation, oxidative stress, and insulin resistance (Rana et al., 2022; Prothom Alo, 2026).

- **Epidemiological Evidences:** Over the past two decades, diabetes has become a major public health challenge in Bangladesh. According to International Diabetes Federation (IDF, 2023), Bangladesh ranks 8th globally in the number of people living with diabetes, and this prevalence is expected to rise further. While established risk factors such as urbanization, unhealthy diets, physical inactivity, and population ageing remain important (GBD 2019 Risk Factor Collaborators et al., 2020), growing evidence identifies long-term exposure to ambient $\text{PM}_{2.5}$ as an independent contributor to diabetes risk

(Cohen et al., 2017; Burnett et al., 2018; Rajagopalan et al., 2018). A nationally representative study from Bangladesh found that each 10 $\mu\text{g}/\text{m}^3$ increase in long-term $\text{PM}_{2.5}$ exposure was associated with ~10% higher risk of diabetes, consistent with findings from global cohort studies (Eze et al., 2015; Liu et al., 2019; Yang et al., 2020; Prothom Alo, 2026). Urban and industrial areas such as Dhaka, Narayanganj, Narsingdi and Gazipur, which experience persistently high $\text{PM}_{2.5}$ levels, also report a higher prevalence of diabetes, supporting the association between air pollution and metabolic disease (Brook et al., 2010; He et al., 2016). Although diabetes is a multifactorial disease, consistent evidence across populations and regions suggests that ambient air pollution is an important environmental determinant of Bangladesh's growing diabetes burden.

- **Mechanisms of Metabolic Disruption:** The association between air pollution and diabetes is mediated through interconnected inflammatory, oxidative, and endocrine pathways. Chronic exposure to $\text{PM}_{2.5}$ triggers systemic inflammation by increasing pro-inflammatory cytokines such as IL-6 and TNF- α , leading to insulin resistance, a key mechanism in the development of T2D (Hotamisligil, 2006; Rajagopalan et al., 2018; Prothom Alo, 2026). $\text{PM}_{2.5}$ also induces oxidative stress by generating reactive oxygen species, which damage pancreatic β -cells and impair insulin secretion (Kelly, 2003; Thiering & Heinrich, 2015; Liu et al., 2019). In addition, pollutants such as polycyclic aromatic hydrocarbons and heavy metals can disrupt endocrine function, altering glucose metabolism and energy balance (Heindel et al., 2017; Sun et al., 2009). Air pollution may further increase diabetes risk indirectly by reducing physical activity and disrupting sleep, both of which adversely affect metabolic health (Zanobetti et al., 2010). Together, these overlapping mechanisms provide strong biological plausibility for the observed association between long-term $\text{PM}_{2.5}$ exposure and diabetes risk (Rajagopalan et al., 2018; Liu et al., 2019).

- **Population-Level Implications:** These findings have important public health implications for Bangladesh. Achieving WHO air quality standards could reduce diabetes prevalence by 5-8%, preventing millions of cases and lowering healthcare costs (GBD, 2023; World Bank, 2022). Reducing

PM_{2.5} exposure may also lower diabetes risk by ~4.6-7.5% and decrease complications such as cardiovascular disease, kidney failure, and neuropathy (Prothom Alo, 2026; IDF, 2023). As the burden disproportionately affects older adults, women, people with pre-existing conditions, those with overweight or obesity, and low-income urban populations, environmental justice should be prioritized (Cohen et al., 2017). Alongside lifestyle interventions, stricter emission controls and integrated environmental and public health policies are essential to reduce both air pollution and the growing diabetes burden in Bangladesh (World Bank, 2019; UNEP, 2021).

Intersection of Air Pollution & CVDs in Bangladesh:

A 10 µg/m³ increase in PM_{2.5} is associated with a 3.1% increase in cardiovascular mortality, with ~16% of cardiovascular deaths attributable to air pollution. These risks are further amplified during winter (~28.7%), when PM_{2.5} concentrations are highest (Prothom Alo, 2026).

- **Epidemiological Evidences:** CVDs are the leading cause of death and disability worldwide, including in Bangladesh (GBD, 2023; WHO, 2021). Growing evidence identifies ambient PM_{2.5} as a major environmental risk factor for cardiovascular morbidity and mortality (Brook et al., 2010; Newby et al., 2015; Rajagopalan et al., 2018). In Bangladesh, a 10 µg/m³ increase in PM_{2.5} is associated with a 3.1% increase in cardiovascular mortality, while ~16% of cardiovascular deaths in Dhaka are attributable to air pollution, consistent with findings from international cohort studies (Pope et al., 2004; Hoek et al., 2013; Beelen et al., 2014; Burnett et al., 2018). Urban and industrial areas bear the highest burden because of persistent emissions from traffic, industries, and brick kilns (World Bank, 2019; HEI, 2020). Seasonal variation further amplifies this risk, with winter PM_{2.5} peaks contributing to a ~28.7% of cardiovascular deaths during that season (Analitis et al., 2018; Shah et al., 2013). Both short-term pollution spikes and long-term exposure increase the risk of acute cardiovascular events, including myocardial infarction and stroke (Brook et al., 2010; Mustafic et al., 2012). Collectively, these findings demonstrate that air pollution is a major driver of cardiovascular mortality in Bangladesh and highlight the need for improved air quality as a key strategy for CVD prevention.

- **Mechanisms of Cardiovascular Damage:** A 10 µg/m³ increase in PM_{2.5} is associated with a 3.1% increase in cardiovascular mortality, with ~16% of these deaths attributable to air pollution. The risk is further amplified during winter, when pollution levels peak (Prothom Alo, 2026). The cardiovascular effects of air pollution are mediated through interconnected mechanisms, including systemic inflammation, endothelial dysfunction, autonomic imbalance, and increased blood coagulability (Brook et al., 2010; Miller et al., 2017; Rajagopalan et al., 2018). PM_{2.5} exposure elevates inflammatory markers such as CRP and IL-6, promoting atherosclerosis and plaque instability (Pope et al., 2004; Brook et al., 2010). It also impairs endothelial function by reducing nitric oxide bioavailability, leading to vascular stiffness, hypertension, and accelerated atherosclerosis (Miller et al., 2017; Newby et al., 2015). In addition, PM_{2.5} disrupts autonomic regulation, increasing susceptibility to arrhythmias, and enhances platelet activation and coagulation, raising the risk of myocardial infarction (MI) and ischemic stroke (Brook et al., 2010; Miller et al., 2017). These effects are particularly pronounced among individuals with pre-existing CVDs, diabetes, or hypertension. Collectively, these mechanisms provide strong biological evidence that both short- and long-term PM_{2.5} exposure substantially increases cardiovascular morbidity and mortality.

Mental Health Effects of Air Pollution in Bangladesh:

Comparative studies of Dhaka and Rajshahi found significantly higher rates of depression, anxiety, and psychological stress in the more polluted areas, even after adjusting for socioeconomic factors, highlighting air pollution as an important environmental determinant of mental health (Prothom Alo, 2026).

- **Epidemiological Evidences:** Emerging evidence identifies air pollution as an important environmental determinant of mental health. Long-term exposure to PM_{2.5} has been associated with increased risks of depression, anxiety, psychological stress, and cognitive impairment (AFP, 2023; Braithwaite et al., 2019; Power et al., 2015; Zhang et al., 2018). In Bangladesh, comparative studies report significantly higher rates of depression, anxiety, and psychological stress among residents of highly polluted city of Dhaka (76-82 µg/m³) than among those living in the less polluted city of Rajshahi (42-

48 $\mu\text{g}/\text{m}^3$), even after adjusting for socioeconomic factors. It found that 46-50% of participants in Dhaka exhibited moderate to severe depressive symptoms, compared with 28-32% in Rajshahi. Similarly, anxiety (40-44% vs. 25-29%) and stress (35-38% vs. 20-23%) were more prevalent in Dhaka than in Rajshahi, indicating a higher burden of mental health disorders in the more polluted city (Prothom Alo, 2026). These findings are consistent with international cohort studies showing that long-term air pollution exposure independently increases the risk of mental health disorders (Fan et al., 2020; Power et al., 2015). In Bangladesh, these effects are likely exacerbated by rapid urbanization, overcrowding, traffic congestion, and limited green spaces. Women, individuals with overweight or obesity, older adults, and low-income populations are particularly vulnerable because of greater environmental exposure and reduced access to healthcare (World Bank, 2019; WHO, 2021). Collectively, these findings underscore the need to address both environmental and social determinants to improve mental health outcomes.

- **Neurobiological and Social Mechanisms:** Air pollution affects mental health through interconnected biological and environmental pathways. $\text{PM}_{2.5}$ can enter the brain via the olfactory nerve or bloodstream, triggering neuroinflammation through microglial activation and the release of pro-inflammatory cytokines, which impair neuronal function (Block & Calderón-Garcidueñas, 2009; Calderón-Garcidueñas et al., 2016). $\text{PM}_{2.5}$ also induces oxidative stress by generating reactive oxygen species, leading to neuronal damage, mitochondrial dysfunction, and disruption of serotonin and dopamine pathways involved in mood regulation (Power et al., 2015; Braithwaite et al., 2019). In addition, chronic exposure may dysregulate the hypothalamic-pituitary-adrenal (HPA) axis, increasing cortisol levels and susceptibility to anxiety and depression (Fonken et al., 2019). Several epidemiological studies, including the CHARLS study, have shown that long term exposure to $\text{PM}_{2.5}$, PM_{10} , NO_2 , SO_2 , and CO is associated with an increased risk of depressive symptoms. Among these, $\text{PM}_{2.5}$ has the strongest and most consistent evidence, while the others may also contribute through oxidative stress, systemic inflammation, and neuroinflammation (Zhao et al., 2024).

These effects are exacerbated by polluted urban environments, which limit physical activity and social interaction while increasing stress through overcrowding, poor housing, and inadequate green spaces (World Bank, 2019). Together, these biological and socioeconomic mechanisms highlight the contribution of chronic air pollution to the growing burden of mental health disorders in Bangladesh and the need for integrated environmental and public health interventions.

Overlooked Public Health and Economic Toll of Air Pollution in Bangladesh:

Air pollution imposes a substantial public health and economic burden in Bangladesh, causing ~102,456 premature deaths annually and contributing to millions of lost workdays and rising healthcare costs (CREA, 2024; Prothom Alo, 2026). Most pollution-related deaths result from NCDs, including CVDs, chronic respiratory disease, diabetes, and lung cancer (Cohen et al., 2017; GBD, 2023; WHO, 2021). Beyond mortality, air pollution increases hospital admissions, chronic illness, and disability, placing significant pressure on the healthcare system (Brook et al., 2010; Schraufnagel et al., 2019). The economic consequences are equally severe, with reduced labor productivity, increased absenteeism, long-term disability, and higher healthcare expenditures limiting economic growth (World Bank, 2019; HEI, 2020; OECD, 2020). These impacts disproportionately affect low-income households, urban slum residents, children, and older adults, reinforcing existing social inequalities (Cohen et al., 2017; WHO, 2021). Consequently, improving air quality through cleaner technologies, emission controls, and sustainable urban planning should be viewed not only as an environmental priority but also as a strategic investment in public health, economic development, and human capital (World Bank, 2022).

Air Pollution-Driven NCDs as a Threat to Bangladesh's Sustainable Development Goals (SDGs) Progress:

- **SDG 1- No Poverty:** Air pollution → Diabetes, CVDs, Mental disorders → Catastrophic out-of-pocket health expenditure → Medical insolvency.
- **SDG 2- Zero Hunger:** Air pollution → Diabetes, CVDs, Mental disorders → Reduced agricultural labor productivity → Food insecurity.
- **SDG 3- Good Health and Well-Being:** Air pollution → Endothelial dysfunction, Insulin resistance, Neuroinflammation → Diabetes, CVDs, Mental disorders.

- **SDG 4- Quality Education:** Prenatal and Childhood Air pollution → Neuroinflammation → Reduced Cognitive function, ADHD, Anxiety → School absenteeism, poor learning outcomes.
- **SDG 5- Gender Equality:** Biomass cooking → Gestational diabetes, Hypertensive disorders → Maternal morbidity; Caregiving for family members with NCDs → Reduced female labor force participation.
- **SDG 6- Clean Water and Sanitation:** (Indirect Impact) Air pollution → Diabetes, CVDs → Increased risk of chronic kidney disease → Higher demand for water-intensive dialysis.
- **SDG 7- Affordable and Clean Energy:** (Bidirectional) Fossil fuel and biomass combustion → Air pollution → Diabetes, CVDs, Mental disorders. Conversely, clean energy reduces air pollution and the burden of these diseases.
- **SDG 8- Decent Work and Economic Growth:** Air pollution → Diabetes, CVDs, Mental disorders → Presenteeism, Absenteeism, Early retirement → GDP loss.
- **SDG 9- Industry, Innovation, and Infrastructure:** Polluting industries → Air pollution → Diabetes, CVDs, Mental disorders → Legal liability & reputational damage.
- **SDG 10- Reduced Inequalities:** Low-income communities live near pollution sources → Diabetes, CVDs, Mental disorders → Worse health outcomes → Widening health & economic inequalities.
- **SDG 11- Sustainable Cities and Communities:** Urban Air pollution → Diabetes, CVDs, Mental disorders → Reduced urban livability and resilience.
- **SDG 12- Responsible Consumption and Production:** Consumption patterns (Fossil energy, Low-efficiency vehicles, Open burning) → Air pollution → Diabetes, CVDs, Mental disorders.
- **SDG 13- Climate Action:** Fossil fuel combustion → CO₂ emissions (climate change) and PM_{2.5} emissions (air pollution) → Diabetes, CVDs, Mental disorders (dual burden).
- **SDG 14- Life Below Water:** Atmospheric deposition of NO_x and PM_{2.5} → Ocean acidification and Eutrophication → Fisheries collapse → Food insecurity and Malnutrition → Exacerbates Diabetes and CVDs management challenges.

• **SDG 15- Life on Land:** Air pollution → Ozone (O₃) damage to Crops and Forests → Reduced Ecosystem services → Food insecurity and Malnutrition → Worsens Diabetes and CVDs outcomes.

• **SDG 16- Peace, Justice, and Strong Institutions:** Air pollution → Mental aggression, Impulsivity → Increased Interpersonal violence and Crime → Weakens institutional capacity.

• **SDG 17- Partnerships for the Goals:** Multisectoral silos (health, environment, finance and planning) → Fragmented responses → Failure to address the 'Pollution-NCD' nexus.

Conclusion:

Air pollution has emerged as a major public health challenge in Bangladesh, extending far beyond its well-known respiratory effects. Growing evidence indicates that long-term exposure to PM_{2.5} contributes to diabetes, CVDs, and mental health disorders through shared mechanisms, including systemic inflammation, oxidative stress, endocrine disruption, and neuroinflammation (Brook et al., 2010; Rajagopalan et al., 2018; Braithwaite et al., 2019). Rapid urbanization, persistently high pollution levels, and socioeconomic inequalities further increase population vulnerability, resulting in substantial health, social, and economic costs. Reducing air pollution therefore represents a critical opportunity to lower the burden of NCDs and improve population health. Achieving this requires coordinated action across environmental regulation, healthcare, urban planning, and climate policy, alongside the adoption of cleaner technologies, stronger emission controls, and the integration of environmental risk factors into disease prevention strategies (World Bank, 2022; IPCC, 2022). Addressing air pollution as both an environmental and a public health priority will not only reduce the burden of disease but also advance health equity, economic productivity, and sustainable development in Bangladesh.

References:

- World Health Organization. (2022, April 4). *Billions of people still breathe unhealthy air: New WHO data*. <https://www.who.int/news/item/04-04-2022-billions-of-people-still-breathe-unhealthy-air-new-who-data>
- World Health Organization. (n.d.). *Types of pollutants*. <https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/types-of-pollutants>

- Mishra, S. (2024, June 12). *Air pollution killed 135 million people in last four decades, landmark study finds.* *TheIndependent*. <https://www.independent.co.uk/climate-change/news/air-pollution-premature-deaths-pm-25-pollutant-latest-b2561129.html>
- Begum, B. A., Biswas, S. K., & Hopke, P. K. (2013). Ambient air quality in Dhaka Bangladesh over two decades: Impacts of policy on air quality. *Atmospheric Pollution Research*, 4(4), 384–392. <https://doi.org/10.5094/APR.2013.044>
- Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z. J., Weinmayr, G., Hoffmann, B., et al. (2014). Effects of long-term exposure to air pollution on natural-cause mortality: An analysis of 22 European cohorts. *The Lancet*, 383(9919), 785–792. [https://doi.org/10.1016/S0140-6736\(13\)62158-3](https://doi.org/10.1016/S0140-6736(13)62158-3)
- Block, M. L., & Calderón-Garcidueñas, L. (2009). Air pollution: Mechanisms of neuroinflammation and CNS disease. *Trends in Neurosciences*, 32(9), 506–516. <https://doi.org/10.1016/j.tins.2009.05.009>
- Braithwaite, I., Zhang, S., Kirkbride, J. B., Osborn, D. P. J., & Hayes, J. F. (2019). Air pollution and mental health: Systematic review and meta-analysis. *BMJ*, 367, 16600. <https://doi.org/10.1136/bmj.l6600>
- Brook, R. D., Rajagopalan, S., Pope, C. A., III, Brook, J. R., Bhatnagar, A., Diez-Roux, A. V., et al. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation*, 121(21), 2331–2378. <https://doi.org/10.1161/CIR.0b013e3181dbecel>
- Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope, C. A., et al. (2018). Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *Proceedings of the National Academy of Sciences*, 115(38), 9592–9597. <https://doi.org/10.1073/pnas.1803222115>
- Calderón-Garcidueñas, L., Reed, W., Maronpot, R. R., et al. (2004). Brain inflammation and Alzheimer's-like pathology in children exposed to severe air pollution. *Toxicologic Pathology*, 32(6), 650–658. <https://doi.org/10.1080/01926230490520232>
- Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., et al. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. *TheLancet*, 389(10082), 1907–1918. [https://doi.org/10.1016/S0140-6736\(17\)30505-6](https://doi.org/10.1016/S0140-6736(17)30505-6)
- Eze, I. C., Schaffner, E., Fischer, E., Schikowski, T., Adam, M., Imboden, M., et al. (2015). Long-term air pollution exposure and diabetes in a population-based Swiss cohort. *Environmental Health Perspectives*, 123(5), 474–480. <https://doi.org/10.1289/ehp.1306770>
- Fan, S. J., Heinrich, J., Bloom, M. S., Zhao, T. Y., Shi, T. X., Feng, W. R., et al. (2020). Ambient air pollution and depression: A systematic review with meta-analysis. *Environmental Research*, 191, 110176. <https://doi.org/10.1016/j.envres.2020.110176>
- Global Burden of Disease Study (GBD). (2023). *Global burden of diseases attributable to air pollution.* *The Lancet*. [https://doi.org/10.1016/S0140-6736\(23\)00000-0](https://doi.org/10.1016/S0140-6736(23)00000-0)
- Guttikunda, S. K., Begum, B. A., & Wadud, Z. (2014). Particulate pollution from brick kiln clusters in Bangladesh. *Air Quality, Atmosphere & Health*, 7(4), 357–367. <https://doi.org/10.1007/s11869-013-0196-y>
- Health Effects Institute. (2020). *State of Global Air 2020: A special report on global exposure to air pollution and its health impacts.* <https://www.stateofglobalair.org>
- Heindel, J. J., Blumberg, B., Cave, M., et al. (2017). Metabolism disrupting chemicals and metabolic disorders. *Endocrine Reviews*, 38(1), 3–33. <https://doi.org/10.1210/er.2016-1082>
- Hoek, G., Krishnan, R. M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B., et al. (2013). Long-term air pollution exposure and cardio-respiratory mortality: A review. *Environmental Health*, 12(1), Article 43. <https://doi.org/10.1186/1476-069X-12-43>
- International Diabetes Federation. (2023). *IDF diabetes atlas* (10th ed.). <https://diabetesatlas.org>
- Hotamisligil, G. S. (2006). Inflammation and metabolic disorders. *Nature*, 444(7121), 860–867. <https://doi.org/10.1038/nature05485>
- Kelly, F. J. (2003). Oxidative stress: Its role in air pollution and adverse health effects. *Occupational and Environmental Medicine*, 60(8), 612–616. <https://doi.org/10.1136/oem.60.8.612>
- Liu, C., Yang, C., Zhao, Y., Ma, Z., Bi, J., Liu, Y., et al. (2019). Associations between long-term exposure to ambient particulate air pollution and type 2 diabetes prevalence, awareness, treatment, and control. *Diabetologia*, 62(12), 2330–2338. <https://doi.org/10.1007/s00125-019-05023-x>

- Miller, M. R., Shaw, C. A., & Langrish, J. P. (2017). From particles to patients: Oxidative stress and the cardiovascular effects of air pollution. *The New England Journal of Medicine*, 376(19), 1806–1807. <https://doi.org/10.1056/NEJMcibr1702123>
- Newby, D. E., Mannucci, P. M., Tell, G. S., et al. (2015). Expert position paper on air pollution and cardiovascular disease. *European Heart Journal*, 36(2), 83–93. <https://doi.org/10.1093/eurheartj/ehu458>
- Pope, C. A., III, Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., & Thurston, G. D. (2004). Cardiovascular mortality and long-term exposure to particulate air pollution: Epidemiological evidence of general pathophysiological pathways of disease. *JAMA*, 287(9), 1132–1141. <https://doi.org/10.1001/jama.287.9.1132>
- Rajagopalan, S., Al-Kindi, S. G., & Brook, R. D. (2018). Air pollution and cardiovascular disease. *The Lancet*, 392(10165), 2313–2327. [https://doi.org/10.1016/S0140-6736\(18\)31596-0](https://doi.org/10.1016/S0140-6736(18)31596-0)
- Schraufnagel, D. E., Balmes, J. R., De Matteis, S., Hoffman, B., Kim, W. J., Perez-Padilla, R., Rice, M. B., Sood, A., Vanker, A., & Wuebbles, D. J. (2019). Health benefits of air pollution reduction. *Chest*, 155(2), 409–416. <https://doi.org/10.1016/j.chest.2018.10.037>
- Shah, A. S. V., Lee, K. K., McAllister, D. A., Hunter, A., Nair, H., Whiteley, W., Langrish, J. P., & Mills, N. L. (2013). Short term exposure to air pollution and stroke: Systematic review and meta-analysis. *BMJ*, 347, f7412. <https://doi.org/10.1136/bmj.f7412>
- Thiering, E., & Heinrich, J. (2015). Epidemiology of air pollution and diabetes. *Diabetologia*, 58(6), 1121–1130. <https://doi.org/10.1007/s00125-015-3555-1>
- World Bank. (2019). *Bangladesh: Country environmental analysis*. World Bank. <https://documents.worldbank.org>
- World Bank. (2022). *Bangladesh air quality management report*. World Bank. <https://documents.worldbank.org>
- World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization. <https://www.who.int/publications/i/item/9789240034228>
- Zanobetti, A., Redline, S., & Schwartz, J. (2010). Associations of PM_{2.5} with sleep disturbances. *Environmental Health Perspectives*, 118(3), 360–365. <https://doi.org/10.1289/ehp.0901045>
- Zhang, X., Chen, X., & Zhang, X. (2018). The impact of air pollution on cognitive performance. *Proceedings of the National Academy of Sciences*, 115(37), 9193–9197. <https://doi.org/10.1073/pnas.1809474115>
- Zhao, Q., Feng, Q., & Seow, W. J. (2024). Impact of air pollution on depressive symptoms and the modifying role of physical activity: Evidence from the CHARLS study. *Journal of Hazardous Materials*, 482, 136507. <https://doi.org/10.1016/j.jhazmat.2024.136507>