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INVESTMENT BANK

ASIAN INFRASTRUCTURE FINANCE 2025

INFRASTRUCTURE FOR PLANETARY HEALTH

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AIIB Headquarters, Tower A, Asia Financial Center
No. 1 Tianchen East Road, Chaoyang District, Beijing 100101 China
Tel: +86-10-8358-0000
econ@aiib.org

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ABBREVIATIONS

AIIB	Asian Infrastructure Investment Bank
AMR	antimicrobial resistance
ATACH	Alliance for Transformative Action on Climate and Health
BLL	blood lead level
BOD	biological/biochemical oxygen demand
CDD	cumulative degree days
DALY	disability-adjusted life years
DHS	Demographic and Health Survey
FAO	Food and Agriculture Organization
ILO	International Labour Organization
IPBES	The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
GDP	gross domestic product
GRAP	Graded Response Action Plan
HIC	high-income countries
LFPR	labor force participation rate
LIC	low-income countries
LMIC	low- or middle-income countries
MDB	multilateral development bank
NCD	non-communicable disease
OECD	Organisation for Economic Co-operation and Development
SDGs	Sustainable Development Goals
SSEA	South and Southeast Asia
UMIC	upper-middle-income countries
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
WHO	World Health Organization
WOAH	World Organisation for Animal Health
WVBD	water- and vector-borne diseases
YLD	years lived with disability
YLL	Years of life lost

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ASIAN INFRASTRUCTURE INVESTMENT BANK

Erik Berglof (Chief Economist)

Jang Ping Thia (Lead Economist and Manager)

Abhijit Sen Gupta (Senior Economist)

Vera Siesjo (Senior One Health Scientist)

Vishnu Papineni (Senior Strategy and Policy Officer, Former Staff)

Chunping Xie (Climate Economist)

Nahom Ghebrihiwet (Economist)

Irem Kizilca (Economist)

Jingyu Gao (Economist)

Jiaqi Su (Economics Analyst)

Edith Zheng (Economics Analyst)

Xinyu Kong (Senior Data Administrator and Analyst)

Selim Elbadri, Taiding Guo, Yumin Hu, Sekar Joewono, Dimin Liu, Richard Tyler Simmons, Haocheng Wang, Manchun Wang, Wanying Wang of the AIIB Internship Program

With key support from

Leonardo Magno (Senior Creative Officer)

Maricris Jan Tobias (Senior Editorial Specialist)

Seleha Lockwood (Senior Climate Strategy and Policy Specialist)

Chipo Mubi (Senior Communications Officer)

Luca Feliziani (Senior Graphic Designer)

Abhinav Narayanan (Economist, Former Staff)

Arrad Tabandeh (Economics Analyst)

Kunyang Xu (Communications Assistant)

Rommel Marilla (Graphic Designer)

Mary Jane Caliza (Proofreader)

External Contributors

Pulasthi Amarasinghe (Research Economist, Institute of Policy Studies)

Rakesh Chandra (Assistant Professor, Tata Institute of Social Sciences)

Eyal Frank (Assistant Professor, Harris School of Public Policy)

Yuhang Pan (Assistant Professor, Peking University)

Anand Sudarshan (Associate Professor, University of Warwick)

Cheng Keat Tang (Assistant Professor, Nanyang Technological University)

Amrita Kundu (Assistant Professor of Operations and Analytics, McDonough School of Business, Georgetown University)

Rachel Silverman (Senior Fellow, Center for Global Development)

Dr. Atiq Zaman (Associate Professor at the Curtin University Sustainability Policy Institute, School of Design and the Built Environment)

OECD team

Suzannah Chapman (Policy Analyst, OECD)

Fabien Lenthy (Modeler, OECD)

Alienor Lerouge (Lead Modeler for Public Health, OECD)

Ece Özçelik (Policy Analyst – Lead on Infectious Disease, OECD)

Michele Cecchini (Head of Public Health Unit, OECD)

Aban Marker Kabraji (Senior Regional Advisor for Climate and Environment, UNEP)

Andrea M. Bassi (Senior Associate, International Institute for Sustainable Development, Founder and CEO, KnowlEdge Srl)

External Peer Reviewers

Jane Burston (CEO, Clean Air Fund)

Prof. Tan Sri Dr. Jemilah Mahmood (Executive Director, Sunway Centre for Planetary Health)

Calvin Quek (Executive Director, Nature Finance, Oxford Sustainable Finance Group, Smith School of Enterprise and the Environment, University of Oxford)

Jasmina Glišović (Head of Division, Loans and Social Development Directorate, Council of Europe Development Bank)

Alan Dangour (Director of Climate and Health, Wellcome Trust)

Dr. André Furco (Technical Expert – One Health Approach, WOAH)

Sarika Patel (Acting Health Emergency Lead, WHO)

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FOREWORD

Health is the very foundation of every field of human endeavor. Health is wealth — not just in the economic sense, but in the broadest definition of the term. Personal wealth is built through the innovation and hard work of individuals in good mental and physical health. And national prosperity ensues. Yet one major concern humanity must address in the 21st century is the threat to health posed by the degradation of our planet's natural ecosystems.

The intertwined crises of climate change, biodiversity loss, and environmental degradation are exacerbating global health inequities. Extreme heatwaves cause heatstroke and cardiovascular stress. Air pollution leads to respiratory diseases and cancer, now becoming the second leading cause of death worldwide. Natural disasters disrupt healthcare systems, displace communities, and accelerate the spread of waterborne diseases. Rising global temperatures expand the reach of vector-borne diseases such as malaria and dengue, threatening regions previously unaffected.

When ecosystems thrive, so do human societies. However, the reality is stark. For centuries, we humans have inflicted ceaseless damage on nature. Nature is our protector. But we have treated it badly. The vandalism perpetrated by humans on the planet's landmass and oceans has caused extensive damages far below the surface. Nature is endowed with an immense capacity to heal itself, but the pace of destruction in recent decades has outstripped its capacity for renewal. As a corollary, nature's capacity to protect and sustain human health has also been severely enfeebled. Mountains are now denuded of forests which used to filter air and water. Wetlands have gone dry which could otherwise act as a gargantuan sponge absorbing floods. And loss of biodiversity undermines nature's ability to contain contagious diseases. The dire consequence of the havoc wreaked on our ecosystems is the exacerbation of health crises in human society. Vulnerable populations bear the brunt of this threat despite being the least responsible for environmental degradation. Asia, for example, is expected to face climate-related mortality rates more than 13 times higher than those in North America.

Infrastructure adorns the natural world, not just in an aesthetic manner. It is also practical. Sustainable infrastructure can mitigate many of these risks referred to above while fostering long-term economic sustainability. Low-emission public transportation reduces air pollution and improves public health. Smart water systems prevent disease transmission and ensure clean drinking water. Clean energy reduces respiratory illnesses and premature deaths linked to air pollution. Resilient healthcare infrastructure ensures medical services remain operational during climate-related crises. Nature-based solutions—such as reforestation projects, wetland restoration, and urban greening—enhance climate adaptation while safeguarding public health.

Since its establishment nine years ago, AIIB has done its utmost to strengthen the intrinsic link between sustainable infrastructure and public health. Our commitment to financing the infrastructure for tomorrow is also a commitment to ensuring a healthier future. In response to growing demand from our members, AIIB has introduced its first Health Strategy, underscoring our focus on resilience, inclusivity, and sustainability in health-related infrastructure investments.

AIIB's approach to Infrastructure for Planetary Health seeks to maximize health co-benefits across all infrastructure sectors. Many of our projects, often co-financed with other multilateral development banks such as the World Bank, Asian Development Bank, European Bank for Reconstruction and Development, and African Development Bank, are designed to address the intertwined challenges of health, climate, and nature. By adopting a synergistic, sustainability-focused approach, AIIB aims to catalyze greater private-sector financing and mobilize more private capital to meet planetary health needs.

No country can achieve its full potential with a sick population on a degraded planet. Today, there are 3.3 billion people facing increased health risks due to climate change—a number that will rise as climate-related disasters become more frequent and severe. Economic losses from climate-induced health crises already amount to billions of dollars annually. The cost of inaction will far outweigh the cost of proactive investment in resilient infrastructure.

Multilateral development banks, governments, the private sector, and civil society must work together to prioritize infrastructure that aligns with planetary health objectives. Investments in green bonds, the integration of health considerations into urban planning, and the empowerment of communities with knowledge and resources will be essential. Through the establishment of the Development Banks Working Group for Climate and Health, we hope to accelerate collective action and financing for Infrastructure for Planetary Health.

We can no longer afford to view climate change as a distant crisis. It is here, now, and its impact on global health is all too palpable. We are already falling dangerously short of the USD2.4 trillion needed annually to address climate change. Worse still, less than one percent of multilateral climate funding is directed towards health. Such a paltry amount falls egregiously short of what is required to improve planetary health, as a vital prerequisite for maintaining human health. It is high time that we begin to invest more to protect millions of lives now and in the future.

Supporting human health is about more than saving lives—it is about strengthening communities, safeguarding livelihoods, and ensuring sustainable prosperity for generations to come. Planetary health and human health go hand in hand, and this is precisely what AIIB has striven to achieve. By investing in Infrastructure for Planetary Health, we can break the cycle of environmental degradation and declining health, fostering a healthier global community built on a sustainable economy and supported by a planet that remains safe and resilient.

Jin Liqun
President and Chair of the Board of Directors
Asian Infrastructure Investment Bank

PREFACE

Earth may have breached seven of nine planetary boundaries according to a recent report from the world-leading Potsdam Institute for Climate Impact Research. These boundaries contribute to the stability of the world's life support system. Climate change, the introduction of novel entities, change of biosphere integrity and modification of biogeochemical flows are estimated to be in high-risk zones, while breaches were less severe for land system change and freshwater change. The latest boundary that may have been breached is ocean acidification due to absorption of atmospheric CO_2.

There is a strong connection between the health of our planet and human health, and both are impacted through infrastructure investment. Our infrastructure choices lock us in, sometimes for decades, sometimes for centuries. Infrastructure for Planetary Health is about getting it right for our own survival and for the ecosystems we depend on. The 2023 Asian Infrastructure Finance report on Nature as Infrastructure argued that investing in nature as infrastructure—the most precious infrastructure for sustaining life on Earth—not only holds the key to mitigating and adapting to the escalating effects of climate change and biodiversity decline but ultimately to safeguarding human health and well-being.

Over the last decades, we have made astonishing progress in global health. Child mortality has fallen by 70 percent. We have nearly eradicated polio and dramatically scaled up access to new vaccines, including for some of our major killers like malaria and cervical cancer. Contracting HIV and AIDS is no longer a death sentence, and although inequities persist, we now live, on average, almost 30 years longer than we did 50 years ago.

However, human-induced changes to climate, nature and biodiversity now profoundly impact human health and well-being, posing serious and escalating threats to our global health gains, economies and development. Currently, a quarter of global deaths yearly can be attributed to various known avoidable environmental factors. Air pollution is the largest environmental cause of disease and premature death, causing over seven million deaths every year, more than the combined global death caused by tuberculosis, HIV/AIDS and malaria.

After decades of declines in global poverty levels, as many as 44 million people could be driven into extreme poverty by climate-driven health impacts by the end of the decade, principally in Africa and South Asia. Climate and nature degradation-driven health impacts will only intensify, exposing billions more people to life-threatening extreme temperatures, outbreaks of water- and vector-borne diseases, emerging zoonotic diseases, sandstorms, wildfires and catastrophic extreme weather risks, threatening to push millions of people into poverty.

This report argues that we must go beyond a "healthcare infrastructure approach" to safeguard human health and well-being. Safeguarding human health means achieving planetary health, which will require broad societal transformation. Infrastructure for planetary health offers a paradigm shift in how we think of, invest in and build systems to safeguard human health. Infrastructure is an essential part of the solution, not only for building resilient health systems but also as part of the broader focus on health, climate mitigation, adaptation, and nature-based solutions and conservation efforts in all infrastructure.

A global planetary health response could unlock billions of dollars in additional funding from health and climate financing agencies, climate-affected countries, philanthropies and the private sector. By maximizing investments in planetary health infrastructure through the development of strategic partnerships, innovative financing and thought leadership in integrating and scaling infrastructure investment in the nexus between health, climate change and nature, we can provide our members with infrastructure based on the latest evidence in equitable, people-centered development, a science-based approach, and Universal Health Coverage. Such investments would not only avoid human suffering but also result in a more productive and prosperous economy.

The 2023 Asian Infrastructure Finance report Nature as Infrastructure provided examples of how investments in mangroves, wetlands and forests can generate significant economic returns if nature assets are properly valued. This year's AIF report on Infrastructure for Planetary Health demonstrates that the impact on health outcomes and the associated costs provide an additional economic argument for why we should invest in nature, including in preserving keystone species, zoonotic surveillance and restoring natural habitats.

We are entering largely uncharted territory with accelerating climate change and biodiversity loss. Social and natural sciences must work more closely to better understand the interlinkages between climate, nature and human health. Part of this must be to explore the potential for nature to provide solutions to our global health challenges. We are, for example, constantly discovering new medicinal benefits of herbs and nature's impacts on mental and physical health. In assessing the value of nature's full potential and designing infrastructure investments, we must take these benefits into account.

There is still time for the global economy to safeguard human health from the impacts of climate change and nature degradation. A unique window exists to invest in planetary health infrastructures to mitigate and adapt to the escalating impact of the climate crisis and biodiversity loss on human health. Today's health challenges are complex and require global effort and cross-sectoral collaboration. Planetary health focuses on understanding and quantifying human health impacts from global environmental disruptions. Building planetary health infrastructure will allow humanity and the natural systems we depend on to thrive now and in the future.

Erik Berglof
Chief Economist
Asian Infrastructure Investment Bank

EXECUTIVE SUMMARY

Climate change, environmental degradation and biodiversity loss are impacting human health and well-being at an accelerating rate, increasing death, disability, loss of productivity and poverty. These changes exacerbate the risk of exposure to a myriad of climate sensitive-diseases and health conditions. Often these causes interact to amplify the impact on health. More heat and humidity increase the dangers from air pollution. More extreme rainfall and degraded wetlands combine to raise the risk of flooding which in turn leads to the spread of diseases, loss of livelihoods and damage to critical health infrastructure.

Developing economies, particularly people living in poverty, the elderly and children in these countries, are disproportionately affected by these health impacts. Income inequality is often high and healthcare systems are weak and underfunded. People with more resources can afford to reduce risks through private means, for example, by buying air purifiers and air conditioners and constructing homes with better flood protection. Investing in infrastructure that combat climate change and reverse nature loss becomes especially important to those that do not have access to these means.

Global warming brings heat-related stresses and cardiovascular diseases. Adverse extreme weather events directly affect the physical and mental well-being of populations, increasing risks of water and vector-borne diseases, threatening food and water security and damages healthcare infrastructure. Overexploitation of nature and harmful practices bring related hazards, such as the spread of zoonotic diseases, antimicrobial resistance, and chemical-related health impacts. Environment, nature and infrastructure provisions are important determinants of health beyond incomes or healthcare expenditures.

This report underscores the intricate interconnections between climate change, environmental degradation, biodiversity loss, and human health, presenting a compelling case for adopting a "planetary health" paradigm to address these global challenges. *The Asian Infrastructure Finance 2025: Infrastructure for Planetary Health* report aims to invest in infrastructure for development while at the same time enhancing the health of people and the planet. This can be achieved through a holistic approach that considers health, climate mitigation, adaptation, nature-based solutions and conservation efforts in all infrastructure development.

This report presents compelling evidence of the multifaceted health challenges particularly faced by developing countries due to climate change, nature degradation, and biodiversity loss. The report highlights increased water- and vector-borne diseases in select Asian countries due to flooding and rising food insecurity linked to rainfall volatility. It also points to how elevated temperatures increases infant mortality in South and

Southeast Asia (SSEA) and the severe health and cognitive development impacts caused by the inadequate recycling of lead—widely used in various industries and renewable energy storage—that contaminates soil, water, and air.

The burning of coal for electricity generation is at the heart of both climate change and environmental degradation. Reducing reliance on coal and improving air quality will require various measures. This includes green investments, expanding cross-province electricity trading, implementing local pollution controls, re-naturalizing peatlands, and mitigating the effects of burning of crop fields to improve air quality and overall health outcomes. The report also highlights the staggering economic toll of health-related issues exacerbated by climate change, including antimicrobial resistance (AMR), mental health challenges, and productivity losses. Our analysis shows that annual AMR-related costs alone are projected to reach USD13 billion in Indonesia, USD20 billion in Brazil, USD82.2 billion in India, and USD85.4 billion in China by 2050.

Finally, the report highlights the interdependence of nature and human health, and how biodiversity loss threatens vital ecosystem services such as food security, traditional medicine, natural disaster protection, and disease regulation. A recent study found that the drop in vulture populations in India led to 100,000 additional human deaths per year, due to the rise of other disease-carrying scavengers such as rats and feral dogs, carrying diseases such as rabies, anthrax and tuberculosis and contamination of ground water due to the leftover carcasses. This, coupled with the rising prevalence of zoonotic diseases, underscores the urgent need for integrated approaches like “One Health,” which connect human, animal, and environmental health to address these interconnected challenges effectively.

Three key investment themes emerge in the report:

First, it is necessary to invest in accessible, green, resilient and inclusive healthcare infrastructure. Increasing the accessibility and climate resilience of healthcare would ensure effective operations during disasters and extreme weather events and adapt to changing disease patterns due to climate change and nature degradation. Investing in low-carbon sustainable health systems would reduce overall carbon emissions. Inclusive infrastructure reduces health disparities, strengthens healthcare system and overall public health, improves social and economic development, and ensures that no one is left behind in receiving the quality care they need.

Second, scaling up green infrastructure and opting for a health-in-all-infrastructure approach can support health outcomes. A planetary health-in-all-infrastructure approach integrates health, nature and climate considerations into the planning, design, and implementation of all infrastructure projects, ensuring that built environments actively promote well-being of people and planet. By prioritizing clean air, safe water, green spaces and active transportation, this approach reduces disease burdens, nature degradation and climate change and improves public health outcomes. Further, retirement of coal plants, backed by renewables and adequate transmission, reduces population exposure to air pollution. Improved flood controls and water and sanitation infrastructure reduce waterborne and related diseases, which are especially critical in post-extreme weather events. Heat stresses will increasingly pose health challenges, requiring enhanced healthcare support to vulnerable population segments and greener, natural infrastructure that mitigates heat impact.

Finally, nature is an important solution to better health. Nature-based approaches in infrastructure or investing directly in nature deliver multiple benefits to health and well-being. Well-functioning ecosystems provide clean air and water, food, medicines and protection against extreme weather events. The report highlights valuable ecosystem services that mangroves provide for human well-being and health, including prevention of damage to properties and infrastructure during floods and typhoons, carbon sequestration and food provision. The conservation of keystone species is important, as the loss of these species can have major health impacts.

These examples underscore the importance of nature conservation, such as biodiversity conservation, reforestation, marine protection, greening cities, sustainable agriculture, and livestock production to improve health outcomes, including reducing diseases, promoting physical activity and improving mental health.

The main recommendations of the report are as follows:

Adopt the Planetary Health Paradigm: Policymakers and MDBs should integrate health, climate, and biodiversity into all infrastructure development design and strategies.

Invest in Nature as Infrastructure: Prioritize nature-based solutions and technologies that promote both environmental sustainability and public health.

Expand Inclusive Healthcare Access: Focus on improving healthcare systems, particularly in vulnerable regions and for disadvantaged populations, to address inequity and the rising burden of climate-induced health conditions.

Strengthen Global Collaboration: Enhance cross-sectoral coordination through frameworks like the One Health approach, including coordination on biodiversity conservation.

Close the Financing Gap: Mobilize resources through MDBs and innovative financial instruments to address health, climate, and nature challenges.

This report emphasizes that safeguarding human health requires achieving planetary health, demanding a fundamental shift in infrastructure development. By adopting a holistic approach, stakeholders can work collectively to ensure a sustainable and healthy future for all. Well-designed infrastructure development thus brings health co-benefits; increases healthcare resilience; reduces carbon emissions, biodiversity loss and nature degradation; supports workforces; and spurs greater economic returns. The report calls for integrating health considerations into climate and nature policies, emphasizing initiatives such as urban green spaces, biodiversity conservation, and global health frameworks. The report highlights the necessity of green infrastructure and healthcare systems resilient to climate impacts.

CHAPTER 1

OVERVIEW

1.1 Objective and Background of the Report

There have been remarkable improvements in global health and wealth in the past few decades. Average global life expectancy rose by nearly 30 years [Dattani et al. (2018)], while child mortality dropped by over 60 percent [Dattani et al. (2018)]. The number of people globally living in extreme poverty dropped from 63 percent to less than 10 percent, even with an increase of 5.5 billion people since 1950 [Hasell et al. (2018)].

However, these health gains are now threatened by emerging challenges due to climate change and nature degradation. The escalating consequences of climate change, nature degradation and biodiversity losses are already impacting human health and well-being, exposing billions more people by the end of the decade to life-threatening risk due to catastrophic extreme weather events, outbreaks of water- and vector-borne diseases, air pollution, chemical hazards, antimicrobial resistance, emerging zoonotic disease [WHO (2021); Jafino et al. (2020)].

People living in poverty, especially women, children, and the elderly, are particularly exposed and bear the heaviest burden of ill health and disease due to these factors. Within these populations, persistent differences based on class, gender, race and age determine people's vulnerabilities and health outcomes. Chapter 2 of the report highlights efforts to reduce air pollution in Asia and provides evidence of the positive impact on lowering infant mortality.

Focusing on climate change, the latest report of the Intergovernmental Panel on Climate Change (IPCC) finds that 3.3 to 3.6 billion people live in settings that are "highly vulnerable to climate change." [IPCC (2023)]. The effects are felt disproportionately by low- and middle-income countries.

Asia and the Pacific remain the world's most disaster-hit regions due to weather, climate, and water-related hazards, and many climate hotspots exist in Asia. The regions have historically been more affected by floods, droughts and storms than any other region of the world: 97 percent of all people affected by floods, 83 percent of all people affected by droughts, and 92 percent of all people affected by storms over the period 1960–2007 reside in Asia and the Pacific [ADB and SIDA (2011)]. With projected escalating temperature increases and the frequency and intensity of storms and tropical cyclones, climate change is expected to impact almost every sector of human and economic activity. After decades of declines in global poverty levels, as many as 44 million people could be pushed into extreme poverty by climate-driven health impacts by the end of the decade, mainly in Africa and South Asia [Jafino et al. (2020)].

Chapter 3 provides evidence of higher water- and vector-borne diseases in select Asian countries due to floods, as well as higher food insecurity due to rainfall volatility, using Sri Lanka as a case study. Chapter 4 shows how increased temperatures have affected infant mortality in South and Southeast Asia (SSEA). Both chapters underscore the need for expanded healthcare access and green infrastructure to mitigate health risks.

Chapter 5 highlights the health and cognitive development risks posed by lead, which continues to be used widely in industrial products. The chapter argues for the need to upgrade production and recycling facilities in developing countries, using Bangladesh as a case study. Box A provides cross-country correlations that point to the higher vulnerability of developing countries to environmental factors.

This report combines original empirical work and case studies, drawing on existing literature and expert discussions to arrive at the recommendations. This report stresses the need to go beyond a "healthcare approach" to safeguard human health and well-being. Safeguarding human health means achieving planetary health, which requires a broad societal transformation. Infrastructure is an essential part of the solution, not only to build accessible, green and resilient health systems but also as part of the broader focus on health, climate mitigation, adaptation, nature-based solutions and conservation efforts in all infrastructure.

1.2 Health is Wealth

Human-induced negative impacts on the climate, environment and biodiversity result in death, disease and injuries, not only affecting the quality of life but also reducing productivity and burdening health systems and economies. Maintaining good health reduces the likelihood of diseases and, therefore, the risk of financial hardship due to expensive out-of-pocket expenditures for medical treatments and loss of labor force participation.

Health and the climate crisis are profoundly interconnected and transcend national borders. The interlinkages are complex and differ depending on geographical location, urban and rural areas, etc. By 2030, the accumulated financial loss from extreme temperatures alone is expected to reach USD2.4 trillion and over 2 percent of total working hours worldwide are projected to be lost yearly due to temperature increases [WEF (2024)]. In South Asia and Sub-Saharan Africa, the resulting productivity loss may reach 5 percent [ILO (2019)]. Chapter 9 highlights the labor market losses from mortality and morbidity and argues that reducing morbidity burdens has sizeable labor force payoffs. Furthermore, there is also early evidence that extreme temperatures reduce workforce participation directly and potentially indirectly through infectious diseases—this is expected to affect developing countries and females more.

The GRAM study update forecasts an estimated 1.91 million deaths that can be attributed to AMR and 8.22 million deaths associated with AMR in 2050 [Naghavi et al. (2024)]. Chapter 6 of this report presents estimates that by 2050, there could be a significant reduction in life expectancy due to AMR if no actions are taken. The findings further reveal annual potential losses from AMR estimated to be USD20 billion, USD85 billion, USD82 billion and USD13 billion for Brazil, China, India and Indonesia, respectively.

It is important to note that the impact of climate events and nature degradation on health is primarily driven by morbidity rather than mortality [WEF (2024)]. With 588 million disability-adjusted life years (DALYs) lost and economic impact losses amounting to USD3.5 trillion, Asia is projected to face the second-highest impact globally [WHO Council (2023)]. Projections indicate that these health outcomes could amount to as much as USD1.3 trillion. Asthma alone is anticipated to incur costs amounting to USD9.4 billion, while ischemic heart diseases are projected to cost USD5.6 billion and add 2.9 million DALYs.

However, the most substantial economic and population impacts are tied to mental health and generalized anxiety disorder [WHO Council (2023)]. According to the WHO, depression is the leading cause of disability worldwide, affecting over 300 million people. The impacts of climate change, natural disasters, and biodiversity loss are exacerbating mental health challenges, giving rise to conditions such as anxiety, trauma, and chronic stress. For example, rising sea levels and extreme weather events displace millions of people annually, potentially leading to increased rates of post-traumatic stress disorder and depression. Air pollution has also been linked to cognitive decline and mood disorders which shows a direct connection between environmental degradation and mental health [Bhui et al. (2023)]. A landmark study in China revealed that long-term exposure to fine particulate matter (PM2.5) significantly reduced cognitive performance and exacerbated depressive symptoms [Zhang et al. (2018)].

The cost of mental health conditions (and related consequences) is projected to rise to USD6 trillion globally by 2030, from USD2.5 trillion in 2010, driven by lost productivity, increased healthcare expenditures, and the broader societal impacts of untreated mental health disorders [WEF (2024); The Lancet Global Health (2020)].

Investing in green infrastructure presents a promising avenue to enhance mental and physical well-being while addressing environmental challenges. Urban green spaces, for example, offer multiple benefits for mental health by providing settings for recreation, stress reduction, and social interaction. The “City in a Garden” initiative in Singapore demonstrates how integrating greenery into urban planning can reduce anxiety and depression rate [Tan et al. (2021)], while also promoting biodiversity and urban cooling. Evidence from Melbourne, Australia, shows that residents living within 500 meters of large green spaces were significantly less likely to report psychological distress compared to those with limited access [Astell-Burt et al. (2019)].

By 2050, overall morbidity and mortality from climate-intensified natural disasters are expected to result in 15 million deaths, more than 2 billion healthy life years lost, and USD12.5 trillion in economic losses [WHO Council (2023)]. The risk from climate change and nature degradation threatens to destabilize both healthcare systems and the planet.

1.3 Nature and Health: Biodiversity and Ecosystems Services for Health

Biodiversity and ecosystem services are essential for human existence and high quality of life [IPBES (2019)]. A nature-based approach can deliver multiple benefits to human health and well-being. For example, well-functioning ecosystems can provide nutritious food, clean air and water [IPBES (2019)]. Biodiversity is also directly linked to health and the health system. Over 50 percent of modern drugs are developed from natural products, and an estimated 50,000–70,000 plant species are harvested for traditional or modern medicine [IPBES (2019)].

The current biodiversity loss rate is estimated to be about 1,000 times higher than historically natural rates [Pimm et al. (2014)]. The overexploitation of nature is one of the main factors behind the spread of new diseases. Changes in land use that bring wildlife, livestock and humans into closer contact with each other and the illegal and uncontrolled trade of live wild animals create conditions for and facilitate the development and spread of diseases. In particular, zoonoses are infectious diseases that can be transmitted from animals to humans. Seventy-five percent of communicable diseases are zoonotic, and these diseases are increasing at alarming rates [Galaverni et al. (2020)]. Chapter 7 highlights the linkages between nature and human health. In Chapter 8, the report describes the One Health approach, integrating human, animal, and environmental health and its crucial role in tackling pandemics, food security and environmental degradation. The chapter highlights the need for cross-sectoral coordination and data sharing between sectors to timely detect outbreaks and mobilize towards containment, with a case study reflecting the opportunities and challenges in Cambodia.

Loss of biodiversity also contributes to increased infections caused by viruses, bacteria, parasites and fungi [Galaverni et al. (2020)]. The health implications of loss of biodiversity and ecosystem services include, for example, decreased access to both terrestrial and marine nutrition. Seventy-five percent of our food crops depend on pollinators, but 40 percent of pollinator species, such as bees and butterflies, face the risk of extinction [IPBES (2016)]. Biodiversity loss is also likely to lead to reduced access to traditional medicines, reduced options for future drug development, increased disease burden and reduced protection against pollution as ecological barriers are weakened [Roe et al. (2019)].

The national biodiversity strategy and action plans (NBSAPs) [CBD (n.d.)] are important instruments to support the national implementation of the Convention and to integrate conservation and sustainable use of biodiversity into sectoral and cross-sectoral activities, including infrastructure. The Asian Infrastructure Investment Bank (AIIB) (2023) highlighted the need to think of nature as our most essential infrastructure. Integrating biodiversity conservation into infrastructure development alongside nature-based solutions (NBS) and natural infrastructure is crucial to safeguard not only nature but also human health.

1.4 Building on the Planetary Health Paradigm

A report released in September 2024 reveals that six of the nine planetary boundaries–humanity's safe operating spaces–are now substantially breached. There is a looming risk of breaching the 1.5-degree Celsius planetary boundary on climate between 2030 and 2035. Planetary health provides policymakers with a new framework to think about human health, understanding that human health is instinctually interconnected with the health of our planet and all living creatures on it. Planetary health focuses on understanding the human health impacts of global environmental disruptions and developing solutions that will allow humanity and the natural systems we depend on to thrive now and in the future [Caeser et al. (2024)].

Infrastructure for Planetary Health presents an opportunity to invest in a cross-sectoral, transnational and integrated approach to building new and existing infrastructure that optimizes development, works to mitigate and adapt to the effects of climate change as well as improves the health of humans and the planet. Achieving planetary health is about drastically changing global economies, industries and consumption patterns to reduce environmental and human health impacts. This means a radical shift to healthier and more environment-friendly production processes and behaviors and the creation of a complete set of new technologies and infrastructure for the future to replace existing ones that are not sustainable. Making this shift should be seen as an investment for the future, both as protective and preventive actions against threats to planetary health.

1.4.1 Global Policy Landscape for Planetary Health

The rising economic, social and health costs of climate change and nature degradation, particularly on infrastructure and the most vulnerable, should prompt global policymakers to achieve consensus on the need for an integrated approach to infrastructure investment [IPCC (n.d.)]. Global sustainable development policies, agreements and frameworks have acknowledged the interlinkages between climate, health and nature and a planetary health approach since the 1980s [Brundtland Commission (1987); UNEP (2022); Horton and Lo (2015); Pongsiri et al. (2017); Pongsiri et al. (2019)].

Emphasizing the importance of holistic approaches in global policy can be traced back to the Rio Conventions' emphasis on sustainable development and living in harmony with nature [UN (1992)]. Subsequent UN Sustainable Development Goals (SDGs) recognized the interlinkages between health and other goals [UN (2015)]. The COP21 Paris Agreement acknowledged the right to health in the context of climate change [UNFCCC (2015)].

Health has gained increasing prominence in global climate discussions. At COP26 in 2021, 50 countries committed to building climate-resilient and sustainable health systems and joined the WHO-led Alliance for Transformative Action in Climate and Health (ATACH). COP27 emphasized the interconnections between climate change and health with the launch of the Initiative on Climate Action and Nutrition (I-CAN). At COP28 in 2023, the UAE Presidency hosted the first health day, leading to the Declaration on Climate and Health, which has now been endorsed by over 150 countries [The Rockefeller Foundation et al. (2025)].

The Kunming-Montreal Global Biodiversity Framework highlighted the interlinkages between biodiversity and health [UNEP (2022)]. COP27 and G20 declarations focus on climate and health, while COP28 declarations and the multilateral development bank and public development banks joint roadmap emphasize financing climate and health solutions [UNFCCC (2022); G20 (2023); COP28 UAE Declaration (2023); COP28 Guiding Principles (2023); MDBs (2023); MDBs and PDBs (2024)]. A UN resolution in 2022 declared access to a healthy environment a human right [UN (2022)]. In June 2024, the Seventy-seventh World Health Assembly (WHA) passed a resolution recognizing climate change as a significant threat to global health and well-being [77th WHA (2024)].

The October 2024 Lancet Countdown report on health and climate change revealed that health threats of climate change reached record-breaking levels [Romanello (2024)]. The G20 Health Ministerial Declaration on Climate Change, Health and Equity, emphasized the urgent need for global intersectoral collaboration to address the health impacts of climate change, focusing on sustainability, resilience, equity, the SDGs and a One Health approach that leveraged alliances such as the WHO-led Alliance for Transformative Action on Climate and Health (ATACH) [G20 (2024)].

Such global policy developments are aligned with the core principles in AIIB's Climate Action Plan, emphasizing the need for a holistic approach [AIIB (2023)]. This opens an opportunity to design infrastructure for development that promotes planetary health at its core.

Integrated planning of climate, nature and health investments is crucial for countries to access funding and effectively address climate, nature and health goals. While more than 90 percent of Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs) include considerations for health, many countries lack a clear understanding of the financing required to implement climate, nature and health solutions. It is essential to translate the increasing political commitment into actionable and financeable plans that enable the implementation of climate and health initiatives.

The updated NDCs in 2025, along with the development of robust NAPs and Health National Adaptation Plans (HNAPs), provide opportunities for countries to communicate their climate and health commitments to the global community. This also presents an opportunity for the global community to come together and provide the necessary finance to support these commitments. By strengthening planning and coordination, countries can better access funding and effectively address the intersection of climate change and health.

However, a 2021 survey conducted by the World Health Organization (WHO) revealed that only 28 percent of countries received international funding for climate change and health activities, with the lack of information financing opportunities being a key challenge. Countries often face other barriers such as complex finance access processes, hindering their ability to meet climate and health commitments. These findings highlight the need for improved global policies and mechanisms to support countries in accessing the necessary funding for climate and health initiatives [The Rockefeller Foundation et al. (2025)].

This report provides new research evidence and perspectives and aims to inspire action among all stakeholders to invest in planetary health and sustainable development.

1.5 Financing for Climate, Nature and Health

Finance commitments for climate and health have seen a ten-fold increase from less than USD1 billion in 2018 to USD7.1 billion in 2022. This was mainly driven by Development Assistance Committee (DAC) donors. In 2022, bilateral donors provided USD4.8 billion, multilateral health funds USD1.5 billion, MDBs USD600 million, philanthropies USD160 million, and multilateral climate funds USD23 million. This demonstrates a growing prioritization of climate and health within leading funds [The Rockefeller Foundation et al. (2025)].

The United Nations High-Level Advisory Board on Effective Multilateralism estimates that the SDG financing gap has grown from USD2.5 trillion before the COVID-19 pandemic to between USD3.9 and USD7 trillion in 2023. According to the World Bank, in 2030 there will be a USD176 billion annual gap in healthcare budget financing for the world's fifty-four poorest countries [World Bank Group (2019)].

Infrastructure is a key enabler of sustainable development and influences the achievement of a large number of SDGs. An estimated USD274 billion to USD371 billion per year is needed alone to achieve SDG3 (Ensure healthy lives and promote well-being for all at all ages) in 67 low- and middle-income countries by 2030.

According to the UNEP Adaptation Gap Report 2023, low- and middle-income countries need a minimum of USD11 billion per year throughout this decade to address the health impacts of climate change. However, this estimate only covers the additional costs of disease control for specific illnesses like malaria, dengue, diarrheal diseases, and heat-related mortality. It includes the indicative costs of improving disease surveillance and strengthening water, sanitation, and hygiene systems and health infrastructure. This estimate represents only a fraction of the total funding needed to address the wide-ranging impacts of climate change on human health, such as respiratory illnesses, malnutrition, mental health, and other infectious diseases. Additionally, it is crucial to reduce the greenhouse gas emissions of health systems. Therefore, a much larger amount of funding will be required to comprehensively tackle the health consequences of climate change.

Despite the urgent need for health-specific climate action, it remains significantly underfunded. Previous estimates indicate that only 6 percent of adaptation funding and a mere 0.5 percent of multilateral climate funding are allocated to projects explicitly focused on protecting or improving human health. This leaves countries ill-equipped to respond to the climate crisis and safeguard human health. Furthermore, the available finance does not adequately reach those who need it the most. Less than half of the total funding is directed towards low-income countries, and a substantial portion of bilateral donor financing are loans rather than grants. This limited access to funding further exacerbates the challenges faced by countries in addressing the health impacts of climate change [The Rockefeller Foundation et al. (2025)].

With the growing financing needs, multilateral development banks (MDBs) are becoming even more important. At the global level, initiatives led by MDBs are addressing broader gaps in health infrastructure. In June 2023, the WHO, in collaboration with the African Development Bank (AfDB), European Investment Bank (EIB), and Islamic Development Bank (IsDB), launched the Health Impact Investment Platform [MDBs and WHO (2023)]. This platform aims to mobilize approximately €1.5 billion in concessional loans and grants to strengthen primary healthcare services in low- or middle-income countries (LMICs). Despite these promising efforts, substantial investment gaps persist in health infrastructure, particularly in LMICs. MDBs could play a pivotal role in addressing these gaps by providing financial resources, technical assistance, and policy guidance to integrate health services into broader health infrastructure projects.

The financing needs for planetary health are substantial and will require a variety of financing instruments and innovative approaches to increase and prioritize investments to scale up action. Finance for climate and nature should be recognized for their health benefits. Finance for health can also take into account climate and nature to achieve a greater impact. There is no one-size-fits-all approach in climate-health investment. MDBs can use its convening role to support countries to identify and mobilize the needed financing for new infrastructure for planetary health.

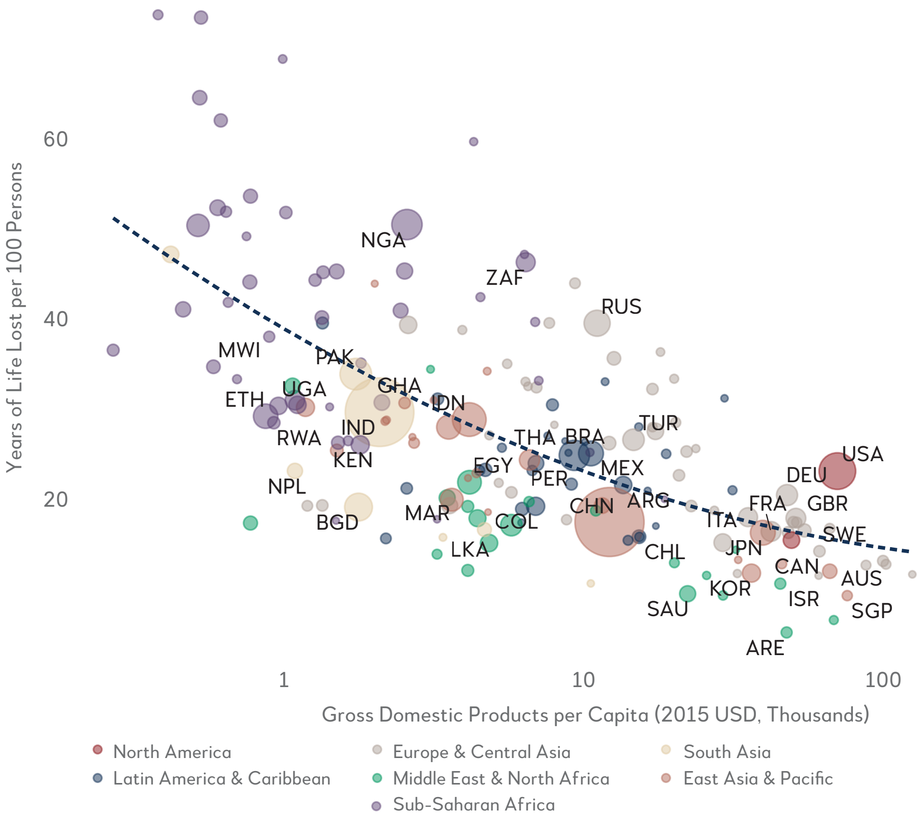
Box A: Environment, Incomes and Health—Are Developing Economies More Vulnerable?

This box item provides a review of countries' health outcomes against various economic, social, and environmental factors and highlights the vulnerabilities of developing economies.

Wealthy countries have lower mortality

Figure A1 illustrates a negative correlation between the Years of Life Lost (YLL) rate and per capita incomes.[a] Improvements in health have been primarily attributed to enhanced living standards, robust public health infrastructure, and advances in medical technology [Weil (2014)]. Higher incomes individually provide nutritious food and medical services [Fogel (2004)]. National wealth also fosters investments in health-promoting public goods and infrastructure [see Zhang (2012); Cutler et al. (2006)]. The effectiveness of public health measures and healthcare systems also correlates with institutional quality and economic development [see Cutler and Lleras-Muney (2006); Deaton (2006)].

Figure A1: YLL Rate and GDP Per Capita in 2021



Source: World Health Organization and World Bank World Development Indicators.
Notes: GDP per capita is presented on a logarithmic scale. The size of the circles represents the relative population sizes.

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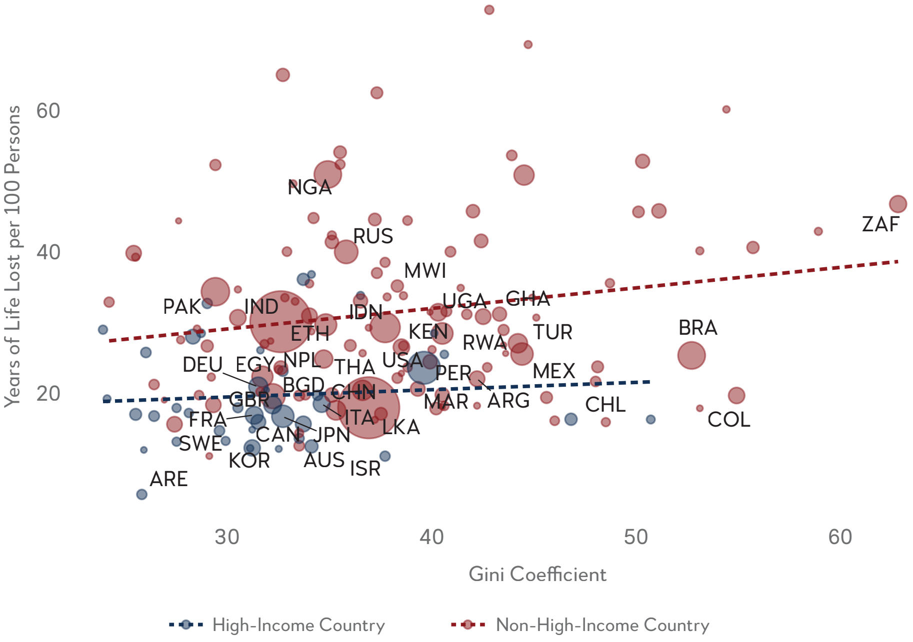
Box A *continued*

Income disparities affect health outcomes more in developing economies

However, there are significant disparities in mortality even amongst countries with similar incomes. As depicted in Figure A2, the YLL is positively correlated with the Gini coefficient for developing countries, which contrasts with high-income countries (HICs) where no correlation is observed.[b] In developing countries, significant disparities in health measures like infant mortality and malnutrition are observed across different wealth quintiles, with children from the lowest quintile facing approximately twice the risk of premature death compared to those from the highest quintile [Gwatkin et al. (2007)]. Furthermore, Biggs et al. (2010) reported that in Latin American countries, higher gross domestic product (GDP) had minimal impact on health outcomes during periods of rising poverty, whereas in times of stable or declining poverty and inequality, increased income strongly correlated with health improvements. Thus, for developing countries, healthcare access for lower-income groups is even more critical.

Figure A2: YLL Rate and Gini Coefficient in 2021



Source: World Health Organization and World Bank World Development Indicators.
Notes: The Gini Coefficient values reflect the latest available data as of 2021. The size of the circles represents the relative population sizes.

Elevated vulnerabilities of nature and environmental degradation in developing economies

Environmental factors also have a significant impact on health outcomes. Air pollution is a poignant example. Exposure to particulate matter of 2.5 micrometers or less (PM2.5) significantly increases the risk of respiratory diseases such as asthma, respiratory inflammation, compromised lung function, and even cancers [see Samoli et al. (2005); Lewis et al. (2005)]. Moreover, adverse pregnancy outcomes, including preeclampsia and hypertensive disorders, have been linked to PM2.5 exposure [Pedersen et al. (2017)]. Figure A3 illustrates a positive relationship between the YLL rate and average annual PM2.5 exposure. Notably, mortality is positively correlated with air pollution in developing countries, but not so for HICs.

Intuitively, this could be due to the lack of healthcare resources in developing countries to cope with the health risks of air pollution. Furthermore, overpopulation, unregulated urbanization, and rapid industrialization exacerbate health risks and complicate environmental governance in these regions [Mannucci and Franchini (2017)]. In wealthier countries, citizens are more likely to afford air-conditioners and purifiers or have access to a controlled environment that insulates them from poor air quality.

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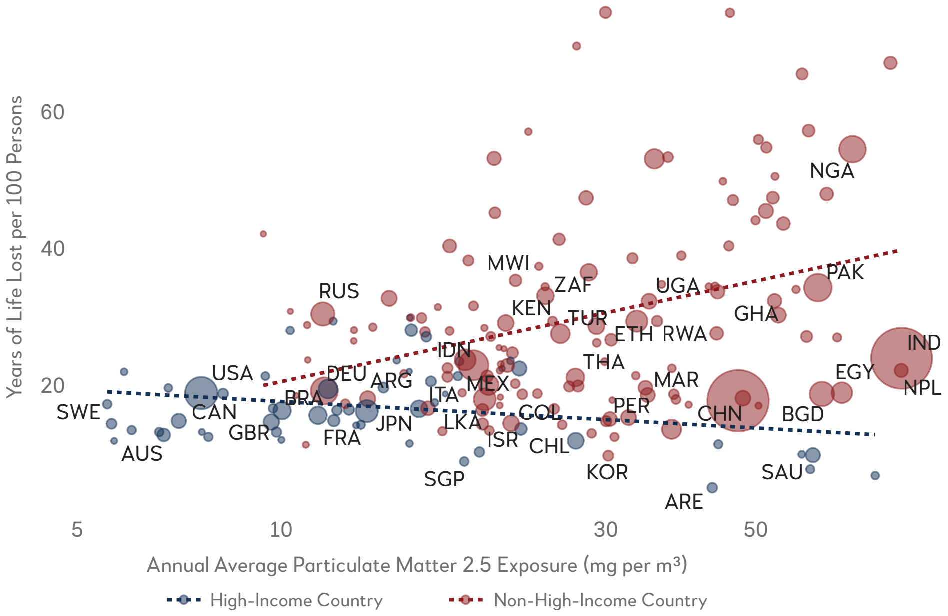
Box A *continued*

The 2021 State of Global Air report shows that 8.1 million deaths globally were attributed to air pollution, with 85 percent resulting from non-communicable diseases such as heart disease and lung cancer, primarily in lower-income regions.

Water pollution is another critical issue. Interaction with contaminated water is known to be a significant cause of many diseases, such as diarrhea, skin diseases, cancer and various childhood diseases [Lin (2022)]. Major pollutants include industrial waste, urban sewage and agricultural runoff. Notably, UNESCO (2017) reported that 80 percent of industrial and municipal wastewater is released into the environment without treatment, negatively impacting human health and ecosystems.

Using the concentration of dissolved oxygen as a proxy for water quality, Figure A4 shows that lower water quality correlates with higher mortality in developing countries.[c] Again, no significant correlation is observed for HICs. This discrepancy underscores the greater vulnerability of populations in developing countries to water pollution, exacerbated by inadequate sanitation and wastewater treatment infrastructure.

Figure A3: YLL Rate and PM2.5 Exposure in 2019



Source: World Health Organization and World Development Indicators.
Notes: Average Annual PM2.5 Exposure per m^3 is presented on a logarithmic scale. The size of the circles represents the relative population sizes.

There is also some evidence on how nature (or the depletion of nature) affects health outcomes. Nature provides essential resources such as clean air, fresh water and fertile soil. The degradation of nature thus undermines the capacity of ecosystems to support health and well-being and intensifies public health pressures by affecting food safety and worsening disease transmission dynamics [AIIB (2023)]. Figure A5 shows that those with higher per capita ecosystem capital in developing countries experience lower mortality. Habitat alteration and disruption can bring human populations closer to disease vectors, fostering environments that facilitate the spread of diseases such as malaria and dengue [Vora (2008)]. These effects are more pronounced in developing countries, where limited healthcare infrastructure exacerbates vulnerabilities.

While wealthier nations have fewer years lost to premature mortality, income is not the sole determining factor. Environmental protection and preservation of nature, coupled with a more even distribution of resources, can partly explain the differences in mortality across countries. Developing countries, having poorer health infrastructure, are seen to be even more vulnerable to environmental factors. Public health policies must pay increased attention to the environmental and social causes of poor health.

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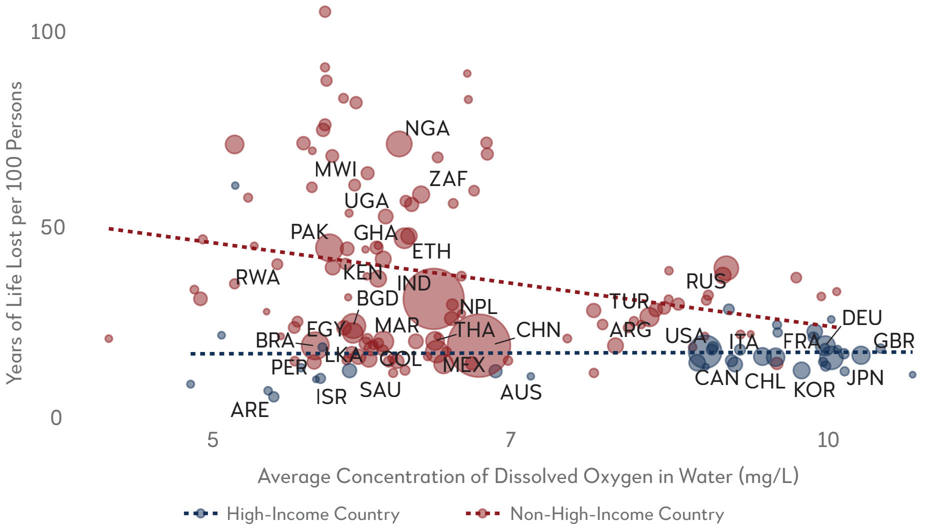
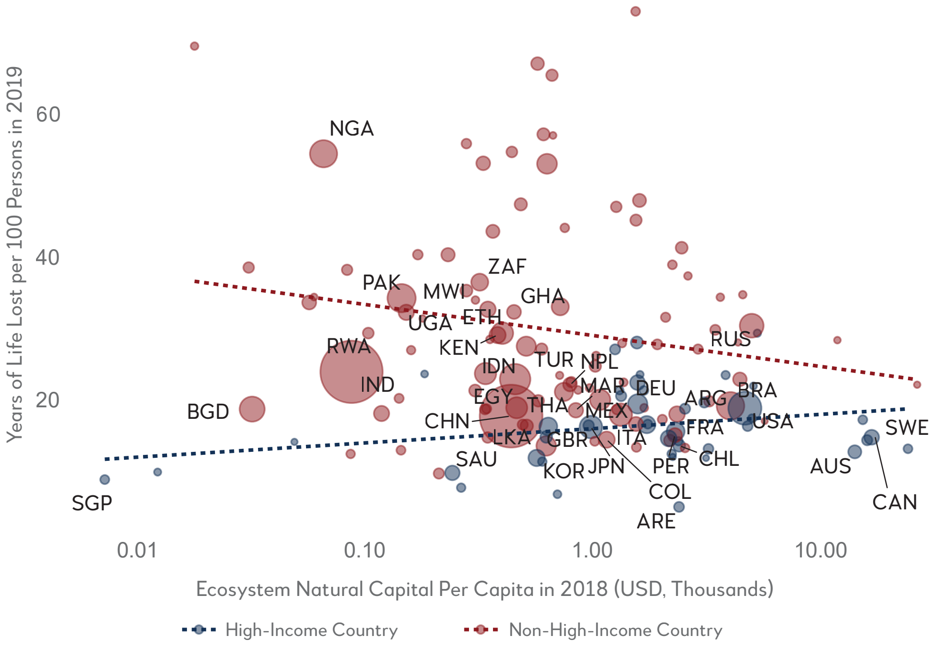
Box A *continued*

Figure A4: YLL Rate and Dissolved Oxygen in Water in 2010



Source: World Health Organization, World Development Indicators and Quality Unknown Report.
Notes: Average Concentration of Dissolved Oxygen is presented on a logarithmic scale. The size of the circles represents the relative size of the population of each country.

Figure A5: YLL Rate and Ecosystem Natural Capital Per Capita



Source: World Health Organization, World Development Indicators, Changing Wealth of Nations, and Natural History Museum.
Notes: Ecosystem Natural Capital per capita is adjusted by the Biodiversity Intactness Index to control for its quality and presented on a logarithmic scale. The size of the circles represents the relative size of the population of each country in 2019.

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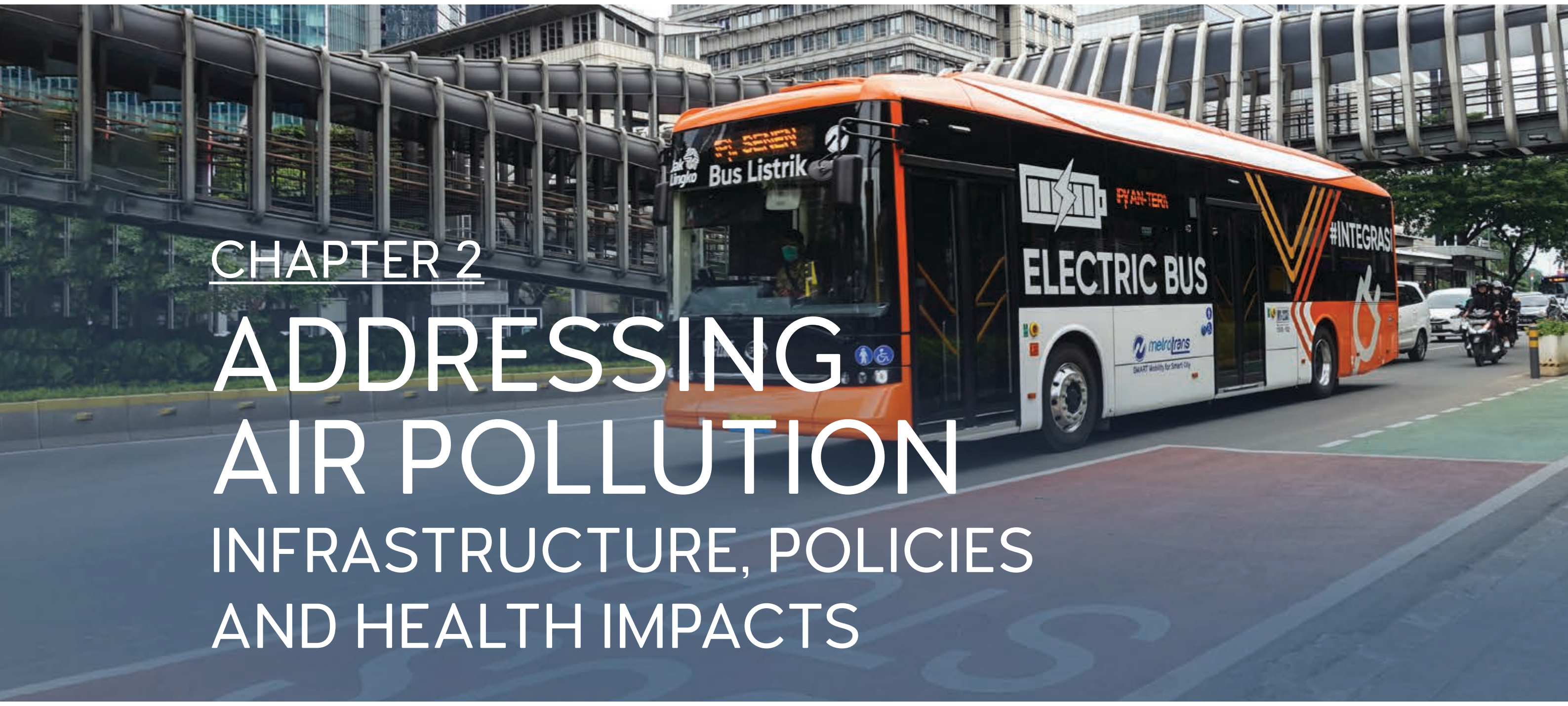
[a] Years of Life Lost (YLL) quantifies the years of life lost due to premature mortality in the population. YLL rate is defined as YLL per 100 persons.

[b] Developing countries in this box item are defined as those classified by the World Bank as low, lower-middle and upper-middle-income countries, excluding high-income countries.

[c] Average Concentration of Dissolved Oxygen in Water is one of the most widely used indicators of water quality, as it directly reflects a water body's capacity to sustain aquatic life.



CHAPTER 2

ADDRESSING AIR POLLUTION

INFRASTRUCTURE, POLICIES AND HEALTH IMPACTS

Highlights

- Air quality in China improved after stringent environmental measures were enacted. The retirement and replacement of old coal-fired powered plants resulted in pollution being displaced to other plants, and investment in renewable energy, transmission and inter-province electricity trading reduced such pollution shifting and consequently improved air quality.
- Measures on controlling air pollution in India's Delhi and the surrounding National Capital Region (NCR) is found to have increased infant birthweight and reduced infant mortality, underscoring how regulatory measures can also be used.
- Indonesia's experiences with peat land management highlight the importance of conservation and restoration of natural habitats to reduce air pollution.
- Improvements in green infrastructure can reduce the number of deaths related to air pollution, estimated at 8.1 million annually, and improve the lives of billions of citizens.

Air pollution is a major health challenge, and pollutants such as PM2.5 and PM10 are reported to cause a wide range of respiratory, cardiovascular and neurological diseases, more than malnutrition, road accidents, drug and alcohol abuse, and war and terrorism [Cohen et al. (2017)]. Overwhelmingly, the vast majority of health conditions come from fossil fuel related air pollution, having significant relevance for decisions on infrastructure for planetary health [Health Effects Institute (2024)]. Studies on the health risks associated with super-pollutants such as methane, black carbon, and ozone indicate significant climate forcing impact, particularly in Asia [BMJ (2023)]. It is estimated that the global cost of health damages associated with exposure to air pollution is USD8.1 trillion [World Bank (2022)], equivalent to 6.1 percent of global GDP [World Bank (2022)]. WHO data show that almost all of the global population (99 percent) breathe air that exceeds WHO guideline limits and contains high levels of pollutants [WHO (2025)]. China and India constitute 38 percent of this group [Rentschler and Nadezda (2023)]. The health cost is tremendous, amounting to 5.2 percent and 5.6 percent of China's and India's GDP in 2016 [Yin et al. (2021)].

It will not be possible for most countries in Asia to meet SDG3 targets on non-communicable diseases (NCD) without actions to reduce air pollution, which is severely undermining significant progress SDG 3 targets. Furthermore, the 2021 State of Global Air reports that 8.1 million deaths globally are attributed to air pollution, becoming the second leading risk factor for death, including for children under the age of five. The global burden of disease due to air pollution has overtaken tobacco [Health Effects Institute (2024)].

Policymakers have started to act. In March 2014, the State Council of China issued the Air Pollution Prevention and Control Action Plan. China began enforcing a series of groundbreaking and tough environmental measures. These included launching a nationwide monitoring and disclosure program, setting national standards for pollution levels, augmenting environmental targets in the evaluation of bureaucrats for promotion, implementing environmental policies such as cap-and-trade programs, electrification of public transit systems, and enforcing environmental regulations through strict monitoring and inspections [Greenstone and Fan (2019)]. A series of reforms were also implemented on coal-fired electricity generation, including enforcing stringent emission standards for power plants [Karplus and Wu (2023)], increasing pollution discharge fees [Gowrisankaran at el. (2020)], conducting regular inspections for compliance, switching to renewable energy (RE) or natural gas and retiring older pollution-inefficient coal-fired power plants.

In 2019, India launched the National Clean Air Program, a five-year action plan to reduce particulate pollution levels for PM2.5 and PM10 by 20 percent to 30 percent nationwide by 2024 (revised to a tougher 40 percent in 2022). Policymakers set national ambient air quality standards and strengthened the implementation and enforcement of mitigation measures for the prevention, control and abatement of air pollution.

Furthermore, the government aims to improve nationwide air quality monitoring for accurate assessments to aid in targeting and enforcement actions. Efforts are made to enhance public awareness of air pollution and encourage households to reduce pollution from domestic sources. If the clean air program can achieve its intended targets, researchers expect to extend average life expectancy by 1.3 years [Greenstone and Fan (2019)]. The Indian government also introduced the National Policy on Biofuels in 2018 and set higher blending targets of 20 percent ethanol in petrol and 5 percent biodiesel in diesel by 2030. Blending with fossil fuels can cut down on carbon monoxide and other pollutants during combustion [US EPA (2025)].

In Indonesia, environmental measures are often targeted towards metropolitan areas suffering from the worst air quality. For instance, in 2018, stricter Euro 4 emission standards were enforced in Jakarta to reduce automobile emissions. Policymakers are also phasing out older pollution-inefficient vehicles and promoting the adoption of electric and hybrid vehicles. The government is further expanding air quality monitoring efforts in Jakarta, Surabaya, and Medan to provide accurate real-time information. Tougher emission regulations, harsher penalties, and stricter monitoring are also enforced in industries in Java and Sumatra to reduce industrial emissions. Notably, the Peatland Restoration Agency was established in 2016 to restore 2.6 million hectares of dry peatland drained for plantations and cultivation. Dried peat is highly flammable and could release 10 times more carbon compared to forest fires. Restoring peatlands to a more natural state is critical in preventing wildfires and air pollution.

2.1 Air Quality Trends in China, India and Indonesia

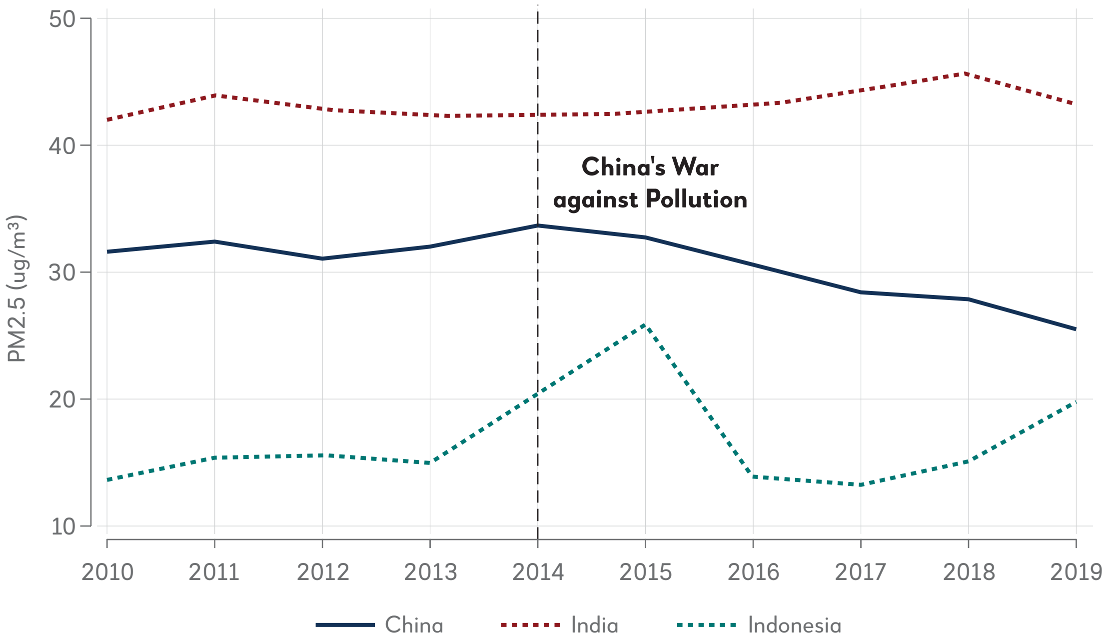
Figure 1 summarizes the annual average atmospheric concentrations of PM2.5. Substantial improvements were recorded in China, with a staggering 24.2 percent reduction between 2015 and 2019 to a nationwide average of 25.5μg/m^3 in 2019 (though this is still higher than the 15μg/m^3 level recommended by WHO). India saw less improvement. Steady increases in PM2.5 are documented from 2016 onwards, reaching a peak of 45.7μg/m^3 in 2018 (three times higher than the recommended levels by WHO). In Indonesia, nationwide average PM2.5 levels are lower compared to China and India. Yet between 2014 and 2015, PM2.5 levels experienced a sharp 32 percent increase, reaching 25.9 μg/m.[3] The deterioration of air quality is primarily due to the massive forest and peatland fires in Sumatra and Kalimantan. With the reduction in forest fires, PM2.5 levels reverted to 15.1μg/m³ in 2015 and 2016 before steadily increasing to 19.7μg/m³ in 2019.

Satellite analysis also reveals regional changes. Using granular 10 kilometer-by-10 kilometer grids across China, India and Indonesia, Figure 2 maps these changes. Overall, in China, substantial reductions in PM2.5 occurred in key regions in the east. Specifically, PM2.5 levels in Beijing fell by 36 percent to a city-wide average of 38.1μg/m³ in 2019. Similar trends are documented in Shenzhen and Guangzhou. Overall, these trends reflect the success of the Air Pollution Prevention and Control Action Plan (APPCAP) implemented in 2013. The APPCAP aims to reduce PM2.5 in the Beijing-Tianjin-Hebei region, the Yangtze River Delta and the Pearl River Delta by 25 percent, 20 percent and 15 percent, respectively.

Conversely, air quality has deteriorated in less populated areas in the west and in the northeast. Yet the increases in these cities are relatively smaller at around 14 percent. Pollution is also relatively lower compared to the past experiences of cities in the east.

Air quality has worsened in many regions of India. Deterioration in air quality is particularly concerning for major metropolises such as Delhi and Mumbai. For instance, PM2.5 levels in Mumbai experienced a 32 percent increase to a city-wide average of 40.4μg/m³ in 2019. While the relative increase is smaller at 25 percent for Delhi, PM2.5 levels spiked to unhealthy levels of 103.4μg/m³ in 2019. Similar trends are also documented for cities within the NCR surrounding Delhi.

Figure 1: Annual Average PM2.5 for China, India and Indonesia

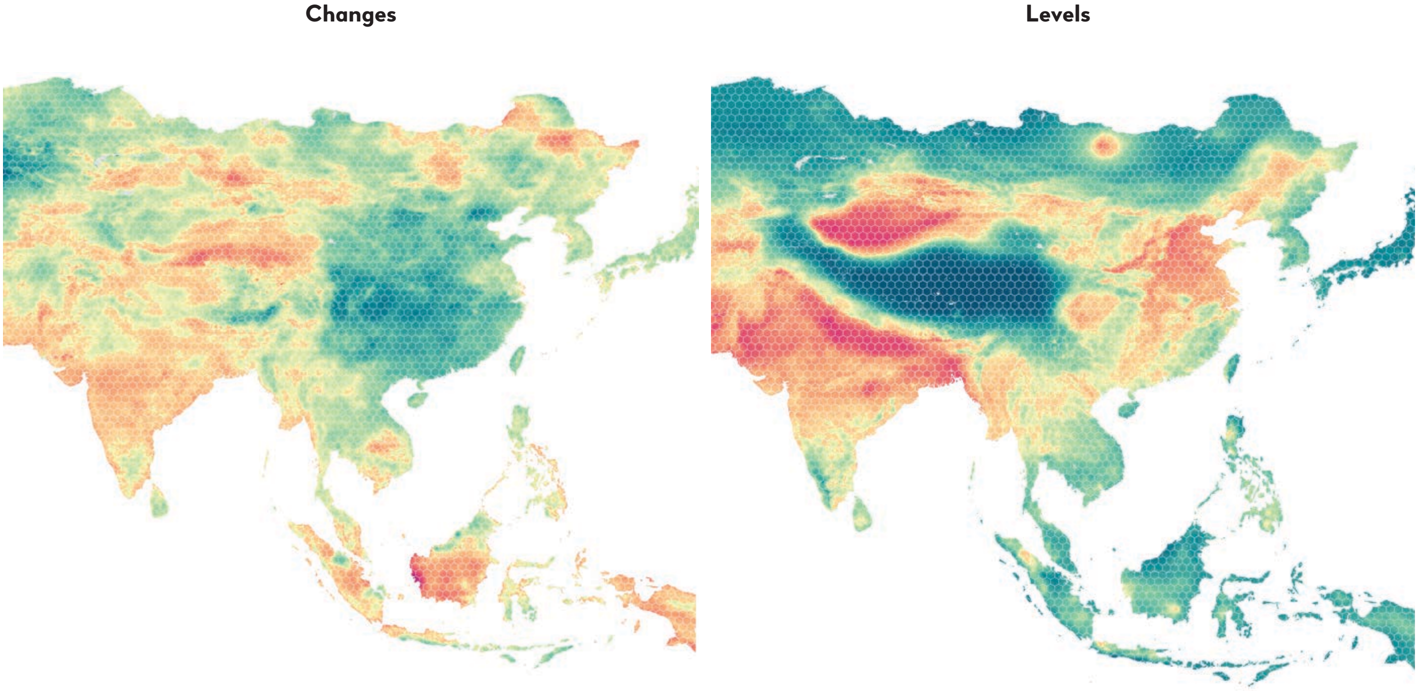


Source: Atmospheric Composition Analysis Group.

The government responded by implementing the Graded Response Action Plan (GRAP) to improve air quality around NCR. Once air quality hits unhealthy levels in Delhi, a series of immediate and restrictive measures on pollution-generating activities surrounding the NCR will be triggered to prevent air quality from further worsening.

For Indonesia, the largest increase in PM2.5 was observed around cities in the provinces of Western and Central Kalimantan. For example, PM2.5 levels in Pontianak, Ketapang and Sambas of Western Kalimantan escalated by more than 64 percent, 39 percent and 35 percent over this period, reaching a city-wide average of 28.9µg/m^3, 20.6µg/m^3 and 18.4µg/m^3, respectively. As mentioned, this surge is due to the prevalent forest and peat land fires in these areas. Unsurprisingly, the worst air quality is recorded in major urban cities, such as Jakarta and Medan, and surrounding cities, such as Deli Serdang and Depok. These trends justify the government's decision to direct environmental measures to urban areas and regions susceptible to forest and peat land fires.

Figure 2: Levels and Long-Run Changes in PM2.5 (10x10 km Grids) Asia



Changes

Levels

Source: Atmospheric Composition Analysis Group.

Notes: Levels and long run changes in Particulate Matter 2.5 (PM2.5) at 10km-by-10km grids across Asia. Long run changes are computed based on the differences in average concentrations from the first (2010,2011,2012) and last three years (2017,2018,2019) of the data collected. PM2.5 levels are based on annual averages from 2017, 2018 and 2019. Changes in PM2.5 concentrations range from red (increases) to blue (decreases), with darker shades indicating greater magnitudes of change. PM2.5 levels range from red (above mean) to blue (below mean), with darker shades representing values further from the average values of 30.55 µg/m^3.

2.2 Effects of Retirement of Coal-fired Power Plants on China's Air Quality

Coal combustion from heavy manufacturing industries and power plants is a major source of air pollution [Ma et al. (2017)]. To reduce emissions from power plants, more than 180 coal-fired power plants with a total production capacity of more than 70 million megawatts were retired across China between 2000 and 2014.

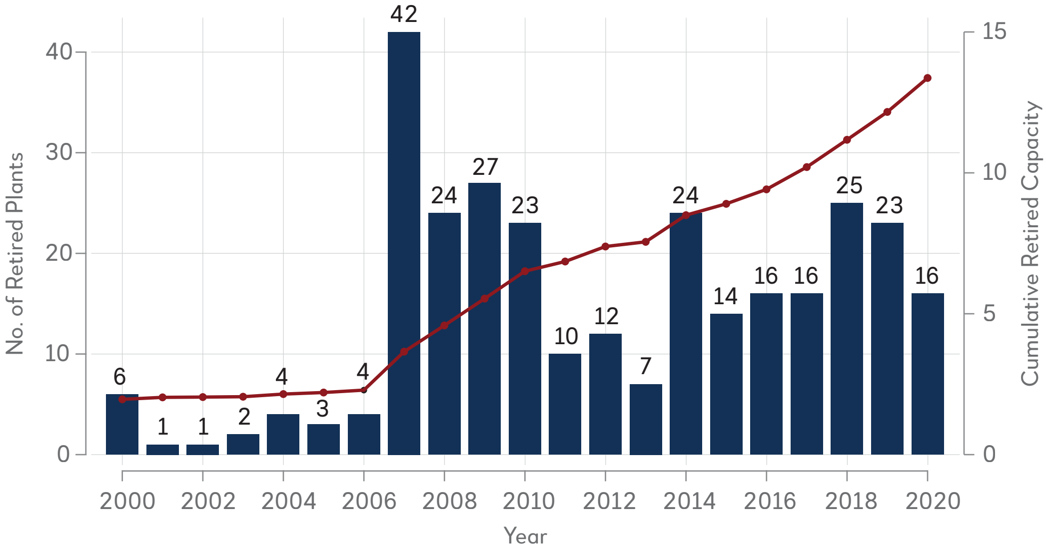
Statistics show that retired plants were two times smaller than those in operation, were much older, and were situated in densely populated areas. Intuitively, one should observe an improvement in air quality. However, if production quotas are allocated to other coal plants, the net improvements will be minor, and some population segments will continue to be exposed. Hence, it is paramount for researchers to account for this displacement effect. This section provides further explanation.

This research relies on high-resolution granular satellite data from NASA to measure sulfur dioxide (SO_2) levels, a byproduct from coal combustion, for the surrounding areas of retired and operational power plants. A difference-in-differences empirical strategy is used, comparing SO_2 levels around power plants (within 35 kilometers) before and after they are retired with comparable areas further away (between 35 and 50 kilometers). To measure displacement effects, this research identifies neighboring power plants within 100 kilometers that remain operational and repeat the same estimation. Figure 5 provides a summary of how this research is conducted. More details of data and analysis can be found in Appendix 1.

Table 1 presents the estimated closure and displacement effects. Unsurprisingly, the retirement of older and less pollution-efficient coal-fired power plants resulted in a localized 2.4 percent reduction in sulfur dioxide (SO_2) within 35 kilometers of the retired power plants compared to areas further away. The sample includes 152 coal-fired power plant closures across China between 2004 and 2014.

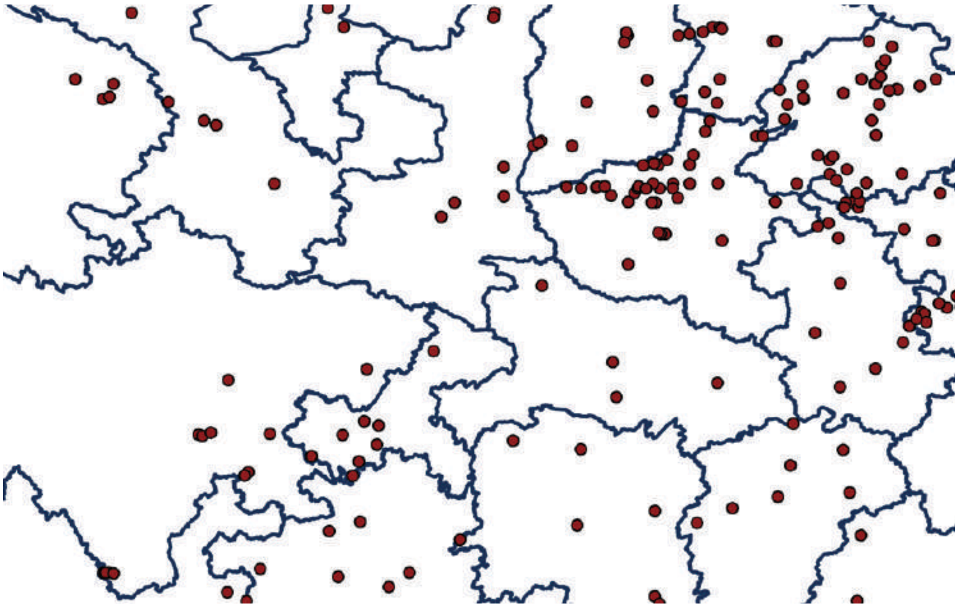
A variety of empirical specifications, including different levels of geographical fixed effects, such as city, county, plant and grid-level fixed effects, are estimated. Province-by-year fixed effects are also included. The improvement in air quality remains robust and ranges between 1.6 percent and 2.4 percent.

Figure 3: Coal-fired Power Plant Closures (2000 to 2020) Across China



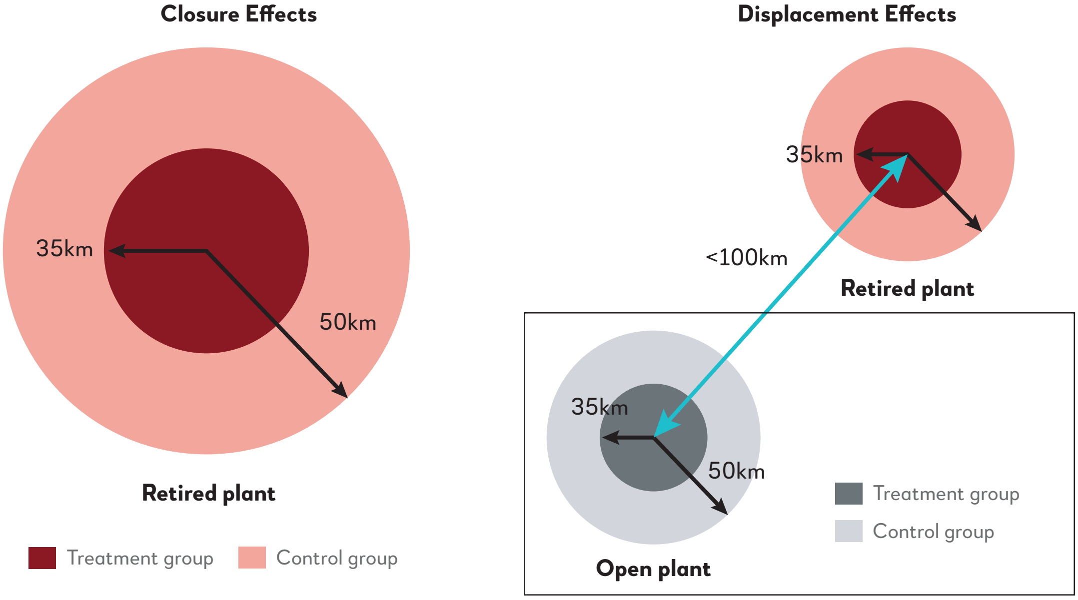
Source: AIIB staff estimates.

Figure 4: Spatial Distribution of Coal-fired Power Plants in China Retired Over Time



Source: Global Energy Monitor.

Figure 5: Treatment and Control for Estimating Closure (Red) and Displacement (Grey) of Coal-fired Power Plants in China



Source: Fan et al. (2023)

Table 1: Closure and Displacement Effects of Coal-fired Power Plants in China

	(1)	(2)	(3)	(4)	(5)
			Panel A: Closure Effect		
Close * Post	-0.019**	-0.019**	-0.016**	-0.024***	-0.024***
	(0.008)	(0.009)	(0.008)	(0.008)	(0.007)
Observations	189915	189915	189915	189915	189915
R2	0.44	0.46	0.45	0.47	0.49
Mean Dep Variable	0.47	0.47	0.47	0.47	0.47
			Panel B: Displacement Effect		
Displacement * Post	0.025***	0.038***	0.041***	0.020***	0.017***
	(0.008)	(0.007)	(0.008)	(0.007)	(0.005)
Observations	493777	493777	493777	493777	493777
R2	0.39	0.42	0.41	0.43	0.45
Mean Dep Variable	0.41	0.41	0.41	0.41	0.41
Year month FE	Y	Y	Y	Y	Y
City FE	Y				
County FE		Y			
Plant FE			Y		
Grid FE				Y	Y
Province * Year FE					Y

Notes: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$. Robust standard errors clustered at the plant level in parentheses. The dependent variable is the natural logarithm of monthly SO_2 at the grid level from 2004 to 2014. Panels A and B summarize the estimated closure and displacement effects on SO_2 levels. Close [*] Post is a dummy variable denoting grids within 0-30 kilometers from a retired power plant after the plant is retired. Near [*] Post is a dummy variable denoting grids within 0-30 kilometers from an operating power plant after the nearby power plant within 100 kilometers is retired. All regressions are restricted to areas within 50 kilometers of retired or operating plants.

If production is shifted to other pollutive plants, one would expect to document a spike in SO_2 levels around neighboring operating coal-fired power plants. Panel B of Table 1 confirms there was indeed displacement, with a 1.7 percent increase in SO_2 from operating power plants within 100 kilometers. This showed that nearby operating power plants had intensified their electricity generation to meet electricity shortfalls due to plant shutdowns.

It is vital to examine whether there can be measures to reduce such displacement. Conceptually, displacement could stem from various reasons. One is the lack of cleaner alternate energy sources, such as natural gas, nuclear and/or renewable energy. Another is the possible distortions in electricity dispatch between provinces, preventing the allocation of energy production to the "best" locations with the lowest pollution "damage" to citizens. If provincial leaders had incentives to import electricity from other provinces, this would reduce the need for reallocating quotas within their own provinces. These hypotheses motivated further research, with findings presented in Table 2.

As shown in column 1, there is a significant displacement effect of 1.9 percent surrounding the operating coal-fired power plant. However, these effects are 0.3 percent lower with every additional renewable energy power plant within 100 kilometers. This attenuation is especially evident for cleaner energy sourced from wind, solar and gas, although the estimate for hydro source is statistically insignificant, as shown in columns 2 to 5. Collectively, these results suggest that the availability of cleaner energy sources is needed to minimize displacement and realize air quality improvement from coal plant retirement.

Table 2: Determinants of Pollution Displacement Effects from Plant Closures

	1	2	3	4	5	6	7
	Clean Energy	**Wind**	**Hydro**	**Solar**	**Gas**	**Imports**	**Post 2015**
Near × Post	0.019***	0.018***	0.010	0.016**	0.017***	0.022***	0.013**
Near × Post × RE	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.005)
Near × Post × Wind	-0.003*** (0.001)						
		-0.010***					
Near × Post × Hydro		(0.003)					
			0.001				
Near × Post × Solar			(0.014)				
				-0.005**			
Near × Post × Gas				(0.002)			
					-0.009***		
Near × Post × Import					(0.002)		
						-0.031**	
Near × Post × Post2015						(0.013)	
							-0.024**
							(0.010)
Observations	454452	454452	454452	454452	454452	454452	849818
R2	0.45	0.45	0.45	0.45	0.45	0.45	0.39
Mean Dep Variable	0.41	0.41	0.41	0.41	0.41	0.41	0.35

Notes: *p < 0.10; **p < 0.05; ***p < 0.01. The dependent variable is the natural log of monthly SO_2 from 2004 to 2014. Regression samples for all specifications include observations within 50 kilometers of operating plants. In Columns 1 to 5, RE/Wind/Hydro/Solar/Gas indicates the total count of renewable energy/wind/hydro/solar/gas power plants exceeding the respective average capacity within a 100 kilometers radius of retired coal-fired power plants. In Column 6, Imports is a binary variable equal to 1 for plants located in provinces with imported electricity from other provinces that exceed the national average. In Column 7, Post2015 is a binary variable that takes the value 1 if the observations fall after January 2015. The sample spans from 2004 to 2020. All regressions include a full set of control variables, grid, year-month and province-by-year fixed effects. Standard errors clustered at the plant level are in parentheses.

Operating power plants in areas more likely to import electricity elsewhere have smaller displacement effects. In regions with limited electricity imports (below the national average), a clear displacement effect is evident at 2.2 percent and increasing electricity imports, in fact, more than mitigates the displacement effect. This result suggests that the closures of nearby power plants combined with electricity imports from other provinces improved air quality. Quite simply, the ability to transmit and trade electricity from other provinces was critical to overall air quality improvement.

Realizing the inefficiency in the power generation industry, the State Council of China implemented major reforms in 2015. These reforms included the removal of inter-provincial electricity trade barriers, promoting industrial investment and consumption of renewable energy, and transmitting surplus renewable energy power to eastern regions [see Ming et al. (2016); Ni et al. (2018); Guo et al. (2020)]. This effect is captured by the variable Near × Post × Post2015. After the reforms, there was a statistically significant 2.4 percent decrease in SO_2 displacement effects surrounding operating coal-fired power plants. In other words, the reforms post-2015 saw displacement effects eliminated, making coal plant shutdowns even more effective in reducing air pollution.

2.3 Effects of the Response Action Plan on Air Quality in India

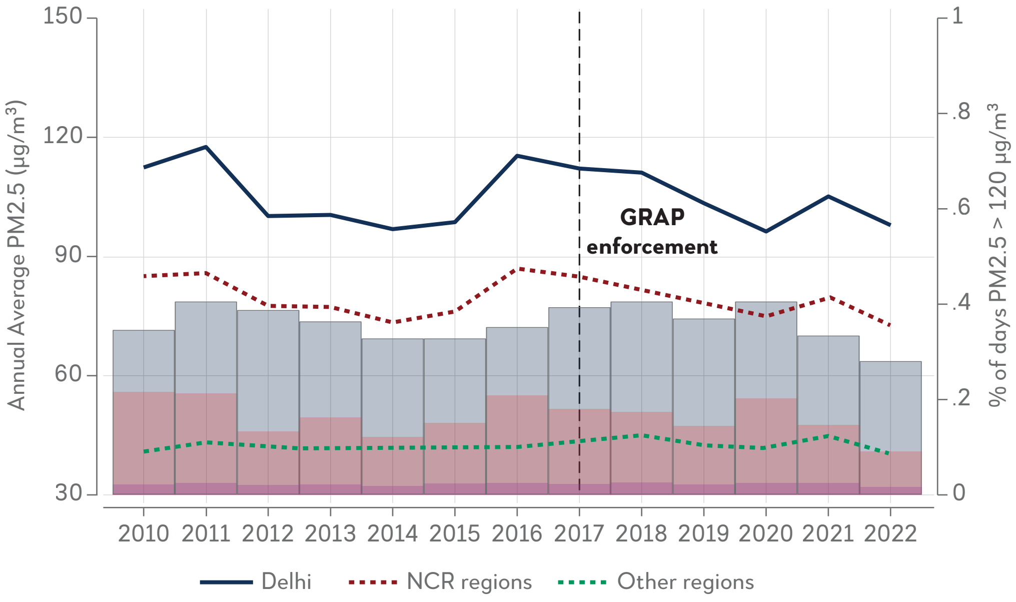
The Graded Response Action Plan (GRAP) was first implemented in January 2017 by the Ministry of Environment, Forest and Climate Change to combat the severe episodes of air pollution in Delhi and the National Capital Region (NCR). Specifically, this is a set of emergency responses enforced when air quality in Delhi hits unhealthy levels, only to be lifted when air quality improves. There are 24 districts within Delhi and NCR, covering 55,083 square kilometers with more than 46 million residents.

Figure 6 shows the high pollution in Delhi and the NCR compared to the rest of India. Between 2010 and 2022, PM2.5 levels in Delhi and the NCR were around 3 and 2 times higher than in the rest of India. The percentage of months with unhealthy air quality (PM2.5 above 120 μg/m^3) was 30 times higher in Delhi and 20 times higher in the NCR compared to other parts of India. Figure 7 also plots the distributions of daily average PM2.5 levels before and after the enforcement of GRAP in Delhi and NCR. The percentage of days with poor air quality above 120μg/m^3 drops after the enforcement.

However, over the long run, there is spatial variation in the efficacy of GRAP, as seen in Figure 8. These measures appear more effective in districts north and east of Delhi as PM2.5 levels in Panipat, Sonepat and Meerut are 7.5 percent, 6.8 percent and 6.1 percent lower, respectively. Conversely, they are less effective for districts south and west of Delhi as PM2.5 levels are 6.8 percent, 5.3 percent and 3.6 percent higher in Bharatpur, Alwar and Bhiwani, respectively. What could explain the variation in policy effectiveness? It is apparent the effectiveness weakens outside Delhi, suggesting that it could be challenging for policymakers to monitor and enforce measures in districts further away to ensure compliance.

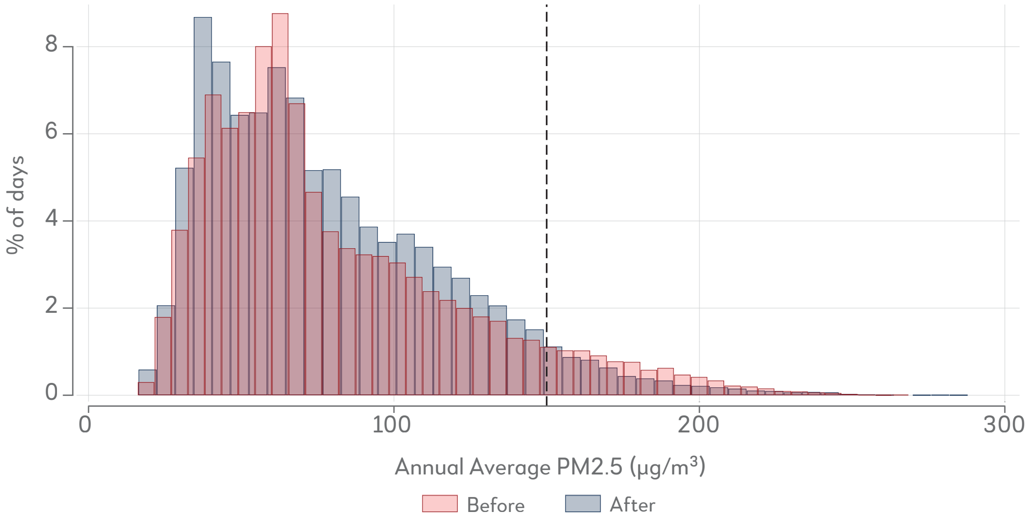
To measure GRAP's causal effects on air quality and health, this research adopts a difference-in-differences empirical approach and compares outcomes associated with Delhi and the NCR with comparable regions unaffected by GRAP before and after the policy's implementation. The data's panel structure is leveraged to compare changes in PM2.5 within grids over time to control for time-invariant unobserved factors across small areas. A rich set of climatic controls, such as precipitation, temperature and wind speed, is further controlled. See Appendix 1 for further details.

Figure 6: Annual Average PM2.5 Levels and Percentage of Months with PM2.5>= 120 μg/m^3



Source: Atmospheric Composition Analysis Group and AIIB staff estimates.

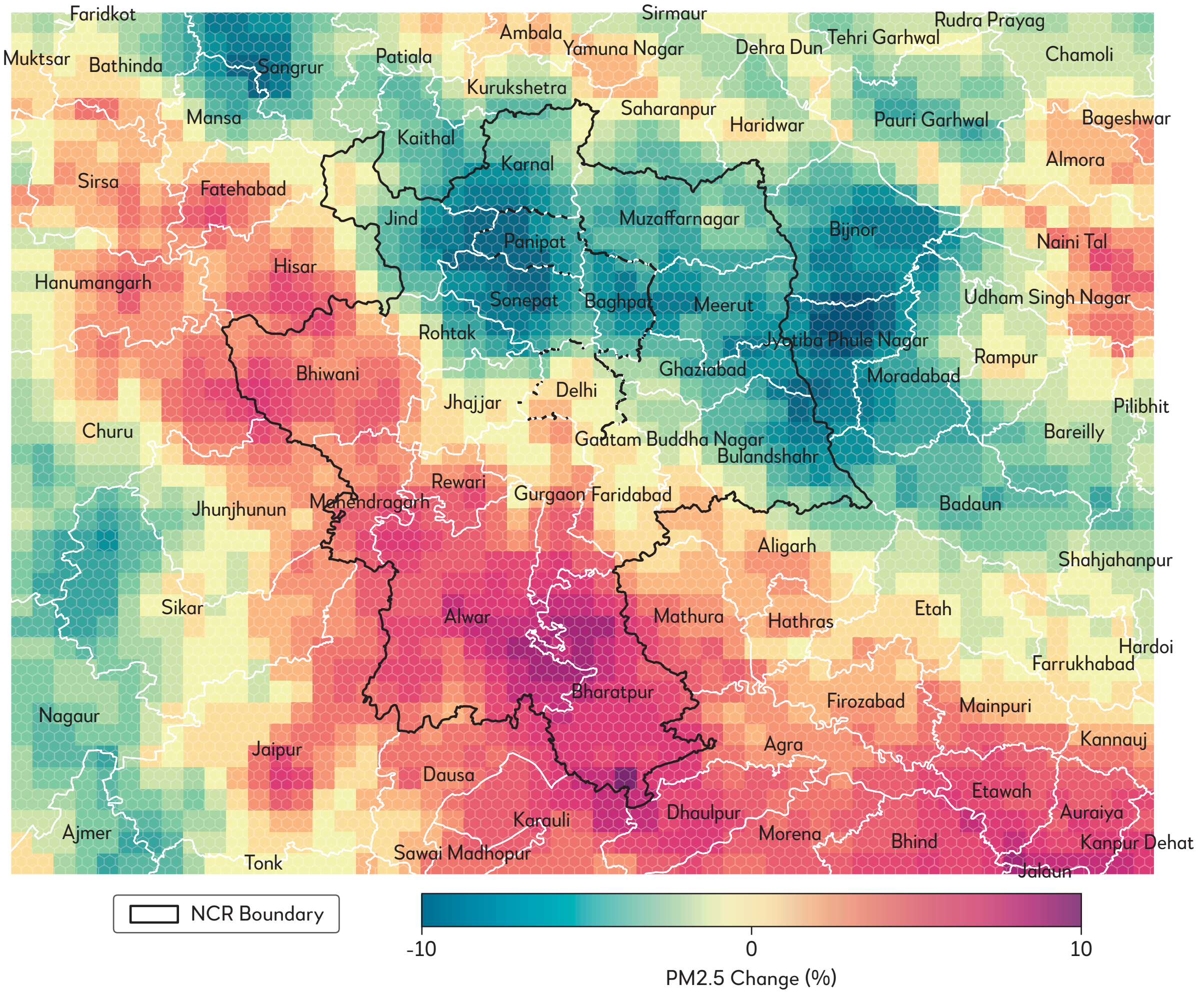
Figure 7: Before and After Air Quality Post GRAP Implementation



Source: Atmospheric Composition Analysis Group and AIIB staff estimates.

Notes: Graded Response Action Plan (GRAP) implementation in the NCR and Delhi, India

Figure 8: Long-Run Changes in PM2.5 Level After GRAP Enforcement Around Delhi and NCR



Source: Atmospheric Composition Analysis Group.

Notes: Long-run changes are computed by taking the difference of PM2.5 levels before (2010-2016) and after (2017-2021) the implementation of Graded Response Action Plan (GRAP).

Table 3 presents the effects of GRAP on air quality in Delhi and the NCR by comparing changes in PM2.5 levels surrounding Delhi and the NCR before and after the enforcement of GRAP in January 2017, with changes in PM2.5 levels surrounding other parts of India unaffected. Delhi and the NCR show a 4.2 percent and 5.1 percent reduction, respectively. This represents an absolute reduction of 4.42μg/m^3 in Delhi and 4.02μg/m^3 in the NCR. Absolute effects are slightly larger in Delhi because the average PM2.5 levels are higher in Delhi compared to the NCR.

The analysis further limits samples to a three-year window before and after the implementation of GRAP (observations between 2015 and 2020Q1). Limiting to a short window around the policy mitigates the risk that estimates could be measuring changes in air quality due to other policies or events. Reducing the sample to before 2020Q1 avoids the confounding effects of COVID-19 lockdowns. Consistent with earlier findings, GRAP is associated with a 3.9 percent and 5.0 percent fall in PM2.5 in the NCR and Delhi, respectively.

Delhi and the NCR are highly urbanized regions. Hence, the analysis further limits the control group to Tier 1 and 2 cities to be comparable (reducing samples by almost 50 percent). The results continue to show sizable decreases in PM2.5 in Delhi and the NCR. Limiting the analysis to Tier 1 cities, which include only Bangalore, Chennai, Hyderabad, Mumbai, Pune, Kolkata and Ahmadabad, the effects are larger at around 10 percent reduction for Delhi and the NCR. The overall results thus show the decrease in air pollution post GRAP.

The analysis also focuses on the health outcomes of infants. First, infants are most susceptible to the nefarious effects of air pollution because their immune systems and lungs are not fully developed during exposure [Schwartz (2004)]. Second, there is a notable advantage of examining their health outcomes over adults to avoid the possibility of historical pollution exposure from contaminating our results [Currie et al. (2009)]. This allows one to draw an immediate link between the short-run air quality improvements associated with GRAP and health outcomes.

Table 3: Effects of GRAP on Air Quality

	(1)	(2)	(3)	(4)
NCR * Post	-0.051***	-0.050***	-0.061***	-0.105***
	(0.002)	(0.002)	(0.002)	(0.004)
Delhi * Post	-0.042***	-0.039***	-0.047***	-0.098***
	(0.004)	(0.002)	(0.003)	(0.005)
Observations	4345983	1755114	97713	49644
R2	0.84	0.85	0.88	0.91
PM2.5 (NCR)	79.64	80.86	80.86	80.86
PM2.5 (Delhi)	105.93	107.00	107.00	107.00
Control Group	All cities	All cities	Tier 1 & 2	Tier 1
Time Frame	2010-2022	2015-2020Q1	2015-2020Q1	2015-2020Q1

Notes: *p < 0.10; **p < 0.05; ***p < 0.01. Robust standard errors clustered at the grid level are reported in parentheses. The dependent variable is the natural logarithm of monthly PM2.5 levels. The variable NCR is a binary indicator that equals one if the grid is located within the NCR, excluding Delhi, and zero otherwise. Similarly, Delhi is a binary indicator that equals one if the grid is located within Delhi. Post takes the value of one for observations after 2017. Reported estimates measure the policy effects of GRAP on PM2.5 levels in Delhi (Delhi * Post) and the NCR (NCR * Post), respectively. Columns 1 and 2 include all districts in India as the control group. Column 3 constrains the control group to include only Tier 1 and 2 cities and Column 4 further limits the control group to only Tier 1 cities. All estimations include grid and year-month fixed effects and control variables, including maximum temperature, minimum temperature, precipitation and evaporation, and their respective squared and cubic terms.

Table 4 presents the effects of GRAP on a rich set of infant health outcomes from a difference-in-differences empirical framework. Estimates in columns 1 to 4 of Panel A suggest that the introduction of GRAP is associated with a 3.1 percent to 3.5 percent reduction in the probability of conceiving a baby with a low birth weight of less than 2.5 kilograms in Delhi. These effects are less precisely estimated and smaller for the NCR. Given that there were 300,350 newborn babies in Delhi in 2022 and approximately 22 percent of the babies are below 2.5 kilograms (or 66,077 babies), estimates suggest that GRAP could have prevented around 2,300 babies from low birth weight.

Consistent results are reported when analysis focuses on newborn birth weight. From columns 4 to 8 of Panel A, results show a 1.4 percent to 1.7 percent increase in average birth weight for babies born in Delhi after GRAP is enforced. This corresponds to a 39- to 47-gram increase in absolute terms. Further analysis of the effects of GRAP on infant mortality rates in Panel B shows that mortality is reduced.

Estimates in columns 1 to 4 of Panel B suggest that six-month infant mortality rates are 1.5 percent to 2.2 percent lower, while estimates from columns 5 to 8 suggest that 12-month infant mortality rates are 0.7 to 1.6 percent lower after GRAP is introduced. Similar but less precise effects are reported for the NCR. Estimates indicate that GRAP has prevented 6,600 infants from premature death in Delhi in 2022.

2.4 Chapter Concluding Remarks

Improving air quality and minimizing exposure are crucial, given the links between poor air quality and a wide range of respiratory, cardiovascular and neurological diseases. Poor air quality is one of the leading causes of premature deaths. Air pollution has distinct gender-specific health implications that can exacerbate existing inequalities. Women, particularly those in low-income communities, often face greater exposure to indoor air pollutants from cooking and heating methods that rely on fossil fuels. This exposure can lead to respiratory diseases, maternal health issues, and adverse pregnancy outcomes. Furthermore, women's health is intricately linked to their roles as caregivers; poor air quality can affect not only their health but also their ability as caregivers. Addressing air pollution through a gender-sensitive lens is essential for promoting equitable health outcomes and improving overall community well-being.

The most pronounced improvements in air quality are recorded in China, and the remarkable success could stem from a comprehensive set of well-coordinated command and control environmental regulations that are effectively executed. The analysis shows the importance of reducing reliance on coal for electricity generation to improve air quality in China and highlights the importance of utilizing supportive measures (green investments and expansion of cross-province electricity trading). Though air pollution remains a serious issue in India, using control measures has improved health outcomes in Delhi and the NCR. For Indonesia, the analysis shows the importance of re-naturalizing peatlands and mitigating the impact of commercial agriculture to reduce air pollution caused by burning. All these hold important policy lessons for other developing economies.

For example, several regions across Asia experience severe air pollution and present vast opportunities for improvement through targeted infrastructure investments and policy interventions. Central Asia, Pakistan, Bangladesh, Viet Nam, and the Philippines are among the regions with significant air quality challenges [Health Effects Institute (2025)]. Major cities, including Karachi, Dhaka, Hanoi, and Manila, suffer from high levels of PM2.5 and other pollutants, often exceeding WHO guidelines by substantial margins. The State of Global Air Quality Funding 2024 report highlights the role of infrastructure investments in improving air quality given the significant allocation of global air quality funding to infrastructure-related projects. Transport alone accounts for 61 percent of such funding, signaling the critical need for investments in sustainable mobility systems, including public transit, electric vehicle infrastructure, and non-motorized transport networks. Similarly, waste management (5 percent), residential buildings (2 percent), and energy (2 percent) also present opportunities for targeted investments that address pollution at its source [CAF and CPI (2024)].

Table 4: Effects of GRAP on Infant Health Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: Birth Weight							
	Low Birth Weight Dummy				Log (Birth Weight)			
NCR * Post	-0.011	-0.019	-0.015	0.002	-0.003	0.000	-0.003	-0.009
	(0.032)	(0.032)	(0.030)	(0.032)	(0.013)	(0.014)	(0.013)	(0.014)
Delhi * Post	-0.031***	-0.035***	-0.034***	-0.035***	0.014***	0.017***	0.016***	0.007*
	(0.006)	(0.005)	(0.005)	(0.007)	(0.003)	(0.003)	(0.003)	(0.004)
Observations	26516	26516	26516	26515	26516	26516	26516	26515
R2	0.01	0.02	0.02	0.05	0.03	0.03	0.05	0.08
Low birth weight/ Birth weight (NCR)	0.20	0.20	0.20	0.20	2784.95	2784.95	2784.95	2784.95
Low birth weight/ Birth weight (Delhi)	0.22	0.22	0.22	0.22	2782.14	2782.14	2782.14	2782.14

	Panel B: Infant Mortality							
	Mortality Before 6 Months				Mortality Before 1 Year			
NCR * Post	-0.021	-0.026**	-0.026**	-0.028*	-0.019	-0.024*	-0.024*	-0.027
	(0.014)	(0.012)	(0.012)	(0.016)	(0.015)	(0.013)	(0.013)	(0.017)
Delhi * Post	-0.017***	-0.021***	-0.022***	-0.015***	-0.011***	-0.016***	-0.016***	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Observations	27581	27581	27581	27580	27581	27581	27581	27580
R2	0.06	0.07	0.08	0.10	0.06	0.07	0.07	0.10
Death before 6 months/ 1 year (NCR)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Death before 6 months/ 1 year (Delhi)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Year month FE		Y	Y	Y		Y	Y	Y
State FE			Y				Y	
District FE				Y				Y

Notes: *p < 0.10; **p < 0.05; ***p < 0.01. Robust standard errors clustered at the state level are reported in parentheses. The dependent variables are as follows for the respective panels–Panel A: a binary indicator for low birth weight (birth weight<2.5kg) and the natural logarithm of absolute birth weight (in grams); Panel B: a binary indicator of death before 6 months, and a binary indicator of death before 1 year of age for infants born from 2015 onwards. The NCR is a binary indicator that equals one if the mother's residence is in the NCR, excluding Delhi, and zero otherwise. Similarly, Delhi is a binary indicator that equals one if the mothers reside in Delhi and zero otherwise. Post is a binary indicator that equals one for births occurring after 2018. Reported estimates measure the policy effects of GRAP on the respective infant health outcomes in Delhi (Delhi * Post) and the NCR (NCR * Post), respectively. All analyses constrain the analysis to births between 2015 and the first quarter of 2020, and include the following list of control variables: mother's age, education, wealth, smoking behavior, occupation, work status, health insurance, religion, place of delivery, prenatal services, doctor assistance, number of antenatal visits during pregnancy, months of breastfeeding and time spent at the place of delivery.

Moreover, globally we have seen policy initiatives that are shaping air quality management [UNEP (2021)]. However, the absence of standardized metrics for tracking and accounting for investments in air quality, climate, and health initiatives represents a significant challenge to effective policy and resource allocation. Without such metrics, it is difficult to identify gaps, prioritize areas of greatest need, or assess the impact of financial flows on improving air quality and associated health outcomes. Efforts by MDBs to standardize tracking climate, nature and broader development outcomes are advancing with the release of MDB common principles for tracking nature-positive finance and climate results metrics at CO28 and COP29 respectively [MDBs (2023); MDBs (2024)]. The Asian Development Bank (ADB) improved tracking of nature-positive investments through its Environmental Action Plan, which also provides a strong foundation for collaborative progress in this regard [ADB (2024)].

CHAPTER 3

IN DEEP WATER

CLIMATE CHANGE IMPACTS ON WATER SYSTEMS AND HUMAN HEALTH

Highlights

- Climate change is increasing the prevalence of an array of water- and vector-borne diseases in developing economies, while also impacting food security.
- Water- and vector-borne diseases disproportionately affect women due to the environment in which they work and the lack of equitable access to clean water, sanitation infrastructure and medical facilities.
- Infrastructure investment, both within and outside the health sector, can help mitigate the impact on health outcomes.

3.1 The Effect of Flooding and Rainfall on Water- and Vector-borne Diseases

Excessive rainfall and floods, an outcome of climate change, jeopardize water availability, quantity and quality, with deleterious impacts on health. Such extreme weather events impact health both in the short and long term. The immediate impact is physical, e.g., drowning, hypothermia and other injuries [Torti (2012)]. Beyond this, excessive rainfall and flooding result in outbreaks of waterborne diseases due to overflow of sewage and damage to water and sanitation facilities and consequent consumption of contaminated water [Levy et al. (2018)]. These include diarrhea, cholera, typhoid and leptospirosis.

Once floodwaters have receded, the leftover standing water becomes a breeding ground for mosquitos, resulting in diseases like dengue and malaria. A damp indoor environment can also contribute to respiratory problems. Anxiety, depression, post-traumatic stress disorder (PTSD) and insomnia are some of the common mental health problems emerging after disasters.

Climate change also facilitates the spread of water- and vector-borne diseases (WVBD) by increasing the geographic range and abundance of disease vectors. High temperatures tend to raise the survival, replication and virulence of the pathogen, which contributes to the proliferation of WVBD [Dhimal et al. (2021)]. Rising global temperatures affect both surface and groundwater quality by increasing the concentration of contaminants in water sources due to increased evaporation.

The burden of WVBD tends to be higher in economies that are not only more vulnerable to climate change but also have a lower readiness (Figure 9).[1] These economies tend to be either more exposed to climate change or possess large sections of the population that are susceptible to climate change hazards.

Many of these economies also lack the business environment, institutional factors, infrastructure and ability to undertake innovation to promote adaptation. The incidence of WVBD is highest in the world's poorest regions, with low-income and lower-middle-income economies exhibiting 52- and 27-times higher incidences compared to advanced economies. Economies in Sub-Saharan Africa have the highest incidence of WVBD, followed by South Asia.

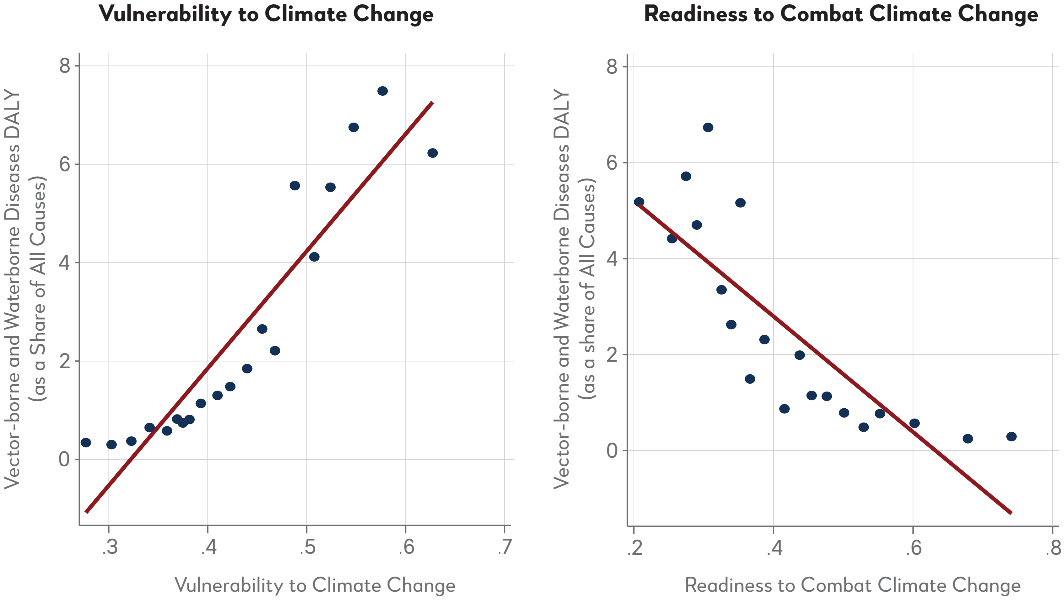
Floods are the most frequent natural disasters globally, accounting for approximately 40 percent of all natural disasters [Coker et al. (2011)]. Climate change has intensified weather patterns, leading to rising sea levels and increased rainfall, which has, in turn, heightened the frequency and severity of floods, putting more people at risk from WVBD.

In Indonesia, for example, the number of flood-related disasters has increased from 492 events in 2008 to 1299 in 2023, with the number of regencies affected by floods rising from 248 in 2008 to 405 in 2022 (Figure 10). A World Bank study reported that between 2015 and 2055, the at-risk population for fluvial flooding is projected to increase from 19.2 million to 33.5 million in Indonesia [World Bank (2019)]. Similarly, in Sri Lanka, floods have affected over 15,000 people across ten districts, resulting in displacement, casualties or injuries [Azeem et al. (2023)].

The rising incidence of floods has significant implications for public health. The danger is particularly acute in flash floods, where water levels rise rapidly, catching people off guard. Following a flood, the displacement of communities, destruction of infrastructure and contamination of water sources contribute to the spread of diseases and exacerbate existing health problems.

In Indonesia, elevated health risks were found after a flood event (Figure 11). The probability of general healthcare visits does not change significantly

Figure 9: Vector-borne and Waterborne Disease Disability-adjusted Life Years (DALY) and Climate Change (Bin Scatter)



Source: AIIB staff estimates based on WHO and University of Notre Dame Data.

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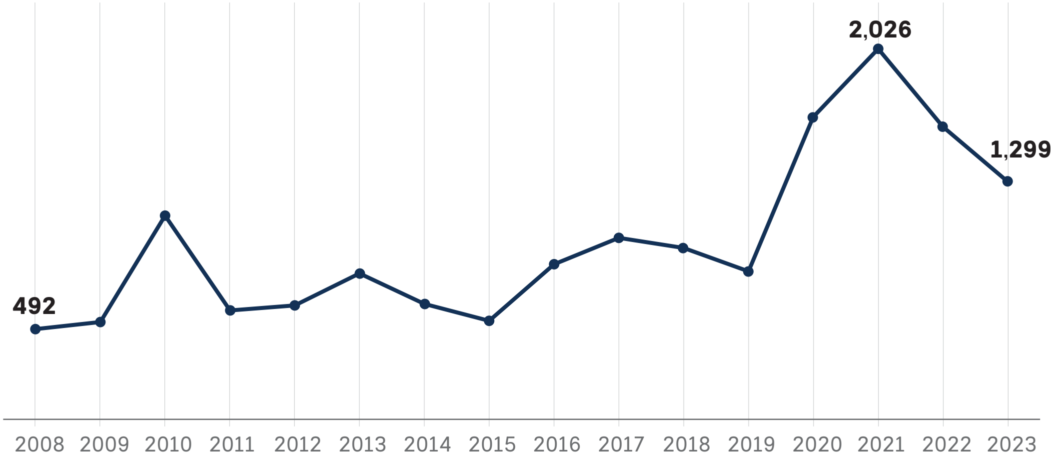
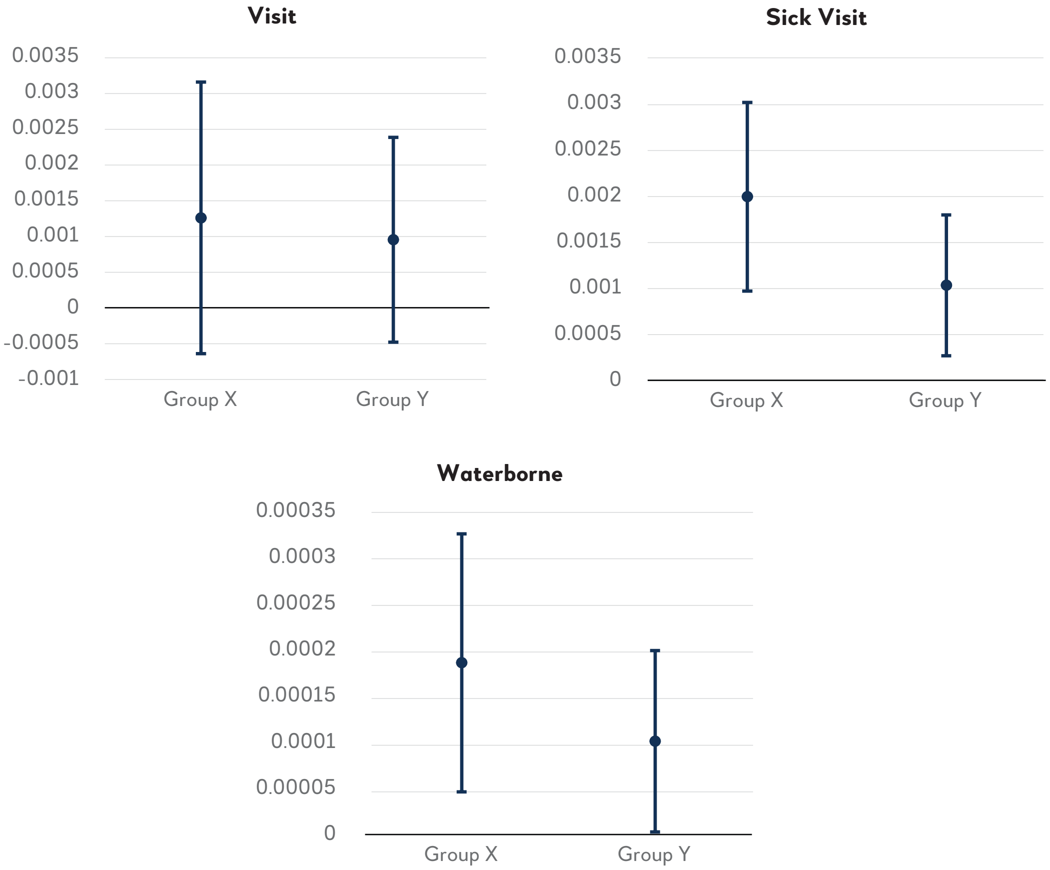
[1] Based on the University of Notre Dame's GAIN Index. Vulnerability measures a country's exposure, sensitivity and capacity to adapt to the adverse effects of climate change. Readiness measures the country's ability to leverage investments and convert them into adaptation actions.

Figure 10: Number of Flood Events in Indonesia



Source: Indonesia National Agency for Disaster Relief (https://gis.bnpb.go.id) and AIIB staff estimates.

Figure 11: Impact of Floods to Probability of Visits, Sick Visits and Waterborne Diseases



Source: AIIB staff estimates.

Notes: Regression analysis was conducted using the Difference-in-Differences methodology by comparing individuals in flood-prone regencies and no-flood regencies. Two groups of flood-prone regencies were tested: Group X, consisting of regencies that experienced more than 11 floods during the observation period, and Group Y, which includes regencies that experienced at least one flood every year in the same period. A more detailed explanation can be found in Appendix 2. A sick visit is a visit to healthcare providers for illness treatment, excluding medical check-ups, pregnancy-related visits and vaccinations. Error bars show a 90 percent confidence interval.

post-flood, but the probability of sick visits rises significantly by 0.1 to 0.2 percent, depending on the treatment group. Furthermore, the probability of contracting waterborne diseases post-floods also increases by 0.01 to 0.02 percent. Thus, in a regency with 100,000 people, there would be 10 to 20 extra cases of waterborne diseases following a flood.

On average, the direct cost of waterborne disease per case in Indonesia is estimated at USD100. Thus, the additional direct costs of waterborne disease in a city with a population of 1 million could be estimated at around USD20,000 per flood event. In 2022, 1,599 flood events impacted 405 regencies, home to 225 million people. This is estimated to have resulted in 289,093 additional cases of waterborne disease, leading to an estimated direct cost of USD28.7 million. This is a conservative estimate, excluding the indirect costs of loss of productivity, mortality and other longer-term effects.

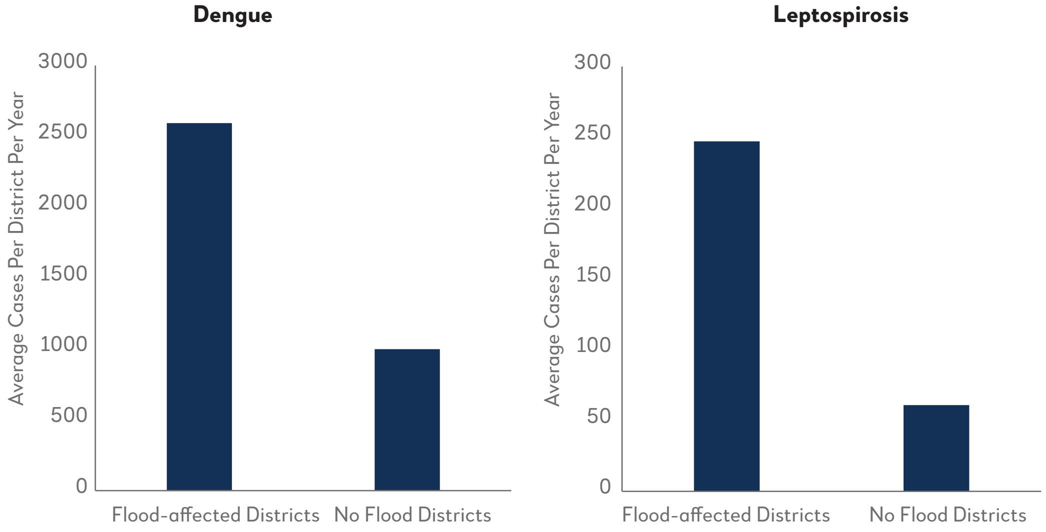
In Sri Lanka, comparing the average number of cases of dengue across flood-affected and non-flood districts shows that the incidence of dengue is 2.5 times higher in the former compared to the latter (Figure 12). The difference is even more stark in the case of leptospirosis. Flood-affected districts report more than four times the number of cases of leptospirosis compared to non-flood districts.

Floodwaters enable the spread of dengue through various ways, like (a) creating stagnant water pools, which are ideal breeding grounds for dengue-transmitting mosquitos, (b) disrupting the sanitation system, which facilitates mosquito breeding, and (c) overcrowding in flood shelters. Similarly, floodwaters spread the Leptospira bacteria by increasing human exposure to contaminated water, particularly in rural and urban poor communities and disrupting sanitation systems. High-intensity rainfall also aids the spread of dengue and leptospirosis through similar channels.

The extent of rainfall is strongly associated with the prevalence of dengue and leptospirosis in Sri Lanka. For example, over the period 2018-2022, granular data at the district level indicates that a 1-centimeter increase in rainfall is associated with an additional three dengue cases (Figure 13). While leptospirosis is less frequently reported, its occurrence is strongly associated with rainfall. Based on quarterly data for 2017, a 1-centimeter increase in rainfall is associated with 0.04 additional cases.

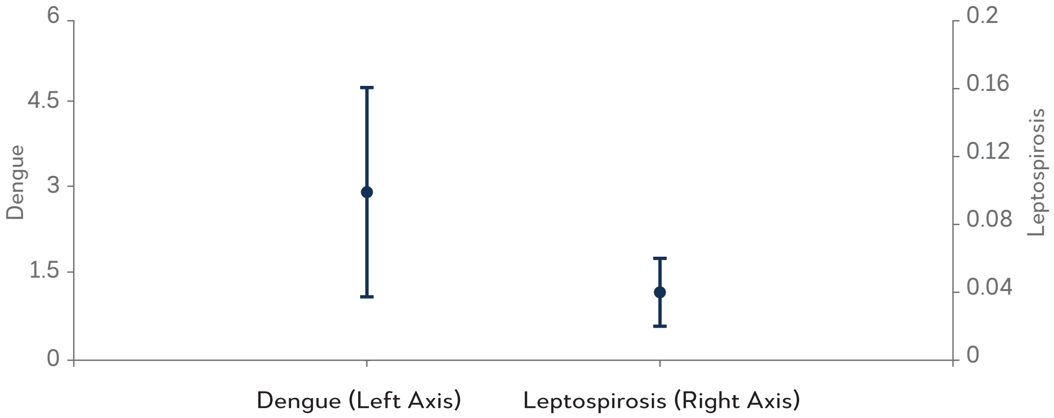
In India, WVBD remain one of the leading causes of morbidity and mortality. Although India has successfully reduced the DALYs caused by WVBD over the last two decades, they accounted for more than 25.2 million DALYs in 2021, about 17.6 percent of the global share. Young children (below five) tend to be particularly prone to diarrhea and malaria,

Figure 12: Incidence of Dengue and Leptospirosis in Sri Lanka



Source: AIIB staff estimates.

Figure 13: Rainfall and Incidence of Dengue and Leptospirosis in Sri Lanka



Source: AIIB staff estimates.

Notes: The regression analysis is conducted using a Fixed Effects methodology. The unit of observation is at the district level, and the regression specification focuses on district-level variation in rainfall, population, and facility changes.

accounting for 8 percent and 5 percent of deaths [UN IGME (2019)]. Climate change, by reducing the quality of surface and groundwater and increasing the exposure to disaster events, is likely to influence the incidence of these diseases in children.

Using data sourced from demography and health survey (2019–2021), logistic regression analysis shows that female children have about 7 percent lower odds of developing malaria compared to males (Figure 14).

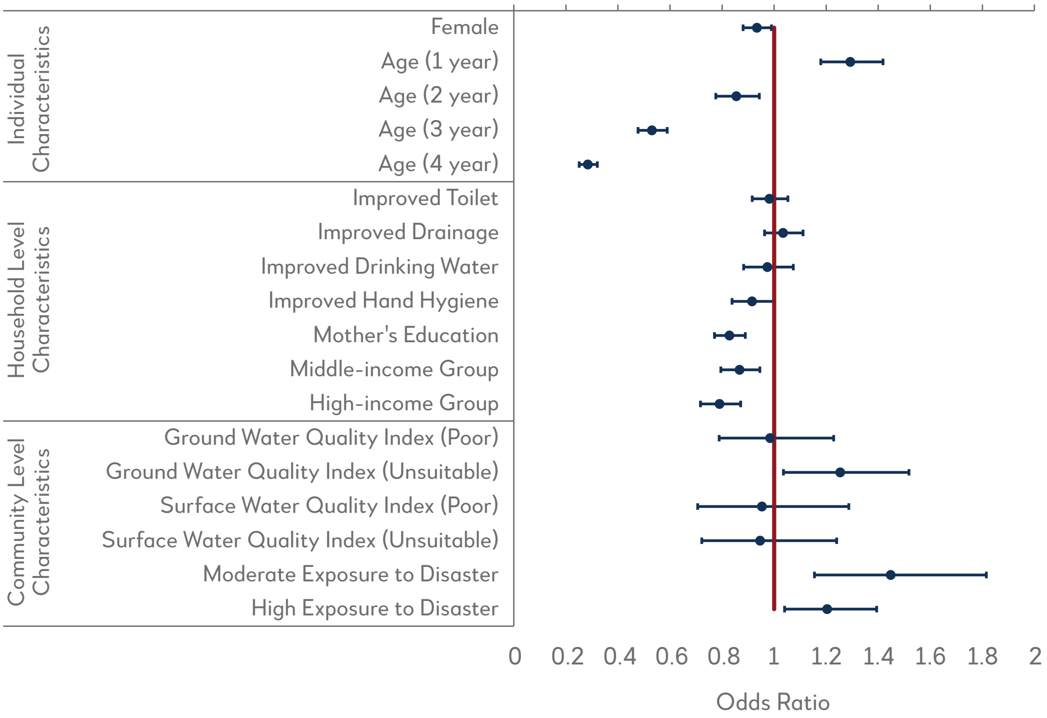
Age is an important factor. While one-year-olds exhibit higher odds of being infected with malaria than infants, older children show progressively lower odds. Certain household factors also have an effect. Children of mothers with education have 15.4 percent lower odds of contracting malaria relative to those with mothers without education. Unsurprisingly, wealthier households showed a lower incidence of malaria.

Children living in areas with unsuitable groundwater quality have 25.4 percent higher odds of malaria compared to those in areas with suitable groundwater. Moderate exposure to disasters is associated with 44.8 percent higher odds of malaria compared to low exposure to disasters, while high exposure to disasters is associated with 20.4 percent higher odds. The relatively higher odds of malaria in districts facing moderate disasters than those facing high disasters may seem counterintuitive. However, this may be driven by the fact that districts undergoing higher frequency and intensity of disasters may have developed better disaster preparations and resilience over a period compared to the group falling in the moderate category. Nevertheless, this needs further exploration.

Female children display about 5.8 percent lower odds of experiencing diarrhea than male children (Figure 15). Age is crucial, with children aged two and above exhibiting progressively lower odds of diarrhea. Among household factors, improved hand hygiene facilities reduce the likelihood of diarrhea by 11 percent. This is unsurprising as diarrhea is caused by ingesting contaminated food or drink or from contaminated hands. Hand washing can interrupt the transmission of diarrhea-causing pathogens. Children from high-income households exhibit 13 percent lower odds of diarrhea compared to those from low-income households.

Finally, groundwater and surface water quality do not significantly correlate with diarrhea. This may result from a large proportion of the population having access to improved drinking water. According to the World Bank, 94 percent of the population in India has access to improved sources of drinking water. At the same time, individuals residing in high-disaster areas show 32.4 percent higher odds of being infected with diarrhea compared to residents in low-disaster areas. Box B highlights the spillover effect of upstream river pollution on downstream local water quality and the impact on diarrhea.

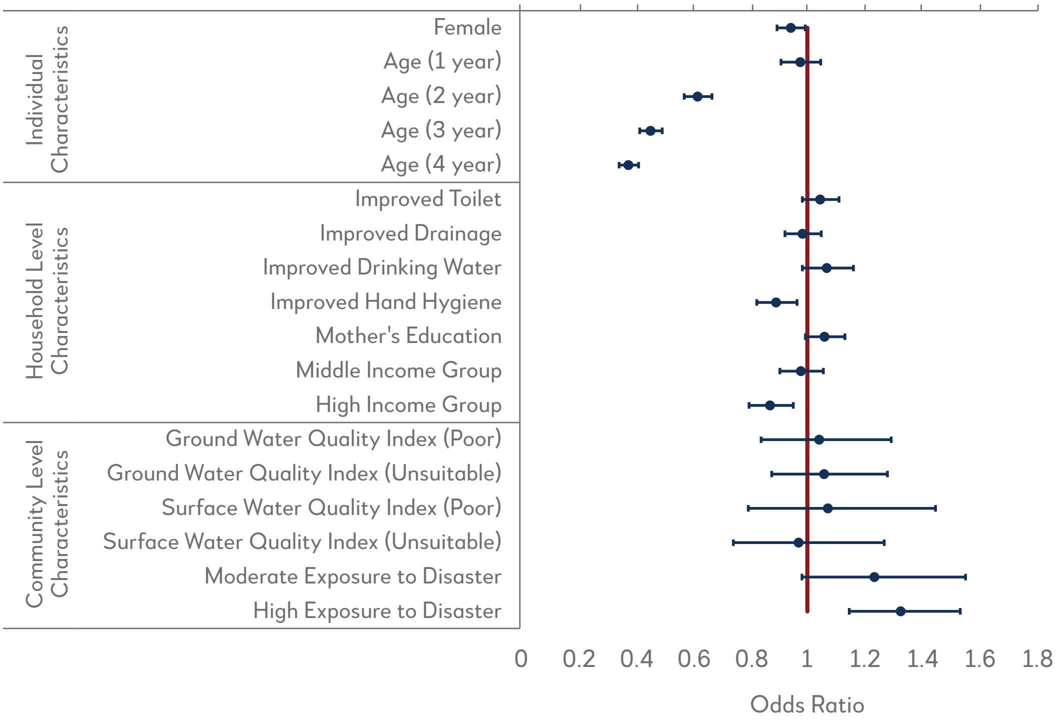
Figure 14: Some Key Drivers of Malaria Prevalence



Source: AIIB staff estimates.

Notes: The coefficients of the logistic regressions are interpreted as the 'odds ratio,' which compares the likelihood of outcome for the given condition to the reference condition. The null hypothesis in a logistic regression is that the 'odds ratio' is equal to 1, i.e., the likelihood of contracting a disease given a particular condition is the same as the likelihood of contracting the disease given the reference condition. In addition, the analysis also tested for the mother's age, religion, caste category, region and place of residence as possible factors influencing the likelihood of malaria or diarrhea. However, most of these factors have an insignificant impact.

Figure 15: Some Key Drivers of Diarrhea Prevalence



Source: AIIB staff estimates.

In the case of both malaria and diarrhea, individuals living in districts facing moderate and high exposure to disasters are found to be more susceptible. This could result from areas exposed to extreme climatic events having poor water quality for a brief period immediately after these events, which is not captured in the average annual water quality data but is reflected in the disease count.

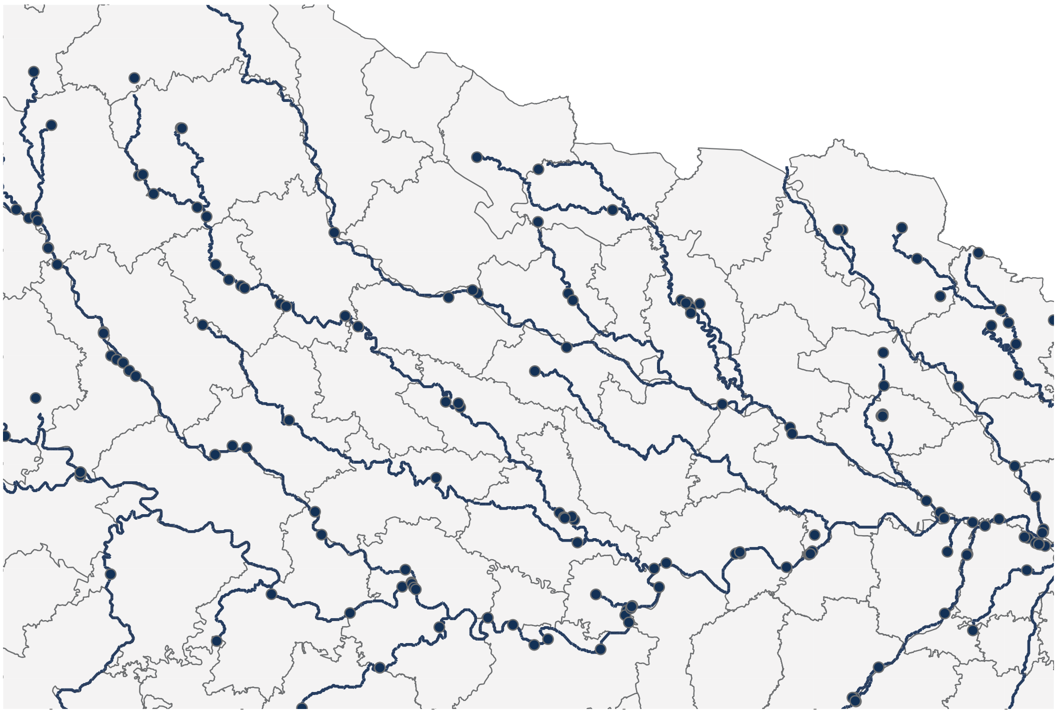
Box B: How Upstream Water Quality Affects Health: Evidence from the Ganges

River water plays a vital role in meeting the consumption, fishing and irrigation needs of households in India. Thus, river pollution can result in myriad adverse health effects. Moreover, since river flow tends to be mainly unidirectional, upstream river pollution can propagate downstream, affecting health across downstream local areas. The following analysis explores the extent of the correlation between upstream and downstream water quality and the consequent health outcomes.

River Ganga is chosen for the analysis as (a) around 40 percent of India's population is directly or indirectly dependent on the river for water [Government of India (2023)], (b) the government introduced a flagship program in 2014 aimed at the effective abatement of pollution and conservation and rejuvenation, and (c) it provides the most detailed record of water quality readings, including pH levels, dissolved oxygen, turbidity, nitrate and other parameters.

As Figure B1 illustrates, various monitoring stations are located across the Ganges basin to track an array of local water quality measures. For each station, all the readings from its upstream stations are weighted by distance and averaged to obtain a measure of upstream water quality. Two water quality measures are selected: Biological/Biochemical Oxygen Demand (BOD), which measures the oxygen consumed in a water sample over a given period, and dissolved chlorine, which measures the concentration of residual chlorine in water.

Figure B1: Ganges River Network and Monitor Stations



Source: AIIB staff estimates.

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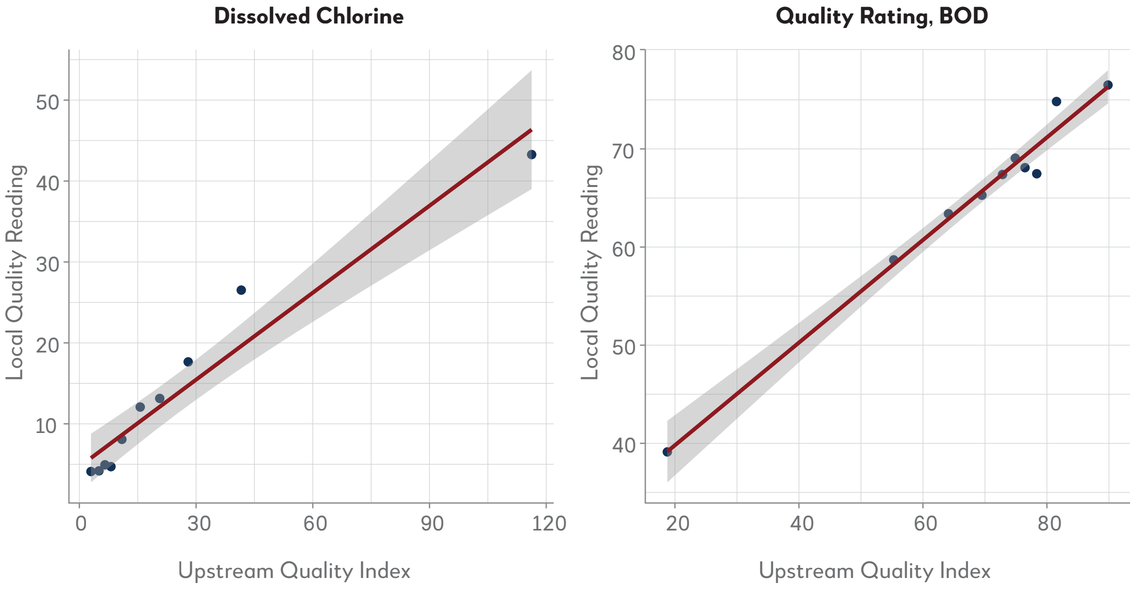
Box B *continued*

Figure B2: Upstream and Local Water Quality Measure (Bin Scatter)



Source: AIIB staff estimates.

The BOD is a comprehensive measure of the concentration of microorganisms, including pathogens, so a lower BOD reading implies better water quality. The analysis uses a BOD quality rating, which is inversely converted from a BOD reading using an expert rating curve. A higher quality rating value indicates a lower BOD reading and better quality. Chlorine is a standard water treatment substance, so a higher reading implies greater water treatment effort. The two parameters reflect the water quality and how river water is treated.

To test the spillover effect of upstream water pollution on downstream local health outcomes, upstream water quality variables are aggregated at the district level, at which health outcomes data are available. With diarrhea being the most common waterborne disease, the impact on incidence in young children (diarrhea cases among inpatients aged 0-5 per 10,000 people) and mortality (percentage of death among children aged 0-5 caused by diarrhea) are chosen.

These outcomes are then regressed on upstream water quality measures while controlling for the location within the river basin, time and state-fixed effects. While upstream BOD quality is negatively associated with the incidence of diarrhea, upstream dissolved chlorine reading is negatively correlated with mortality due to diarrhea (Figure B3).

A higher BOD quality implies that the concentration of organic pollutants, including microorganisms that cause diarrhea, is low, which helps to reduce local diarrhea cases. This is consistent with the literature that has found a robust relationship between reduction in microorganism concentration and health improvements [Ewemoje and Ihuoma (2014), Harshfield et al. (2012), Obiri-Danso et al. (2005)]. Since chlorine is typically used for water treatment, higher levels of upstream chlorine indicate greater wastewater treatment efforts, likely reducing potential death caused by diarrhea downstream. Again, this is consistent with the literature identifying chlorine as a cost-effective way to reduce diarrhea hazards [Solomon et al. (2020), Mengistie et al. (2013), Harshfield et al. (2012)].

Overall, the significant impact of upstream water quality on local health outcomes highlights the need for transboundary policy coordination on issues such as industrial pollutants, sewage and wastewater treatments, and the use of fertilizers and pesticides.

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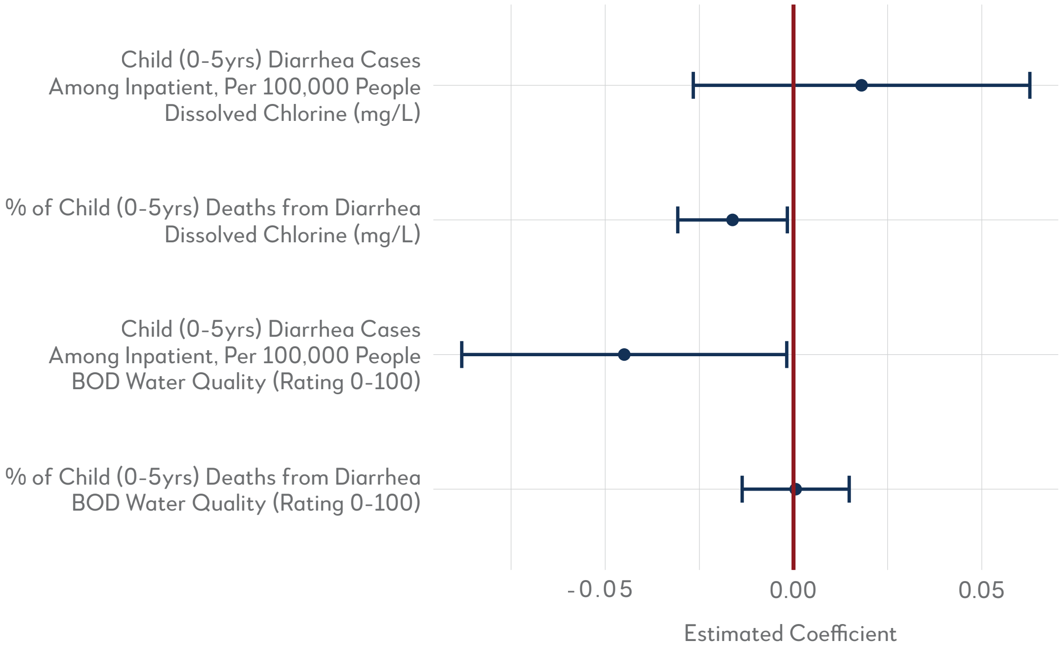
Box B *continued*

Figure B3: Effect of Upstream Water Quality on Selected Health Outcomes



Source: AIIB staff estimates.

3.2 Gender Disparities in Health Risks from Water- and Vector-borne Diseases

In many respects, the bacteria and viruses responsible for WVBD affect all humans indiscriminately. However, women are disproportionately exposed, rendering them more vulnerable to these diseases. In India, females tend to be more susceptible to WVBD compared to males. While Indian males account for 16.5 percent of global males' WVBD DALY, the share rises to 18.8 percent for females.

Even within India, WVBD DALY account for a higher share of overall DALY among females compared to males in the working age group of 15 to 69 years. Moreover, the disparity is broad-based. Across major Indian states and union territories, accounting for more than 95 percent of India's population, females exhibit a higher share of waterborne disease DALYs compared to males (Figure 16). In the case of vector-borne diseases, females tend to be more affected than males.

This could be driven by the differences in the environment in which men and women work. First, women tend to spend more time near stagnant water, both at home and in their workplace, which increases their risk of contracting WVBD [Sorensen et al. (2018)]. Second, significantly higher percentage of female workers are engaged in agriculture, compared to males, making them vulnerable to WVBD.[2] In fact, states where a higher proportion of female workers are engaged in farming activities are also, in most instances, the states with higher incidence of WVBD DALY among women (Figure 17). These diseases pose additional risks for pregnant women, as infections like dengue and Zika virus can lead to preeclampsia, intrauterine growth restriction, and even fetal conditions like microcephaly and impaired cognitive

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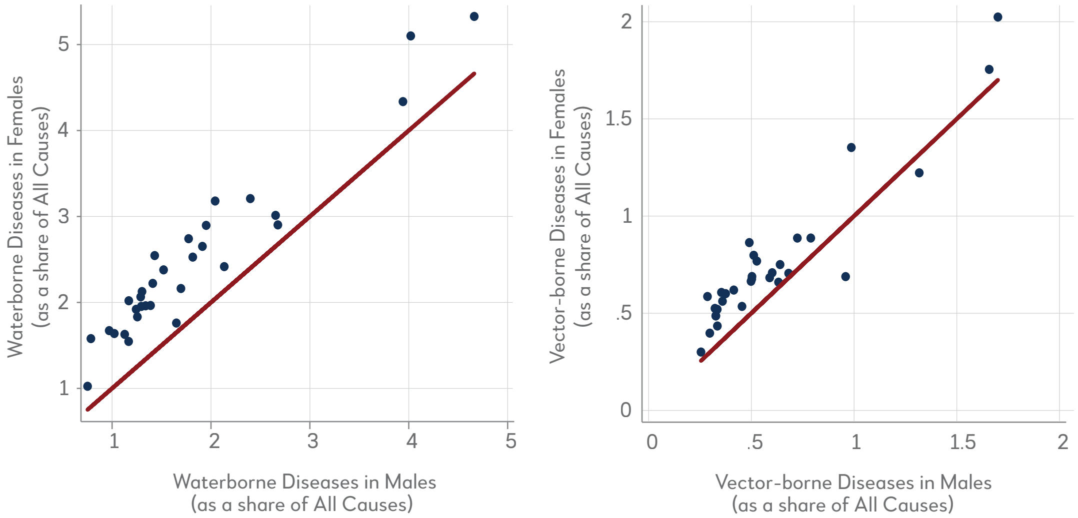
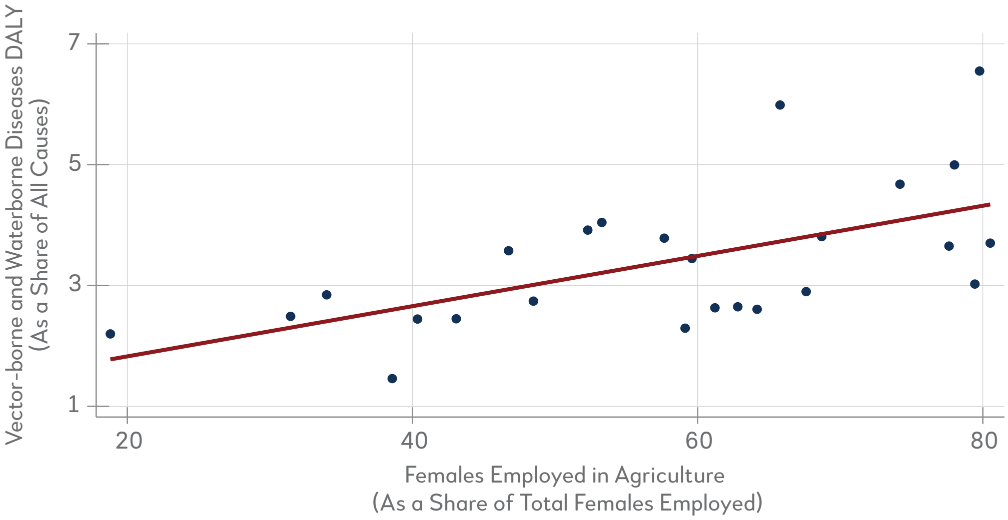
[2] The agriculture sector employs 62.9 percent of female workers, compared to 45.5 percent of male workers [Government of India (2023)].

Figure 16: Gender Differences in Water- and Vector-borne Diseases



Source: AIIB staff estimates and Global Burden of Disease Data.

Figure 17: Female WVBD DALY and Female Participation in Agriculture



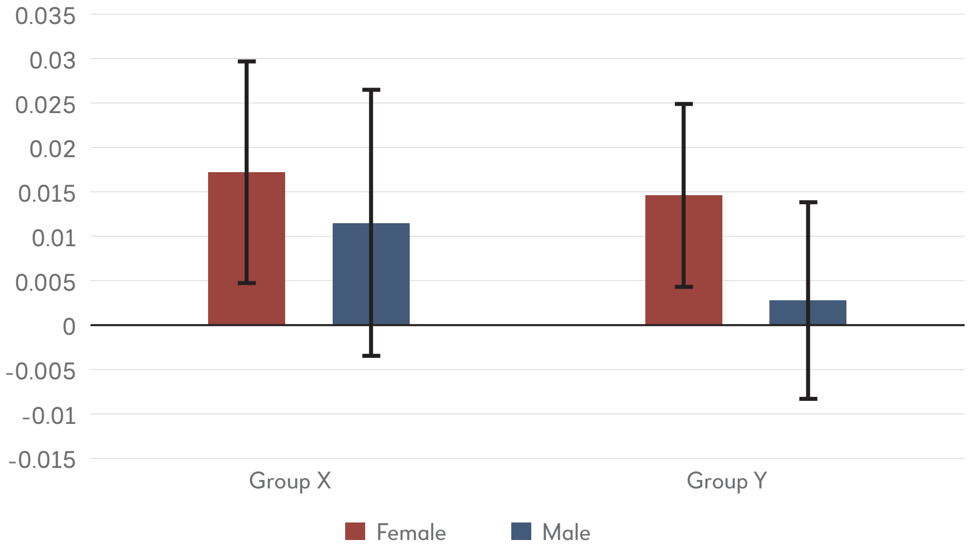
Source: AIIB staff estimates.

development. Third, lack of clean water and proper sanitation infrastructure also disproportionately affects women, especially during menstruation and pregnancy, when hygienic conditions are critical for preventing infections. Finally, unequal access to medical facilities and transportation limits women's ability to seek timely medical attention.

Evidence from Indonesia also suggests that women are particularly vulnerable to these health risks in the context of climate shocks. The probability of women contracting a waterborne disease increases by 0.015 percent after a flood, while no significant increase is observed among men (Figure 18).

Climate events like floods and droughts often force people to rely on contaminated water sources, placing women at greater risk as they often bear the primary responsibility for water collection [see Birch and Meleis (2012) and Pouramin (2020)]. In less developed areas of Indonesia,

Figure 18: Flood Impact on the Probability of Contracting Waterborne Disease by Gender



Source: AIIB staff estimates.

such as Nusa Tenggara and Papua, as well as rural regions, limited access to clean water is strongly linked to women and children taking on the role of water fetchers for their households [Irianti (2019)]. This heightened exposure to contaminated water further increases health risks, particularly in poorer regions with inadequate infrastructure and disaster preparedness. In this circumstance, women face even greater health vulnerabilities, especially during climate-related disasters [WHO (2011)].

There is a need for policymaking to explicitly incorporate gender considerations in climate mitigation and adaptation strategies. This involves recognizing and addressing issues such as lack of access to resources, limited decision-making power and inadequate institutional support. Some of the key focus areas would include (a) gender-responsive disaster preparedness, (b) enhancing occupational health, (c) promoting nutrition security and (d) improving access to healthcare services [Datta et al. (2024)].

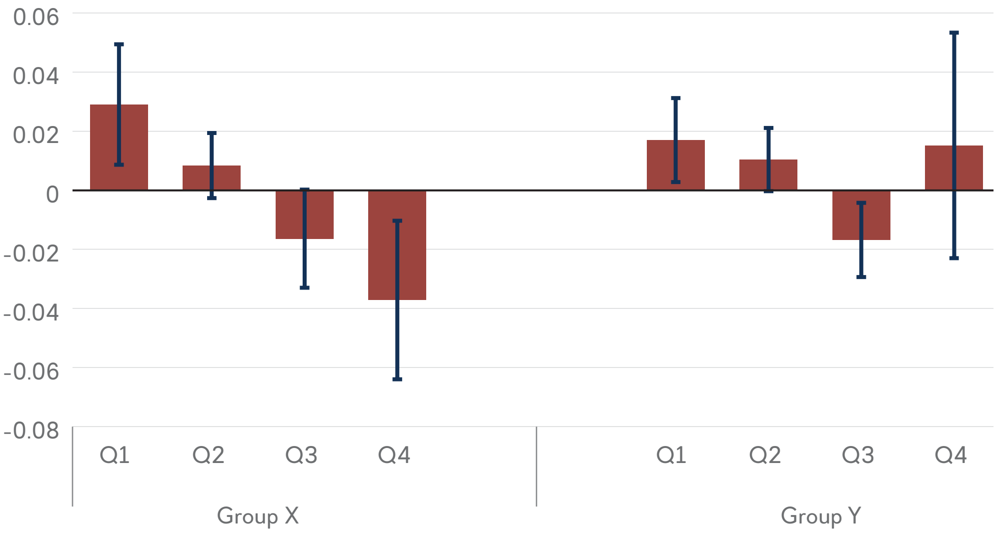
3.3 Role of Infrastructure in Mitigating the Impact of Climate-related Health Hazards

3.3.1 Healthcare Infrastructure Reduces Infectious Disease Risk in Indonesia

Infrastructure can play a critical role in mitigating the impact of climate change on health outcomes. For example, no heightened risk of infectious disease had been found following Hurricane Sandy in New York [Bloom (2016) and Greene (2013)]. This was attributed to the effectiveness of public health measures and increased vigilance of residents in the affected areas.

The analysis in this subsection tests for the relationship between infrastructure provision and disease in Indonesia. Using data from the World Bank on health infrastructure across regencies in Indonesia, the analysis divided the regencies into quartiles based on their level of health infrastructure, such as public investment in the

Figure 19: Flood Impact on Risk of Waterborne Disease by Local Health Infrastructure



Source: AIIB staff estimates.

health sector or number of health clinics, with lower quartile indicating regions with less developed health infrastructure (Groups X and Y are categorized the same way as Figure 11).

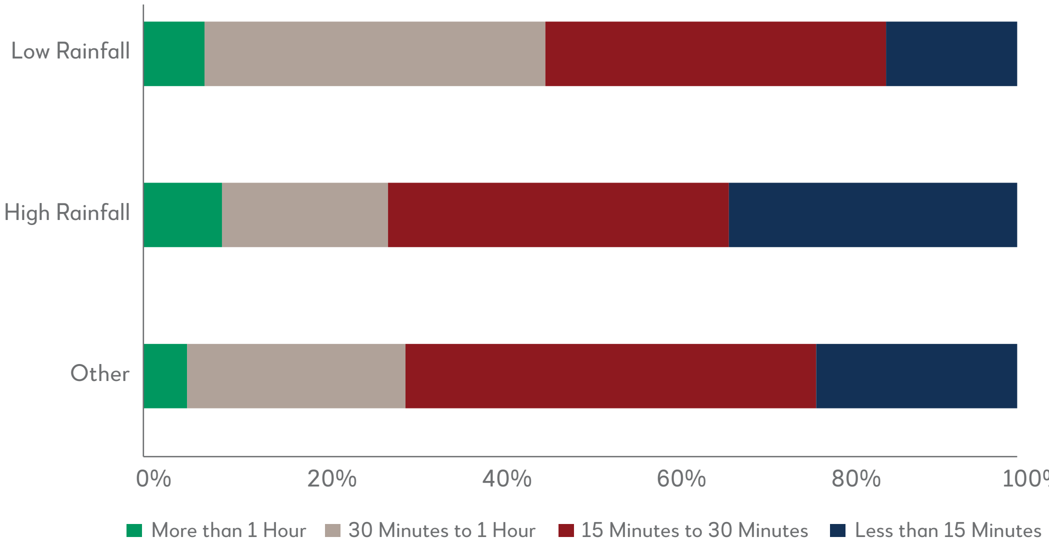
Figure 19 presents the regression results for each quartile subgroup based on government health expenditure as a percentage of GDP. The analysis reveals that the impact of floods on the probability of contracting waterborne diseases is significantly higher in regencies with lower investment in the health sector. In contrast, regencies with higher health sector investment demonstrate a 'protective' effect, similar to the findings for Hurricane Sandy. For instance, in Group X, in the first quartile (Q1) regencies, where health expenditure is limited, an additional 37 people per 100,000 population are expected to contract waterborne diseases after a flood. Conversely, in the fourth quartile (Q4) regencies, where health expenditure is higher, there are 47 fewer cases of waterborne disease per 100,000 population following a flood. In short, regions with more robust health systems show greater resilience. This highlights the crucial role of public health investment and preparedness in safeguarding communities from the growing health threats posed by climate-related disasters.

3.3.2 Healthcare Access and Food Security in Sri Lanka

Changing rainfall patterns can also impact health through its impact on healthcare access. A classification of the various districts in Sri Lanka, based on their access to healthcare facilities, indicates that individuals living in districts facing low rainfall (bottom 10 percent of the distribution) also have longer travel times to access healthcare facilities compared to high rainfall and other districts (Figure 20). More than 46 percent of households in these districts must travel more than 30 minutes to reach the nearest healthcare facilities (Figure 20). This could be partly driven by a high number of rural households in low rainfall districts (92 percent) relative to high rainfall (81 percent) and other districts (82 percent).

To improve access to healthcare in rural and remote areas, it is crucial to not just invest in healthcare infrastructure in underserved communities but also ensure enhanced connectivity to these facilities. This will ensure that vulnerable populations receive timely and adequate healthcare during climate-related events.

Figure 20: Hospital Accessibility in Sri Lanka According to Healthcare Infrastructure

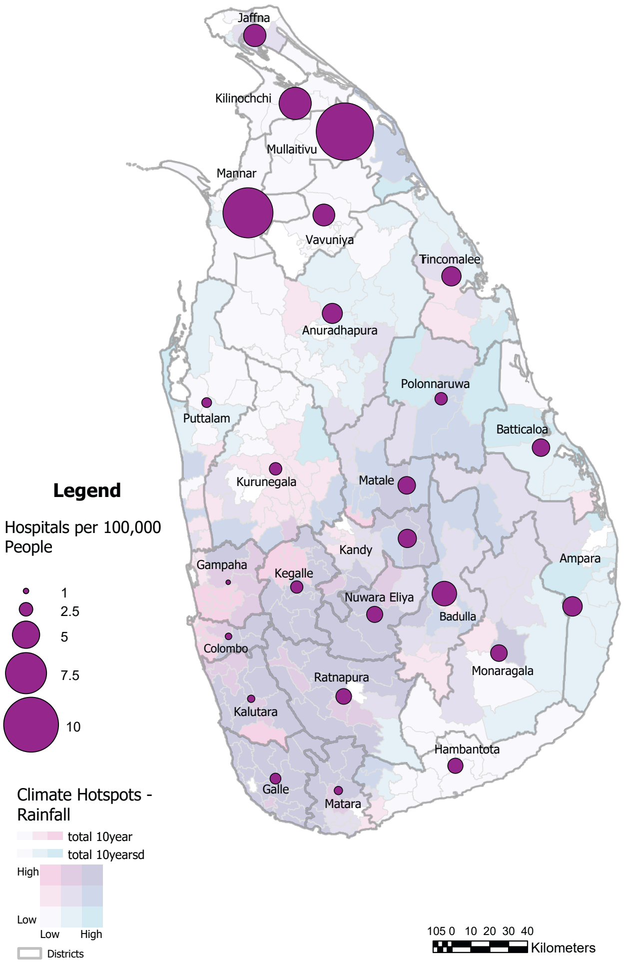


Source: AIIB staff estimates.

Figure 21 further explores the relationship between climate (rainfall) factors and hospital availability. Areas with high rainfall and high rainfall variation show fewer hospitals per 100,000 people at the district level. Certain districts with high urban density, such as Colombo, are subject to variable and high rainfall and have lower hospital density. Such urban districts are likely to have larger hospitals with more facilities to treat a more extensive set of ailments. However, across several parts of the country's south and west, including areas such as Ratnapura, Nuwara Eliya and Kalutara, medical infrastructure is needed to respond to variable and extreme weather. Some of these districts like Ratnapura are highly vulnerable to floods, landslides and other climate-related events every year. Some districts in other areas, such as Polonnaruwa and Badulla, also face variable weather conditions and have relatively lower coverage of hospitals per 100,000 people.

Climate change also exacerbates food security. Rising temperatures, inconsistent rain patterns and rising sea levels can result in growing insect and pathogen populations, increasing soil moisture deficits and raising soil salinity, all of which reduce crop productivity [see Nissanka and Pathinayake (2009); De Silva (2007)]. At the same time, rising sea temperatures and poorer water quality due to pollution reduce fish stock.

Figure 21: Hospital Density and Rainfall Variation Across Sri Lanka



Source: AIIB staff estimates.

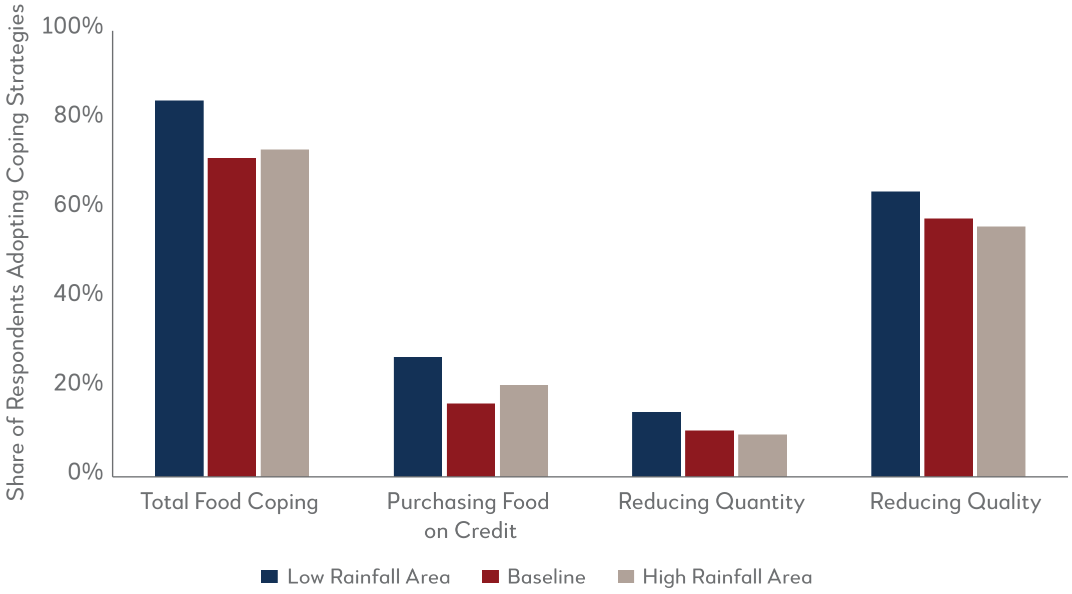
Sri Lankans have been using a variety of coping strategies to deal with food insecurity, including (a) reducing the quantity of food intake, which includes skipping meals and cutting back on the number of meals per day; providing food only to children, elders and males; and reducing the proportion of meals; (b) compromising on the quality of food by reducing protein and opting for cheaper options with high carbohydrate composition; and (c) purchasing food on credit or depending on friends and family.

Figure 22 provides a comparison of coping strategies adopted across the high (top 20 percent), low (bottom 20 percent) and baseline (middle 20 percent) rainfall areas (based on the Multidimensional Vulnerability Index, UNDP National Citizen Survey 2022-23). More than 70 percent of the households are forced to undertake some form of coping strategy across different rainfall areas, with the proportion being highest in low-rainfall areas.[3] Compared to the baseline, a higher share of households living in low-rainfall areas are forced to reduce both the quality and quantity of food consumed. A higher proportion of households purchased food on credit under both high- and low-rainfall conditions compared to the baseline, suggesting a greater need for financial aid to maintain proper nutrition levels. Although a slightly lower proportion of households in high-rainfall areas resort to reducing the quality and quantity of food compared to the baseline, they use more coping strategies.

A probit regression analysis helps to identify the key climate-related drivers of adopting a coping strategy. Households living in extreme-rainfall (low-rainfall or high-rainfall) areas have 10.9 percent to 15.9 percent higher probability of resorting to food coping strategies, compared to other areas. The probability of compromising on the food quality is higher than reducing the quantity of food.

Furthermore, households living in areas with high rainfall volatility also show about 11.9 percent to 12.9 percent higher probability of resorting to a coping strategy, as high rainfall volatility reduces crop yields by making the land unsuitable for production [Felix and Somlanare (2012)]. Finally, an agrarian household (defined as having at least one adult member who is self-employed in agriculture) reduces the probability of resorting to coping strategies. Such households are likely to grow their food and, hence, less likely to adopt a coping strategy.

Figure 22: Food Coping Strategies Across Different Rainfall Areas



Source: AIIB staff estimates.

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[3] The survey was conducted in 2022 when Sri Lanka was in the midst of an economic crisis. The economic crisis is likely to have impacted food consumption choices across the entire country, irrespective of rainfall received in the area. Hence, a comparison of the high- and low-rainfall with a baseline is undertaken to tease out the relationship between rainfall and coping strategies.

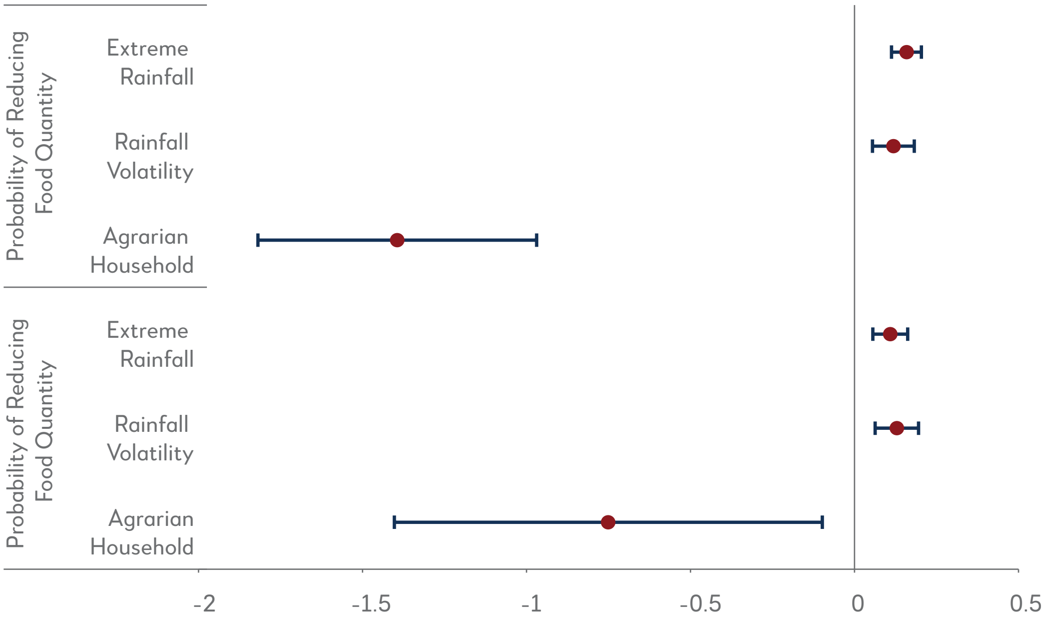
With climate change, strengthening irrigation, coastal protection and health infrastructure will likely enhance food security. Improved connectivity through improved road quality can not only reduce the time taken to travel to healthcare facilities but also allow households to obtain inputs and reach markets. For example, the rural roads program in India has been found to improve the utilization of reproductive health services, rates of institutional deliveries and vaccination rates [see Aggarwal (2021); Burelle (2021)]. Such infrastructure improvements are crucial in disaster-prone regions, where extreme weather events often disrupt transport and delay emergency responses [Espinet et al. (2020)].

Coastal ecosystems, including mangroves and wetlands, play a vital role, and their degradation or destruction amplifies the effects of climate change [AIIB (2023)]. For example, in Sri Lanka, mangroves were lost due to shrimp farming, encroachment, and construction, and their conservation and restoration are vital to mitigating health impacts. Continuing to increase salinity barriers across major rivers could also provide additional protection against food security challenges amidst climate change [Takamatsu et al. (2023)].

Similarly, investing in water distribution by expanding irrigation infrastructure can help increase agricultural productivity. A report from the International Institute for Sustainable Development (2018) shows that agricultural productivity resulting from irrigation can be more than twice as high on a per-hectare basis as rainfed production.

Finally, enhanced health infrastructure is critical. In areas with higher infectious diseases due to climate change, infectious disease control units should be able to diagnose and treat the disease promptly. While establishing new health facilities is often difficult, improvements to expand the capacity of primary healthcare networks will address the current health needs of rural, climate-vulnerable populations and prepare the system for future climate-related health challenges. In addition to preparing for diseases and health issues, healthcare facilities should also integrate climate-resilient infrastructure as they can drastically reduce mortality and morbidity rates during climate-related disasters. Box C presents a simulation of hospital accessibility in Southeast Asia, where the local road network is particularly vulnerable to extreme flooding. The analysis shows that without enhancing the climate resilience of roads, accessibility to hospitals decreases during flooding, even when conservative projections of future flood inundation are used.

Figure 23: Food Coping Strategies Across Different Rainfall Areas



Source: AIIB staff estimates.

Box C: Geospatial Study of Medical Accessibility in Flood Conditions

Riverine floodings pose a significant threat to the transport networks in Southeast Asia. The region has low-lying cities vulnerable to intense monsoon rains and tropical storms. Climate change is expected to increase the intensity of precipitation, leading to more frequent and severe flooding in Southeast Asia [Eccles et al. (2019)]. This heightened flood risk threatens critical infrastructure, including roads, bridges and railways. Particularly, riverine flooding significantly impairs transport accessibility to medical facilities in Southeast Asia, exacerbating public health crises during flood events. The inundation of roads and bridges disrupts the transportation network, making it challenging for emergency services to reach affected areas and for patients to access critical medical care in a timely manner.

Using the OpenStreetMap (OSM) road network and hospital locations, this analysis looks at the driving time to hospitals. It simulates routes and driving times from randomly selected locations to the closest hospitals for Thailand, Cambodia, Myanmar, Lao PDR, and Viet Nam. The exercise computes such shortest routes in two scenarios—without flooding and with flooding. The flooding scenario assumes a once-in-25-year extreme riverine flood occurs in 2030.[a] Depending on the projected inundation level (meters), the roads can be blocked or accessed at a much slower speed [see Choo et al. (2020)].

According to the OSM data, there are 135 hospitals available in Cambodia, 551 in Lao PDR, 627 in Myanmar, 1,026 in Thailand and 282 in Viet Nam. Near each hospital, 10 randomly selected locations are chosen to compute the routes to their nearest hospital. In total, 2,621 hospitals with 26,210 locations were used to compute the routes to their nearest hospital regarding driving time.

Floods increase driving time to hospitals significantly

As expected, the simulated driving time to the closest hospitals during flood increases dramatically across all the five selected economies, compared to without-flood scenarios. Overall (Figure C1), 40 percent of locations see longer driving times to the closest hospitals. Seventeen percent of locations lose road access to hospitals, as the roads nearby connectable to hospitals during non-flood times become completely unpassable (defined in literature as 0.3 meters or above). The average driving time to the closest hospitals increases by 37 percent, from 14 to 19 minutes (see Table C1).

Table C1: Average Driving Time to Closest Hospitals (Minutes)

	With Flood	Without Flood	% Change
Cambodia	29.22	14.31	104
Lao PDR	16.75	11.23	49
Myanmar	16.64	13.51	23
Thailand	17.24	15.20	13
Viet Nam	37.62	17.90	110
Average	19.52	14.19	38

Source: AIIB staff calculation using OSM and flood data by simulations.

Viet Nam appears to be affected the most by prolonged or lost road access to hospitals during flooding. The driving time to the closest hospitals more than doubles, with one-third of simulated points losing medical accessibility completely. These observations are consistent with recent reports, where urban road networks in Viet Nam are particularly vulnerable to floods and other associated natural disasters such as landslides. Results for Cambodia are similar to those in Viet Nam, while it has a much lower share of points losing medical accessibility during flooding (12 percent). Thailand seems to be relatively resilient. Average

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[a] Data source is from the World Resource Institute's Aqua Risk. The riverine flood projection is based on the Representative Concentration Pathway 4.5 (steady carbon emissions) climate change model. Flood data is a global projection of inundation levels (meters) if a once-in-25-year extreme riverine flood hits these countries in 2030.

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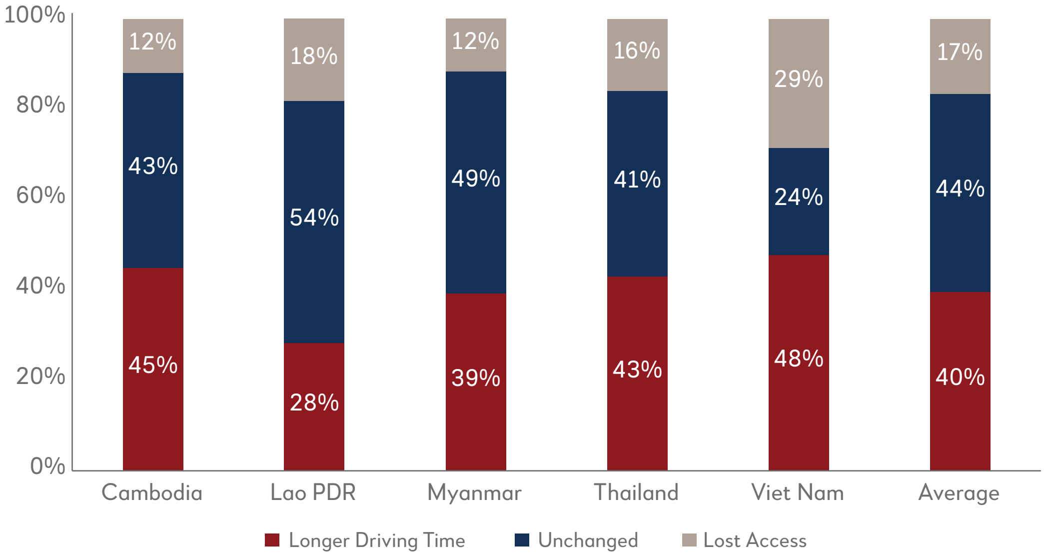
Box C *continued*

driving time to the closest hospitals increases by only 13 percent from 15.2 to 17.2 minutes. Driving time during flooding in Lao PDR and Myanmar increases by 49 and 23 percent, respectively, but a lower share of locations experience such prolonged travel to hospitals.

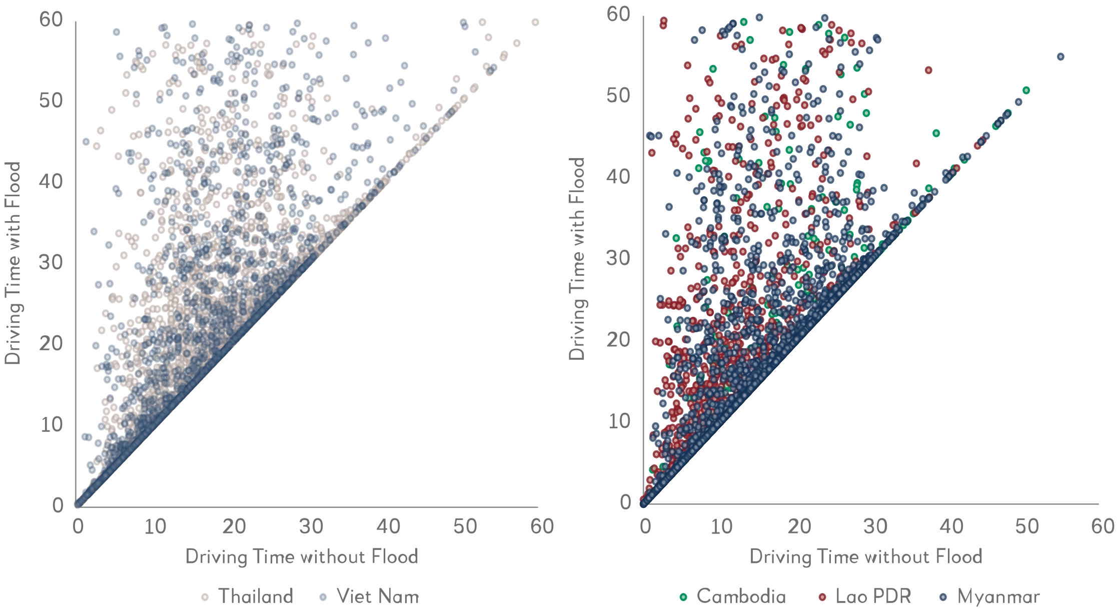
Figure C1: Share of Longer, Unchanged Driving Time and Lost Access to Closest Hospitals

Comparing With to Without Flood Scenarios



Source: AIIB staff calculation using OSM and flood data by simulations.

Figure C2: Scatterplot of Driving Time to Closest Hospitals



Source: AIIB staff estimates using OSM and flood data by simulations.

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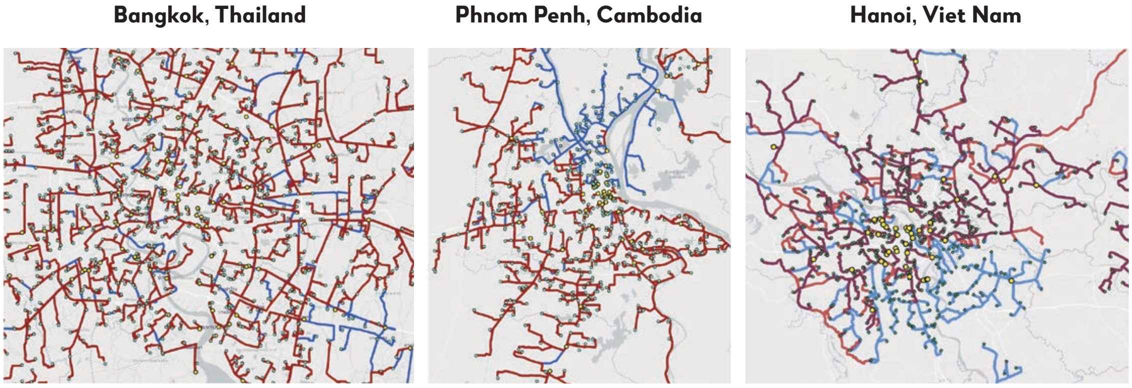
Box C *continued*

Figure C3 shows the driving routes to the closest hospitals in Bangkok, Phnom Penh and Hanoi with and without flood scenarios. Consistent with the results above, most driving routes in Bangkok remain the same, though with lower speeds due to floods. In contrast, many routes in southeast Hanoi and riverside areas in northern Phnom Penh become unavailable during the simulated flood scenario. The population in these low-elevation, flat riverside areas is the most vulnerable to damaged road accessibility to hospitals when flooded.

Figure C3: Routes to Closest Hospitals in Selected Cities



Bangkok, Thailand **Phnom Penh, Cambodia** **Hanoi, Viet Nam**

Far fewer people covered within 30-minute drive to hospitals during floods

The simulation also computed the number of people reachable within a 30-minute drive from all the 2,621 selected hospitals for normal and the same flood scenarios (Table C2). Without floods, around 103 million people can be reached within 30 minutes of the nearby hospitals. However, during the simulated flood scenario, this number would significantly decline by more than 30 percent to 70.3 million. Viet Nam and Lao PDR are affected the most, with 40 percent fewer people reachable within 30 minutes.

Table C2: Population within a 30-minute Drive from Hospitals

Country	No Flood	Flood	% Change
Cambodia	2,326,863	1,969,576	-15
Lao PDR	4,926,802	2,761,229	-44
Myanmar	6,299,636	5,114,962	-19
Thailand	29,245,799	24,926,816	-15
Viet Nam	60,617,512	35,648,327	-41
Total	**103,416,612**	**70,420,910**	**-32**

Source: AIIB staff estimates using Global Human Settlement Data 2020 population estimates for the five countries.

As Southeast Asia continues to urbanize and develop, enhancing flood resilience and the adaptive capacity of transport infrastructure become imperative to mitigate these impacts and ensure sustainable development.

CHAPTER 4

HEAT-RELATED HEALTH STRESS AND INFRASTRUCTURE

EVIDENCE FROM SOUTH AND SOUTHEAST ASIA

Highlights

- In the South and Southeast Asia (SSEA) region, exposure to just one additional day of temperatures exceeding 30 degrees Celsius (°C) annually increases the overall population death risk by 1.6 per 10,000 (compared to a reference temperature of 12-15°C). The effect is more pronounced among elderly individuals over 60, where the risk rises to 4.2 per 10,000.
- The impact on infants is significantly greater: one additional day of temperatures exceeding 30°C raises the infant death risk by 21.8 per 10,000–14 times the risk for the general population. Additionally, in utero exposure to one extra day above 30°C is associated with an increase of 17.8 infant deaths per 10,000 live births. Rural populations are more vulnerable to extreme heat than urban populations, likely due to inadequate infrastructure.
- Statistically, individuals with access to medical facilities, electricity and transportation are less affected by extreme heat. Green and nature-based infrastructure is a critical adaptation measure for mitigating the health impacts of extreme heat. Results suggest that populations living in areas with high greenery experience slightly lower mortality.

4.1 Introduction: Climate Change, Extreme Heat and Health Impact

According to the latest Intergovernmental Panel on Climate Change (IPCC) report, global surface temperatures were 1.1°C higher in 2011–2020 compared to 1850–1900, and they are projected to rise to 3.2°C by the end of this century under current policy scenarios, or even 4.4°C under a very high greenhouse gas emission scenario [IPCC (2023a)]. As global warming intensifies, the frequency, intensity and duration of extreme heat events have surged. Temperatures exceeding 40°C and even reaching 50°C are becoming increasingly frequent across the globe [World Meteorological Organization (2023a)]. These prolonged periods of excessive heat can have devastating impacts across multiple domains, including human health and well-being, public safety, infrastructure and the natural environment [McGregor et al. (2015)].

As global temperatures continue to rise due to human activities, understanding the nature and impacts of extreme heat has become more critical than ever. This alarming trend exacerbates existing vulnerabilities and creates new health-related challenges. The health impacts of extreme heat are profound and multifaceted. Like the Earth, the human body maintains homeostasis through a delicate heat balance. Equilibrium is achieved when the heat entering the body equals the heat dissipated. Core body temperature is meticulously regulated around 37°C (98.6 degrees Fahrenheit) [IQWiG (2022)], though it may rise or fall slightly depending on ambient temperature and individual characteristics. In response to extreme heat, the body's cooling mechanisms place increased demands on the cardiac and renal systems.

Peripheral vasodilation can decrease blood pressure, compelling the heart to exert more effort. Sweating can lead to dehydration, which may cause hyperkalemia and reduced fluid volume in the cardiovascular system. This strain can induce oxidative stress, allowing gut bacteria to enter the bloodstream and potentially leading to critical organ failure. Table 5 illustrates the danger levels of heat (affected by temperature and relative humidity) and their impacts on the human body.

Between 2000 and 2019, an estimated 489,000 deaths per year were attributed to heat, with Asia (45 percent) and Europe (36 percent) bearing the highest burden [World Meteorological Organization (2023b)]. Two heatwaves, in 2003 (Western Europe) and 2010 (Russian Federation), were responsible for 80 percent of all weather-related deaths in Europe between 1970 and 2019 [World Meteorological Organization (2023a)]. A more recent example is the 2024 Indian heatwave, during which the Ministry of Health and Family Welfare (MoHFW), Government of India, reported that 67,637 people suffered from heatstroke, with 374 fatalities recorded between March 1, 2023, and July 25, 2024. Most incidents occurred in rural areas, where outdoor agricultural work and limited healthcare worsened its impact[4].

The health impacts of heatwaves extend far beyond heatstroke. A growing body of evidence indicates that extreme heat significantly contributes to both mortality and morbidity across a range of health issues [Green et al. (2019); Huang et al. (2018)]. Studies reveal a U-shaped pattern, where both extreme cold and hot temperatures negatively impact human health [Heutel et al. (2021); Guo et al. (2012)], with extreme heat having particularly destructive effects on mortality across different age groups [Green et al. (2019); Li et al. (2015); Ma et al. (2015)].

Vulnerable groups, including the elderly, pregnant women, children, outdoor workers and individuals with pre-existing health conditions, are disproportionately affected [Ma et al. (2015); Ingole et al. (2017)]. Infants are particularly vulnerable to temperature extremes, with both high and low ambient temperatures posing significant risks to neonatal health [Dimitrova et al. (2024)]. The interplay between rising average temperatures and air quality is increasingly critical as higher temperatures and sunnier conditions intensify atmospheric chemical reactions, leading to elevated concentrations of ground-level ozone—a pollutant with significant health impacts. Ground-level ozone exacerbates respiratory and cardiovascular NCDs, placing those with chronic obstructive pulmonary disease (COPD) at greater risk [Münzel et al. (2022)].

Table 5: Heat Danger Levels and Their Impact on the Human Body

Danger level	Heat index (°C)	Impact for body
Caution	27-32	Increased vulnerability during prolonged heat exposure or physical activity
Extreme Caution	33-39	Elevated risk of heatstroke and other heat-related illnesses
Danger	40-51	Significantly heightened risk of heatstroke
Extreme Danger	52 and above	Extremely high risk of heatstroke

Source: National Oceanic and Atmospheric Administration. https://www.noaa.gov/jetstream/synoptic/heat-index (September 2023).
Notes: The heat index refers to the "apparent temperature," or how hot it feels to the body, taking into account relative humidity and dry bulb temperature.

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[4] Business Standard (2 December 2024), "Heatstroke took 374 lives, over 67,000 cases till Jul 27: Health Ministry". Government of India (2 December 2024), Lok Sabha, Unstarred Question No. 1907, Heat Stroke Death

Extreme heat is of particular concern. In India, Banerjee and Maharaj (2020) found that exposure to high temperatures during pregnancy leads to an additional two infant deaths per 1,000 births. Similarly, in a study conducted in Philadelphia, Schinasi et al. (2020) reported a 22.4 percent increase in infant mortality risk for every 1°C rise in minimum daily temperature above 23.9°C. These findings, covering diverse geographic and socioeconomic settings, highlight the critical need to consider temperature extremes when assessing and addressing infant health outcomes globally.

Research on its health effects in the SSEA, one of the world's most vulnerable areas, has been sporadic and limited. While some country-level studies exist, covering nations like India, Pakistan, Thailand, Bangladesh, the Philippines and Viet Nam [see Ingole et al. (2017); Ghumman and Horney (2016); Huang et al. (2018); Burkart et al. (2014); Seposo et al. (2017); Phung et al. (2017)], most of these studies focus on a single country or a few cities. The lack of comprehensive analysis across the entire SSEA region leaves a significant gap in public understanding of climate change's health impacts and the associated economic costs.

Historically, medical and public health interventions have focused primarily on individuals, their biology and behaviors. However, research increasingly shows that this approach is often ineffective, as people's choices are heavily influenced by their surrounding environments and contexts. For example, infrastructure is crucial across many sectors, yet infrastructure interventions remain an understudied area with significant potential to mitigate health risks from climate-related hazards [Wake (2023)]. In response to the growing threat of extreme heat, developing sophisticated infrastructure and adaptation strategies is essential. Effective interventions include adopting advanced cooling technologies and building cooling centers, ensuring a reliable power grid for uninterrupted electricity supply, increasing accessibility to healthcare services, improving public transportation and enhancing urban green infrastructure [Kiarsi et al. (2023); Turek-Hankins et al. (2021); Barreca et al. (2016); WHO (2015)].

Green infrastructure, which involves integrating nature-based solutions into urban planning and built environments to deliver environmental, social and economic benefits, such as strategic networks of green spaces, contributes significantly to ecosystem-based adaptation. For example, forms of urban agriculture can reduce physiological equivalent temperature by 10 to 13 percent [Zölch et al. (2016)]. These adaptation strategies not only aim to protect human health and well-being but also contribute to the overall resilience of urban and rural environments in the face of escalating climate challenges. This chapter contributes to such analyses.

4.2 Extreme Heat in South and Southeast Asia

In recent years, the SSEA region has seen a notable increase in the frequency, intensity, and duration of extreme heat events, leading to significant impacts on public health and socioeconomic systems. As illustrated in Figure 24, the number of extreme heat days (with temperatures exceeding 30°C) increased from 101 to 121 between 1950 and 2014 and is projected to rise further to 150 days by 2050, based on the four scenarios from the United Nations World Climate Research Program's climate forecasts.

In South Asia, countries like India, Pakistan and Bangladesh have experienced some of the deadliest heatwaves, with temperatures often exceeding 45°C (113 degrees Fahrenheit). Southeast Asian nations such as Thailand and Viet Nam face the dual challenges of rising temperatures and high humidity, making heatwaves particularly dangerous. Notable events include the 2015 heatwave in India, which claimed over 2,200 lives, and a simultaneous heatwave in Karachi, Pakistan, resulting in over 1,200 deaths.[5]

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[5] The Guardian (31 May 2015), "Rain brings little relief to southern India as heatwave death toll nears 2,200." The Nation (Pakistan) (24 June 2015), "Deaths 1,200 as Karachi wilts under heat."

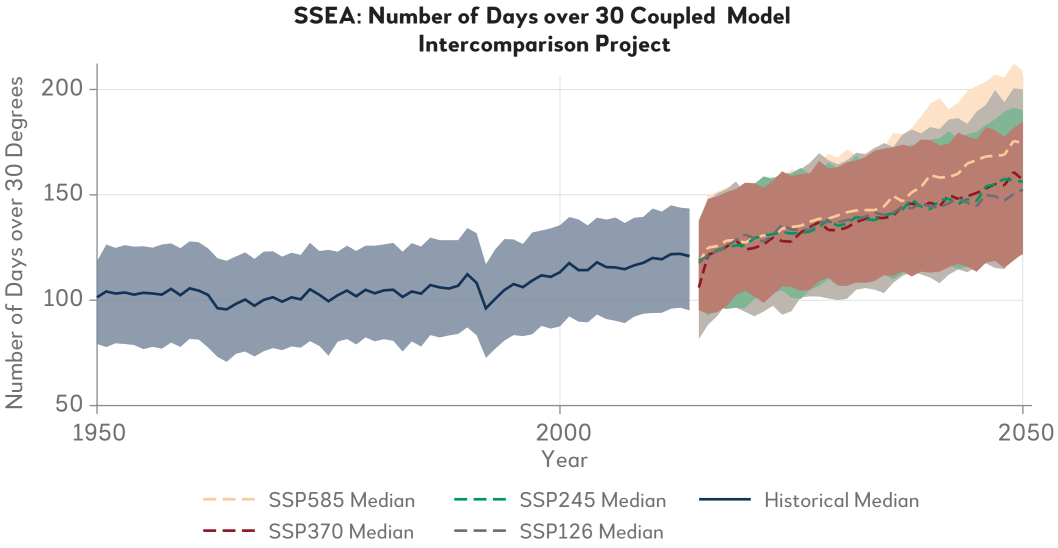
In 2016, the region experienced record-breaking temperatures, with Phalodi, India, reaching 51.0°C, affecting 330 million people. [6] The trend has continued, and since May 2024, India and Pakistan have been grappling with their longest recorded heatwave, setting new temperature records in New Delhi (49°C) and parts of Pakistan (52.2°C).[7]

The risks of climate change in SSEA are not limited to temperature increases. A complex mix of demographic, socioeconomic, and environmental factors exacerbate the region's vulnerability to extreme heat. These include persistently high year-round temperatures and humidity levels, a rapidly growing and aging population, widespread poverty and socioeconomic inequalities, significant occupational exposure to outdoor conditions, limited access to cooling technologies, and inadequate health infrastructure [Dimitrova et al. (2021)]. The interplay of these vulnerabilities makes it difficult for the region to effectively adapt to the rising threats posed by climate change.

4.2.1 Geographical and Socioeconomic Context

Rapid urbanization across many countries in the region, particularly India, Pakistan, Bangladesh and Indonesia, has led to the development of urban heat islands–areas within cities that experience significantly higher temperatures than surrounding rural regions. These islands result from human activities such as deforestation, construction, and the use of heat-absorbing materials like concrete and asphalt. For instance, cities like New Delhi, Dhaka, Jakarta and Karachi regularly experience temperature spikes due to urban heat island effects. The high population density in these urban centers exacerbates the situation, exposing more people to extreme heat in environments that often lack adequate cooling infrastructure. In rural areas, agriculture-dependent populations face severe risks from extreme heat. Prolonged exposure to high temperatures not only poses immediate health risks, such as heatstroke and dehydration but also devastates crop yields, leading to food insecurity and economic hardship.

Figure 24: Historical and Projected Extreme Heat Events in SSEA (1950-2050)



Source: Based on data from World Bank CMIP6 0.25-Degree. https://climateknowledgeportal.worldbank.org.

Notes: SSEA = South and Southeast Asia.
The shaded area below and above the median lines represent the 10th and 90th percentile estimation ranges.

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[6] Wall Street Journal (20 May 2016), "Indian heatwave breaks record for highest temperature." Washington Post (22 April 2016), "Brutal heatwave in India puts 330 million people at risk."

[7] CNBC (14 June 2024), "In pictures: India records 'longest' heatwave, Delhi faces water crisis." Reuters (31 May 2024), "India heatwave kills at least 33, including election officials." Phys.org, "India's heatwave longest ever, worst to come."

4.2.2 Existing Health and Environmental Challenges

The SSEA region also faces a complex array of pre-existing health and environmental challenges that could exacerbate the impacts of extreme heat. Countries in SSEA grapple with a high prevalence of non-communicable diseases (NCDs), which increase the population's vulnerability to heat-related illnesses. For example, cardiovascular diseases, particularly ischemic heart disease, are the leading causes of death in many SSEA countries [Narain et al. (2011); Biswas et al. (2023)]. During extreme heat events, individuals with cardiovascular issues are at higher risk of heat stress and related complications. Respiratory diseases are also common and can be exacerbated by the combination of heat and poor air quality, often associated with heatwaves [Green et al. (2019)].

Several environmental factors in SSEA compound the effects of extreme heat. Air pollution is a significant concern, with many SSEA cities ranking among the world's most polluted [Hasan et al. (2023); IQAir (2024)]. The combination of extreme heat and high pollution levels creates a dangerous synergy, increasing the risk of respiratory distress and cardiovascular events.

Additionally, the region's high humidity further intensifies the problem. High humidity levels combined with elevated temperatures can lead to "wet-bulb" conditions—where the human body's natural cooling mechanism (sweating) becomes ineffective, making it difficult for the body to maintain a safe temperature. Often observed in coastal areas, these conditions can rapidly escalate into life-threatening heat-related illnesses like heatstroke.

4.2.3 Infrastructure Challenge

The lack of adequate infrastructure in SSEA countries significantly impairs their ability to adapt to the extreme heat brought on by climate change. Infrastructure such as electricity, water supply, healthcare and transportation networks are crucial for resilience, yet many SSEA countries experience severe infrastructure shortages. For example, in 2022, 26.3 percent of Myanmar's population and 14.7 percent of Afghanistan's population lacked access to electricity [IEA (2023)]. Indonesia has only 29 kilometers of roadway for every 100 square kilometers of land, compared to 72 kilometers in the United States and 232 kilometers in Germany [Worlddata (2024)]. Only 15 percent of households in Southeast Asia have access to air conditioning [IEA (2019)].

Even with current air conditioner ownership levels, air conditioning contributes significantly to peak power demand during summer. Overloaded power grids, common in densely urbanized areas, are often unable to meet the increasing demand for electricity during extreme heat events, resulting in frequent power outages. Many populations, especially those in rural and low-income urban areas, have limited access to air conditioning, healthcare and other resources necessary to mitigate the effects of extreme heat.

4.2.4 The Potential of Nature-based Solutions

In addition, inadequate urban planning has led to densely populated areas with limited green spaces and poor ventilation in many SSEA cities, restricting residents' ability to find relief during extreme heat events [Estoque et al. (2017)]. Beyond traditional infrastructure, nature-based solutions–such as integrating green spaces, urban forests and natural water bodies into urban design–are critical adaptation measures to mitigate the health impacts of extreme heat. These features help create cooler environments through natural shading while enhancing biodiversity, improving air quality and fostering healthier, more livable cities. A study conducted in Los Angeles estimated that an adequate number of trees, combined with cool surfaces on rooftops and pavements, could reduce heatwave-related mortality by 25 percent [Kalkstein et al. (2022)]. Additionally, McDonald et al. (2020) estimated that urban trees across the United States generate USD5.3 billion to USD12.1 billion in economic value by mitigating heat-related illnesses and deaths, as well as reducing electricity consumption.

4.3 Methodology

The following fixed effect regression is estimated to identify the impact of temperature exposure on mortality (MT):

Equation 1

$$MT_{icym} = \alpha + f\left(T_{cym}\right) + \gamma X_{cym} + \eta M_{icym} + \pi_c + \rho_{ym} + \varepsilon_{icym}$$

where MT_{icym} is a dummy variable, indicating the mortality status of individual i living in cluster c during year y and month m. It takes the value 1 if the individual died in cluster c during year y and month m according to the survey and 0 otherwise. x_{cym} represents a set of control variables at the cluster-by-year-month level, such as precipitation in previous months and other time-variant characteristics of the cluster. M_{icym} refers to a set of individual-level control variables. When analyzing the infant temperature-mortality model separately, the analysis includes covariates such as maternal age, parental education, gender of child, multiple birth indicators and family size. For the overall population temperature-mortality model, the analysis incorporates factors such as the individual's gender, household size and characteristics of their siblings. To mitigate potential under-representative measurement errors caused by the survey sampling process, the analysis applies age-specific weighting in the regression, using data from the Economic and Social Commission for Asia and the Pacific 1990 statistics.

In the model, π_c and ρ_{ym} represent cluster fixed effects and year-month fixed effects, respectively. Including cluster fixed effects can help control for time-invariant characteristics within each cluster, which can confound the temperature-health relationship, such as culture factors, geolocation, elevation and many other long-term factors of the cluster. Year-month fixed effects control for all time-variant common shocks affecting all clusters. In some specifications, the analysis further controls for fixed effects using cluster-by-quarter birth dummies, denoted by λ_{cyq}, which eliminates confounding factors that vary at the cluster-by-quarter level.

The temperature response function is represented by $f(T_{cym})$. For infant deaths, the model focuses on daily temperature exposure during both the in-utero period and in the month of birth, using linear models, higher-order polynomials and splines. Since the Demographic and Health Survey (DHS) data does not report the exact date of the mother's last menstrual period to estimate the date of conception, the analysis considers the nine months preceding the child's birth as the in-utero period. A widely used function form of $f\left(T_{cym}\right)$ is the binned model, expressed as:

Equation 2

$$f\left(T_{cym}\right) = \sum\nolimits_k \beta_j T_{cym}^k$$

where $T_{cym}^{k=1}$ indicates the number of days in a given location, month, and year (cym) where the average daily temperature fell below 0 degrees, $T_{cym}^{k=2}$ represents the number of days with average daily temperature in the (0, 3] interval, $T_{cym}^{k=3}$ for temperature in the (3, 6] interval, and so on. The 12-15 degrees temperature bin is the reference group, so the obtained coefficients of interest can be interpreted as the effect on monthly health outcomes of an additional day spent in bin j, relative to a day spent in the (12 °C, 15 °C] bin.

Two approaches are applied to estimate the heterogenous temperature-health relationship across demographics and socioeconomic factors, identifying groups more vulnerable to extreme heat and exploring potentially effective adaptation methods. The first approach involves re-running the regression for different sub-groups, such as gender and age. This allows for direct comparisons of the estimates of $f\left(T_{cym}\right)$ across these groups. The second approach compares the across-group response function by introducing an interaction term between demographic and socioeconomic factors and the temperature-health function $\left(J_{ic} \times f\left(T_{cym}\right)\right)$:

Equation 3

$$MT_{icym} = \alpha + f\left(T_{cym}\right) + \beta J_{ic} \times f\left(T_{cym}\right) + \gamma X_{cym} + \eta M_{icym} + \pi_c + \rho_{ym} + \varepsilon_{icym}$$

where J_{ic} refers to individual or cluster-level (generally time-invariant) characteristics, such as gender, age group, income level, employment and access to different infrastructure facilities. J_{ic}, therefore, is interpretated as a mediating factor that can potentially reshape the temperature-health relation. The advantage of using this interaction function is that it tests for the difference significance across different models. If the interaction term's coefficient is statistically significant (based on its p-value), it suggests that the effect of temperature on mortality varies significantly between the groups being compared.

To specifically assess the impact of high temperatures, the following model specification is used:

Equation 4

$$MT_{icym} = \alpha + \beta T_{30^{\circ}\mathrm{C}} + \gamma X_{cym} + \eta M_{icym} + \pi_c + \rho_{ym} + \varepsilon_{icym}$$

where $T_{30^{\circ}\mathrm{C}}$ measures the cumulative degree days (CDDs) greater than 30°C. $T_{30^{\circ}\mathrm{C}}$ can be illustrated by the following example: in Delhi in July 2005, if there were two days when the temperature exceeded 30°C, with one day reaching 35°C and another 40°C, the cumulative degree days over 30°C would be calculated as:

Equation 5

$$\mathrm{CDD} = (35 - 30) + (40 - 30) = 15$$

4.4 Data

Health data. Mortality data is sourced from the DHS. The DHS conducts comprehensive household and individual-level health surveys across over 90 countries, collecting information on infant and child mortality from parents and adult mortality from siblings. It has been widely used for mortality-related analyses, particularly in regions where more comprehensive data sources like those from the Centers for Disease Control and Prevention (CDC) are unavailable [Deribew et al. (2016)]. While the DHS may not offer mortality records as detailed as the CDC's, it remains a valuable and feasible alternative for studying mortality patterns in many low- and middle-income countries.

For each individual level death incidence, the dataset includes its location cluster and the exact timing in terms of year and month. Table 6 summarizes the population size, period coverage, and number of location clusters involved for each country sampled. The analysis includes data on 3,360,451 individuals from 64,606 clusters, spanning the years 1963 to 2022 across the eight countries in South and Southeast Asia.

Climate data. Climate data is obtained from the ERA5, which is produced by the Copernicus Climate Change Service at the European Centre for Medium-Range Weather Forecasts. The ERA5 offers a global atmospheric reanalysis, covering climate data from 1940 onward. The raw ERA5 data provides hourly estimates of climate variables at a 0.25°x0.25° horizontal resolution. The single-level atmospheric product of ERA5 is used to generate the cluster-by-day climate factors. For example, the temperature variable derived from single level ERA5 represents the temperature measured 2 meters above the land's surface. Reanalysis data offers the advantage of uniform availability across time and space, minimizing measurement error related to

Table 6: Summary Statistics for Selected SSEA Countries

Country Name	Population Size	Period Coverage	Number of Clusters	Urban Clusters, %
Panel A. South Asia				
India	2,579,752	1970-2021	57,389	44.9
Pakistan	88,970	1970-2018	1,246	43.7
Bangladesh	233,294	1963-2018	1,129	44.4
Panel B. Southeast Asia				
Myanmar	22,989	1980-2016	441	27.7
Cambodia	185,642	1965-2021	1,147	42.6
Timor-Leste	64,620	1974-2016	552	31.0
Indonesia	35,238	1965-2003	572	44.4
Philippines	149,946	1968-2022	2,130	45.8

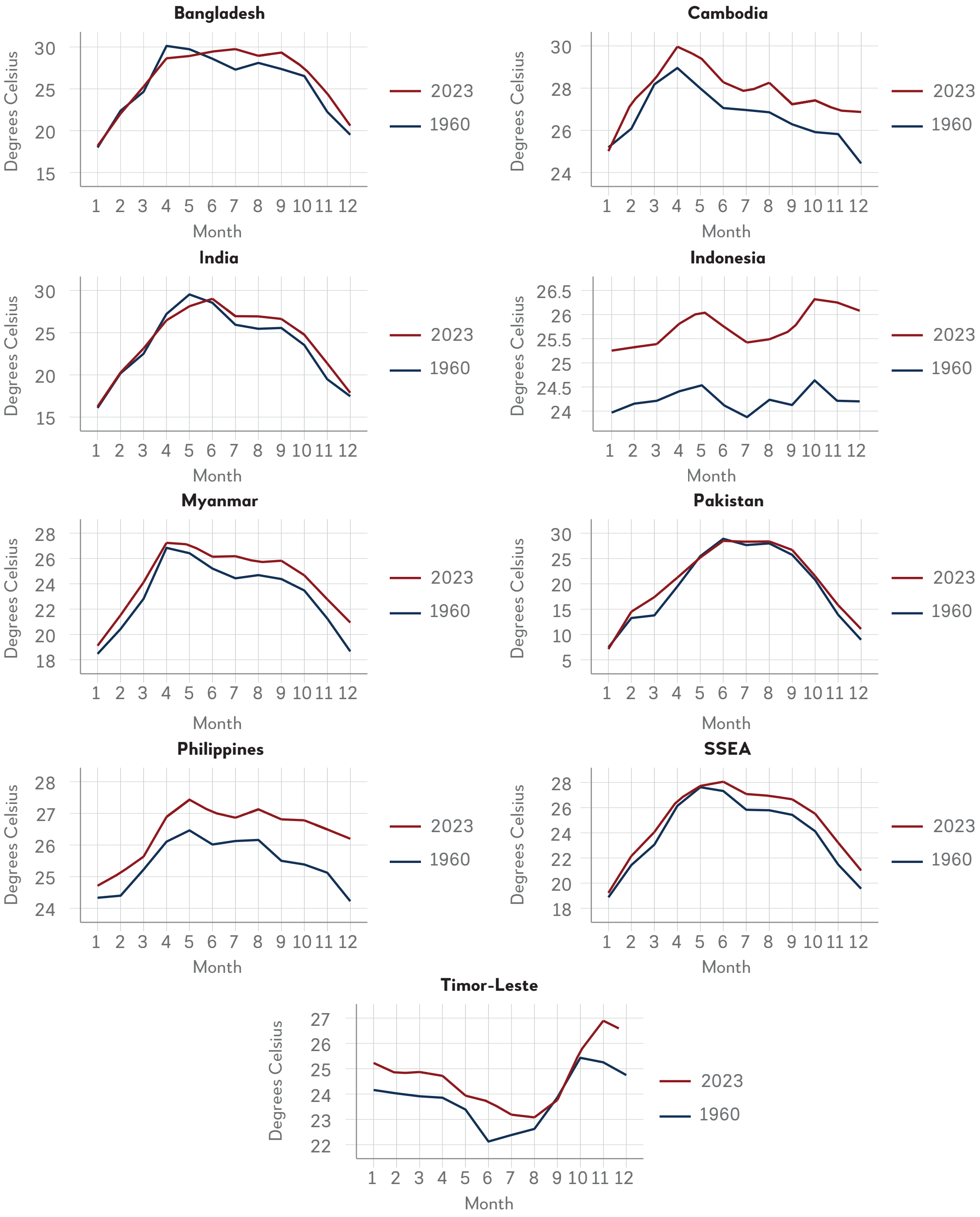
Source: Based on data from the DHS.

cluster-level characteristics. Due to these benefits, reanalysis data has been increasingly utilized in economic research [Burgess et al. (2013)].

Figure 25 illustrates the average monthly temperatures (calculated across the entire region for each month) in SSEA countries in 1960 and 2023, demonstrating a clear upward trend in temperatures across most months for all selected SSEA countries.

The number of people in the SSEA region affected by extreme heat has risen due not only to increasing temperatures but also to population growth and

Figure 25: Climate Change in SSEA: Average Temperature in 1960 vs. 2023



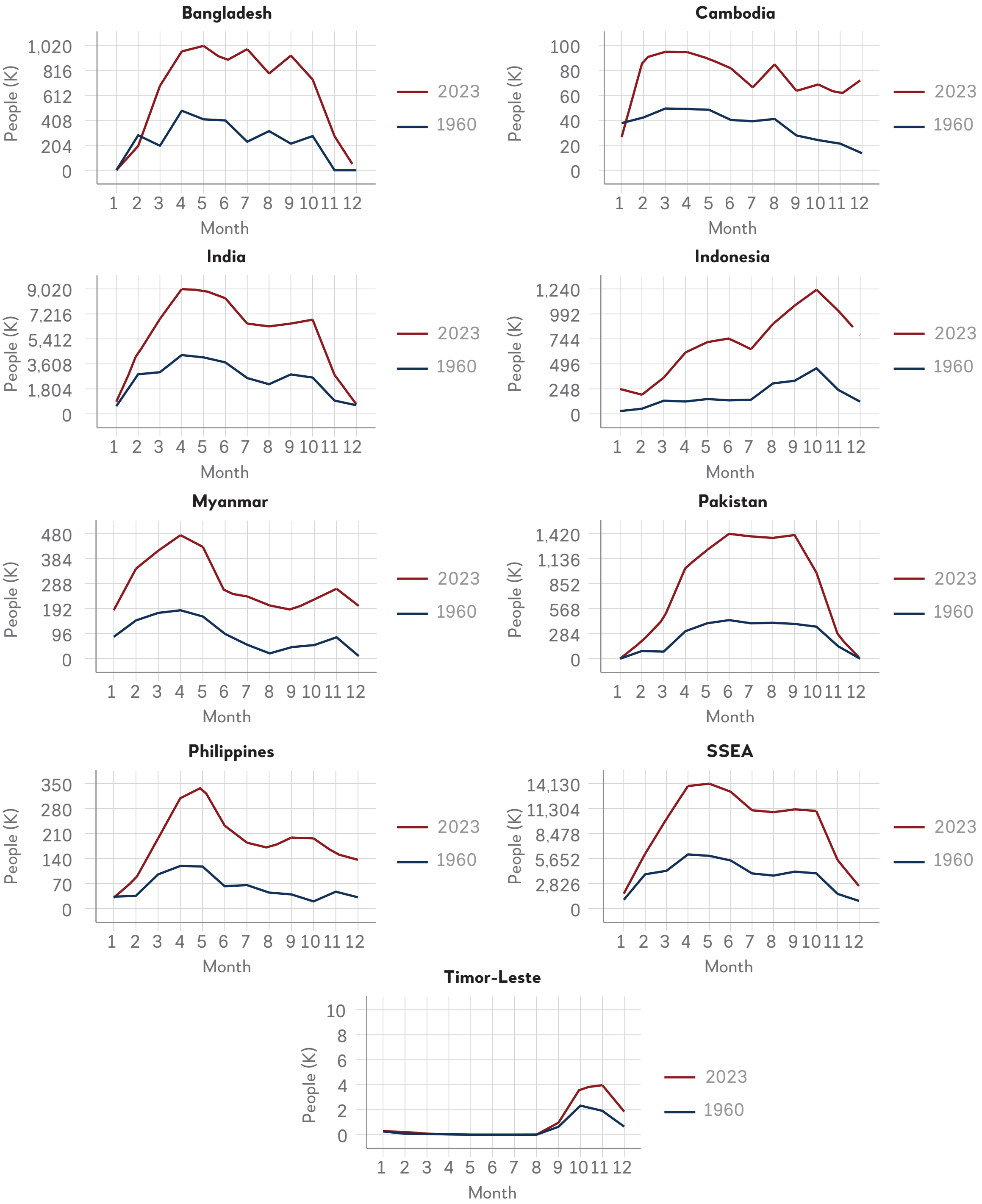
Source: Temperature data derived from the ERA5 Reanalysis.

Notes: SSEA = South and Southeast Asia.

urban migration (see Figure 26). As the population continues to grow, projections suggest that by 2080, approximately 1 billion people in SSEA will face extreme heat for about a month each year, further intensifying the severity of the situation [IPCC (2023b)].

Other data and variables. Socioeconomic factors related to adaptation strategies were obtained from both the DHS and various country profiles. From the DHS database, each cluster and individual reported their access to electricity, roads, ports, medical facilities and other resources relevant to

Figure 26: Population Affected by Max Daily Temperatures Above 30°C (1960 vs. 2023)



Source: Copernicus Complete ERA5 Global Atmospheric Reanalysis (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-complete) (September 2024); Copernicus GHSL – Global Human Settlement Layer (https://human-settlement.emergency.copernicus.eu/).

climate change adaptation. Country-level data from the World Bank and the European Union's Copernicus project provided macro factors such as GDP, per capita GDP, population and air conditioner coverage. These were included in the regression analysis to explore heterogeneous response functions across countries.

4.5 Results: Health Impacts of Extreme Heat in South and Southeast Asia Countries

4.5.1 The Impact of Extreme Heat on Total Population Mortality

Binned model results on overall temperature-mortality relationship. Figure 27 presents the results of a temperature bin model (binned model) examining the nonlinear relationship between temperature exposure and population mortality. The reference group is a mild temperature range of 12 to 15°C, which serves as the baseline for comparison. The analysis reveals that an additional day of exposure to temperatures above 24°C significantly increases mortality risk across all populations. Specifically, exposure to one additional day of temperatures exceeding 30°C annually raises the overall population death risk by 1.6 per 10,000 compared to the reference group.

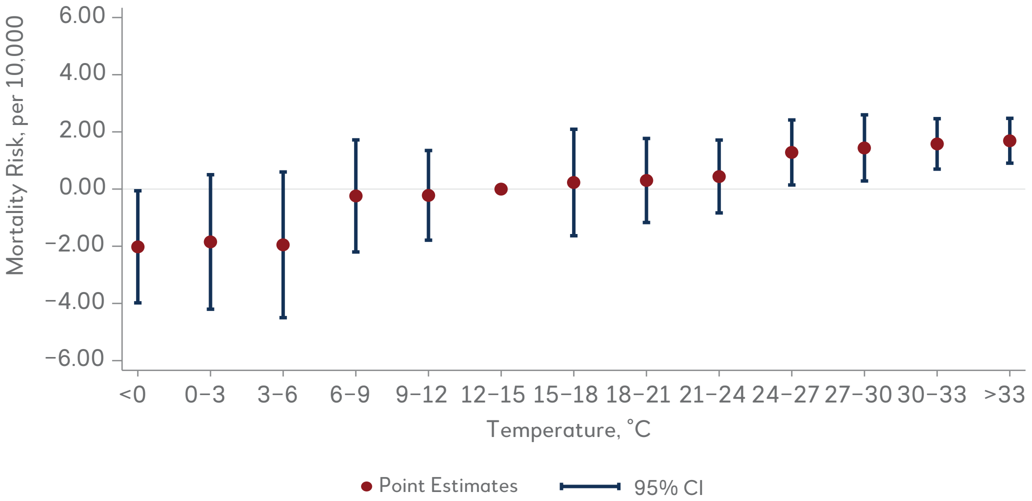
CDD model results on overall temperature-mortality relationship. Table 7 presents the results of the CDD model, which measures the cumulative temperature exceeding a specific threshold (30°C in this case), reflecting both the intensity and duration of high-temperature exposure. The coefficients in columns 1 to 6 show that each additional cumulative degree day above 30°C is associated with a positive and statistically significant increase in mortality risk across all model specifications.

4.5.2 Total Population Mortality: by Gender and by Age Groups

Temperature impact across gender groups. Figure 28 indicates that both males and females exhibit a general trend of increasing mortality risk as temperatures rise. However, it does not reveal any substantial differences between genders regarding the impact of temperature. While the male population shows marginally higher coefficients, especially in higher temperature ranges, these estimates are not consistently statistically significant for some of the temperature bins.

Temperature impact across age groups. Figure 29 shows that the groups most vulnerable to high temperatures are infants, young children and the elderly. The mortality risk for infants is significantly higher than other age groups, with one additional day of temperatures exceeding 30°C annually raising the infant death risk by 21.8 per 10,000.

Figure 27: Impact of Temperature on Total Population Mortality



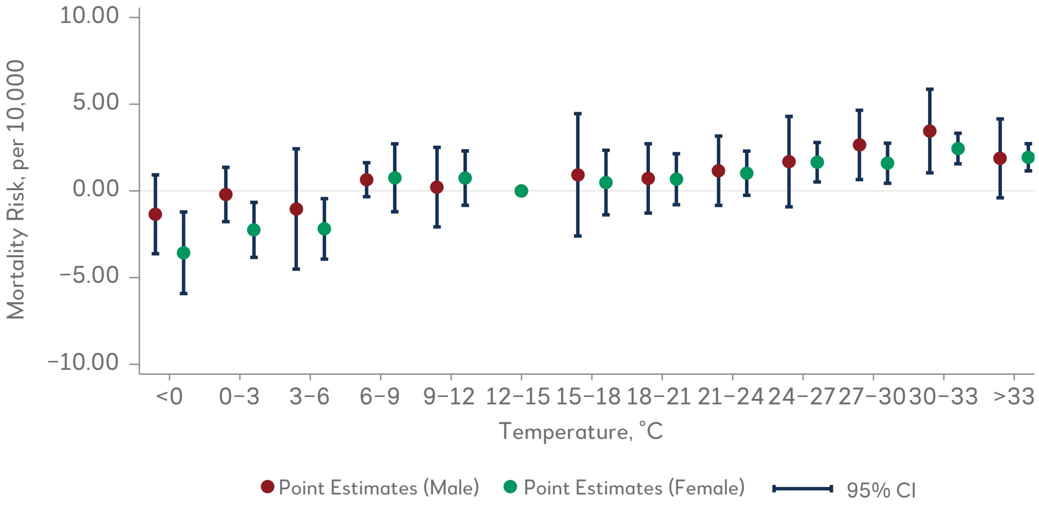
Source: AIIB staff estimates.

Table 7: Effects of Temperature Exposure on Overall Population Mortality

	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative Degree Days Exceeding 30°C	0.005**	0.004**	0.004***	0.003*	0.004**	0.004**
	(0.003)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)
R-Squared	0.461	0.772	0.786	0.505	0.780	0.867
Observations	4,571,002	4,571,002	4,571,002	4,571,002	4,571,002	4,571,002
Number of Clusters	64,606	64,606	64,606	64,606	64,606	64,606
Individual Controls		Y	Y		Y	Y
Family Controls			Y			Y
Interview Year Fixed Effects				Y	Y	Y
Cluster Fixed Effects	Y	Y	Y	Y	Y	Y
Birth Year Fixed Effects	Y	Y	Y	Y	Y	Y

Notes: *** p<0.01, ** p<0.05, * p<0.1. All standard errors are clustered at the DHS cluster level and are reported in parentheses; mortality risk: per 1,000 people.

Figure 28: Impact of Temperature on Mortality Across Gender Groups



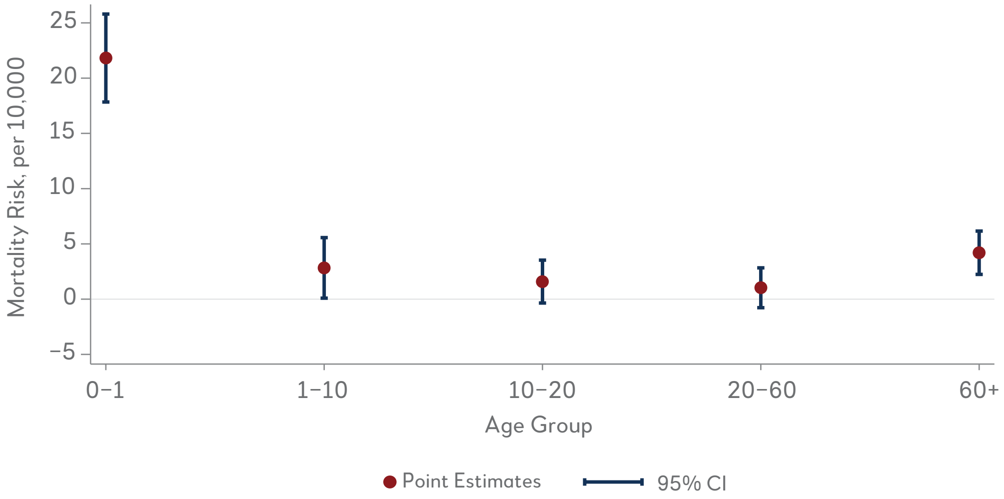
Source: AIIB staff estimates.

While not as severe as for infants, children aged 1-10 also experience a notable increase in mortality risk, with a significant positive coefficient of 2.8. The elderly population (over 60) similarly exhibits an elevated mortality risk, with one additional day of temperatures exceeding 30°C annually associated with a death risk of 4.2 per 10,000.

4.5.3 The Impact of Extreme Heat on Infant Mortality

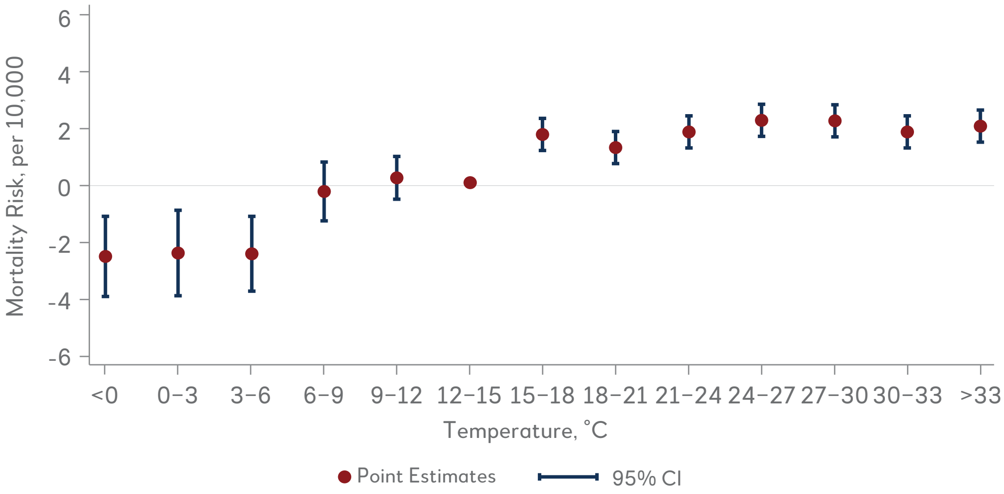
Binned model results on the relationship between in utero temperature exposure and infant mortality. Figure 30 clearly indicates that infant health is highly vulnerable to rising temperatures. Higher temperatures during pregnancy are linked to an increased risk of infant mortality. Specifically,

Figure 29: Impact of Temperature on Mortality Across Different Age Groups (>30°C)



Source: AIIB staff estimates.

Figure 30: Impact of In Utero Temperature Exposure on Infant Mortality



Source: AIIB staff estimates.

in utero exposure to one additional day above 30°C is associated with an increase of 17.8 infant deaths per 10,000 live births, compared to a reference temperature range of 12-15°C.

CDD model results on the relationship between in utero temperature exposure and infant mortality. Table 8 provides robust evidence of a significant positive relationship between in utero exposure to high temperatures and infant mortality using the CDD model. Across all six model specifications, the coefficient for CDD exceeding 30°C remains positive and statistically significant, ranging from 0.018 to 0.028. The inclusion of various control variables, such as individual, family and fixed effects (including cluster and birth year-month fixed effects), reinforces the robustness of the results. These consistent findings across different model specifications suggest a causal link between high-temperature exposure during pregnancy and increased infant mortality risk.

CDD model sensitivity analysis. The sensitivity analysis presented in Table 9 further strengthens the findings by exploring the effects of in utero temperature exposure on infant mortality across various CDD thresholds. The findings consistently demonstrate that higher temperature thresholds result in stronger and more statistically significant impacts on infant mortality. Specifically, CDDs

Table 8: Effects of In Utero Temperature Exposure on Infant Mortality

	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative Degree Days Exceeding 30°C	0.025***	0.028***	0.026***	0.018**	0.019**	0.019**
	(0.007)	(0.007)	(0.008)	(0.009)	(0.008)	(0.007)
R-Squared	0.761	0.802	0.858	0.701	0.737	0.813
Observations	3,360,451	3,360,451	3,360,451	3,360,451	3,360,451	3,360,451
Number of Clusters	64,606	64,606	64,606	64,606	64,606	64,606
Individual Controls		Y	Y		Y	Y
Family Controls			Y			Y
Cluster FE	Y	Y	Y			
Birth Year-Month FE	Y	Y	Y			
Birth Year-Cluster FE				Y	Y	Y
Birth Month FE				Y	Y	Y

Notes: *** p<0.01, ** p<0.05, * p<0.1. All standard errors are clustered at the DHS cluster level and are reported in parentheses; mortality risk: per 1,000 people.

exceeding 33°C exhibit the most substantial effects, with coefficients of 0.030 and 0.032 in models (1) and (2), both significant at the 1 percent level. As the temperature threshold decreases, the coefficients' size and statistical significance decline. For example, CDDs exceeding 27°C still show a significant effect at the 5 percent level, but the impact is smaller than higher temperature thresholds. Meanwhile, thresholds of 21°C and 18°C are no longer statistically significant, indicating that the effect of temperatures below 27°C on infant mortality is less pronounced.

Overall, these results confirm the robustness of the main conclusion: higher temperatures during pregnancy, particularly those above 27°C, are associated with an increased risk of infant mortality. The stronger effects at higher temperature thresholds emphasize extreme heat's harmful impacts on prenatal development and infant health.

4.6 The Role of Infrastructure in Mitigating Heat-related Health Risks

When examining the role of infrastructure in mitigating the health impacts of extreme heat, it is crucial first to understand how heat affects urban and rural areas differently. These settings experience and respond to extreme heat in distinct ways due to variations in infrastructure, population density, environmental conditions and socioeconomic factors. Analyzing these differences allows policymakers to develop infrastructure solutions tailored to the unique challenges of each environment, ensuring that both urban and rural populations receive appropriate protection.

Urban areas, while generally better equipped with infrastructure, face severe heat-related challenges due to the urban heat island effect, where concrete and asphalt absorb and retain heat, leading to significantly higher temperatures compared to surrounding rural areas. This phenomenon mainly affects densely populated urban centers with limited green spaces, amplifying the risks associated with extreme heat for city dwellers [He et al. (2021)]. On the other hand, rural areas may have different challenges. While rural regions often benefit from more natural cooling through vegetation and less dense human activities, they may lack adequate infrastructure to effectively address heat-related health risks [López-Bueno et al. (2021)]. Rural areas frequently face challenges such as limited access to electricity, healthcare facilities, transportation networks and emergency services [Hua et al. (2023); Lu et al. (2022); Douthit et al. (2015)].

Table 9: Effects of In Utero Temperature Exposure on Infant Mortality (Alternative Thresholds)

	(1)	(2)
Cumulative Degree Days Exceeding 33°C	0.030***	0.032***
	(0.010)	(0.008)
Cumulative Degree Days Exceeding 27°C	0.018**	0.017**
	(0.007)	(0.007)
Cumulative Degree Days Exceeding 24°C	0.012*	0.010
	(0.006)	(0.008)
Cumulative Degree Days Exceeding 21°C	0.007	0.008
	(0.005)	(0.007)
Cumulative Degree Days Exceeding 18°C	0.002	0.003
	(0.007)	(0.007)
Observations	3,360,451	3,360,451
Number of Clusters	64,606	64,606
Individual Controls	Y	Y
Family Controls	Y	Y
Cluster FE	Y	
Birth Year-Month FE	Y	
Birth Year-Cluster FE		Y
Birth Month FE		Y

Notes: *** p<0.01, ** p<0.05, * p<0.1. All standard errors are clustered at the DHS cluster level and are reported in parentheses; mortality risk: per 1,000 people.

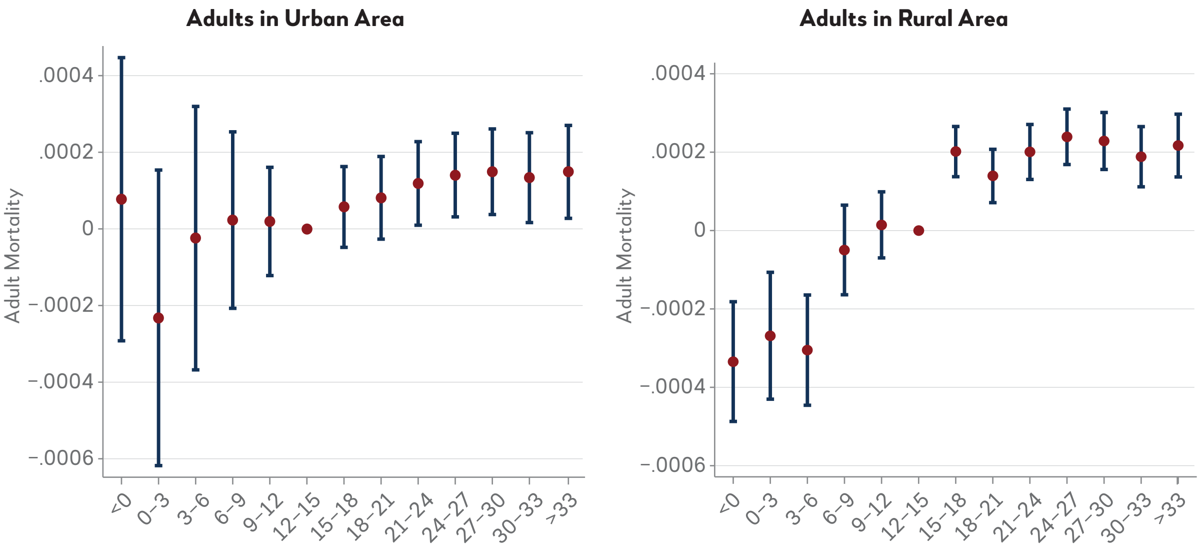
4.6.1 Heat-related Mortality: Urban vs. Rural Populations

Figure 31 highlights the significant difference in the health impact of extreme heat on adults living in urban versus rural areas. For adults residing in urban areas, there is no significant correlation between temperature and mortality when temperatures are below 21°C, as indicated by the confidence intervals crossing zero. However, once temperatures exceed 21°C, a positive and significant relationship emerges, though the coefficients remain relatively small. This suggests a moderate increase in mortality associated with higher temperatures in urban areas.

In contrast, adults living in rural areas show a significant correlation between temperature and mortality starting at temperatures above 18°C. The coefficients are notably larger than those observed in urban areas, indicating a stronger link between rising temperatures and mortality. This suggests that adults in rural areas are more vulnerable to temperature increases, particularly at higher thresholds.

Compared to urban areas, the stronger relationship between extreme heat and mortality in rural areas can be attributed to several factors. Rural populations often have limited access to healthcare, making it more challenging to treat heat-related illnesses promptly. Additionally, rural infrastructure is generally less developed, with fewer cooling centers, air conditioning and public transportation, leaving people more exposed to extreme heat. Many rural workers are also engaged in outdoor occupations like agriculture and construction, which involve prolonged exposure to high temperatures, whereas urban jobs are more likely to be indoors with climate control, offering better protection from heat. These factors combined contribute to the heightened vulnerability of rural populations to extreme heat.

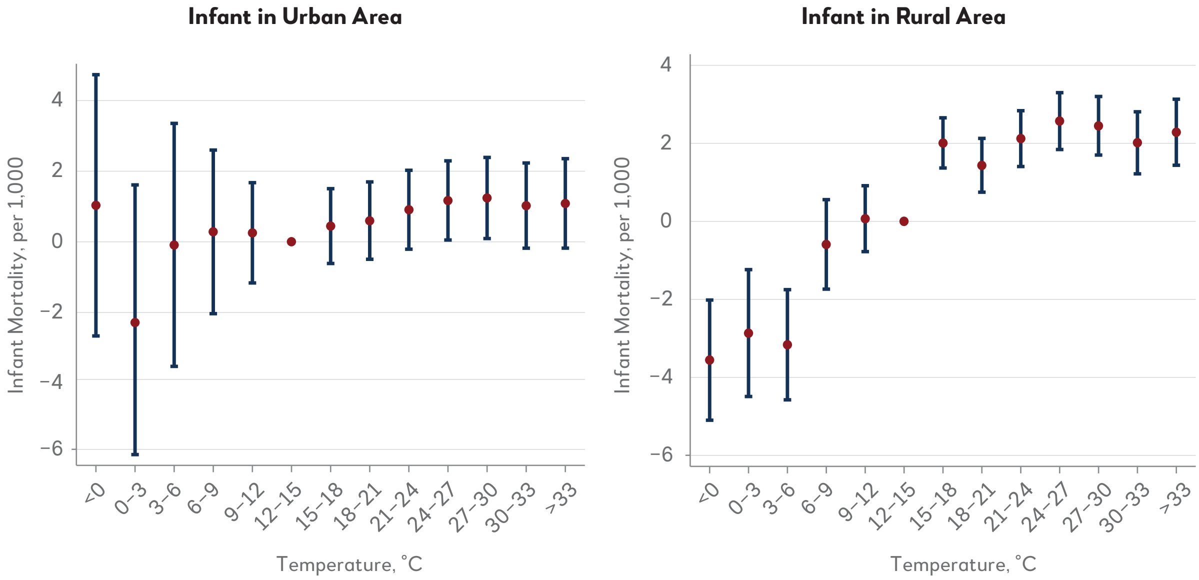
Figure 31: Adult Mortality by Living Area (Urban vs. Rural)



Source: AIIB staff estimates.

Notes: Left chart shows the effects on adults living in urban areas; right chart shows the effects on adults living in rural areas.

Figure 32: Infant Mortality by Living Area (Urban vs. Rural)



Source: AIIB staff estimates.

Notes: Left chart shows the effects on infants in urban areas; right chart shows the effects on infants in rural areas.

Figure 32 shows the relationship between temperature and infant mortality in urban and rural areas. In urban areas, there appears to be no significant relationship between infant mortality and temperature for most of the temperature range, as the confidence intervals overlap with zero, indicating less statistical significance.

In contrast, the relationship becomes significant for rural areas at temperatures above 18°C, with the coefficients increasing notably as the temperature rises. This suggests that infants in rural areas are more vulnerable to extreme heat, with a clear positive relationship between higher temperatures and increased infant mortality, particularly above

18°C. The coefficients in rural areas are also much larger compared to urban areas, indicating a more substantial effect of temperature on infant mortality in rural regions.

This result is consistent with the temperature-adult mortality relationship for urban and rural areas, with rural populations being more vulnerable to extreme heat than urban populations. Rural areas exhibit a stronger and more significant relationship between temperature and mortality in both cases.

4.6.2 Heat-related Mortality: Access to Medical Facilities

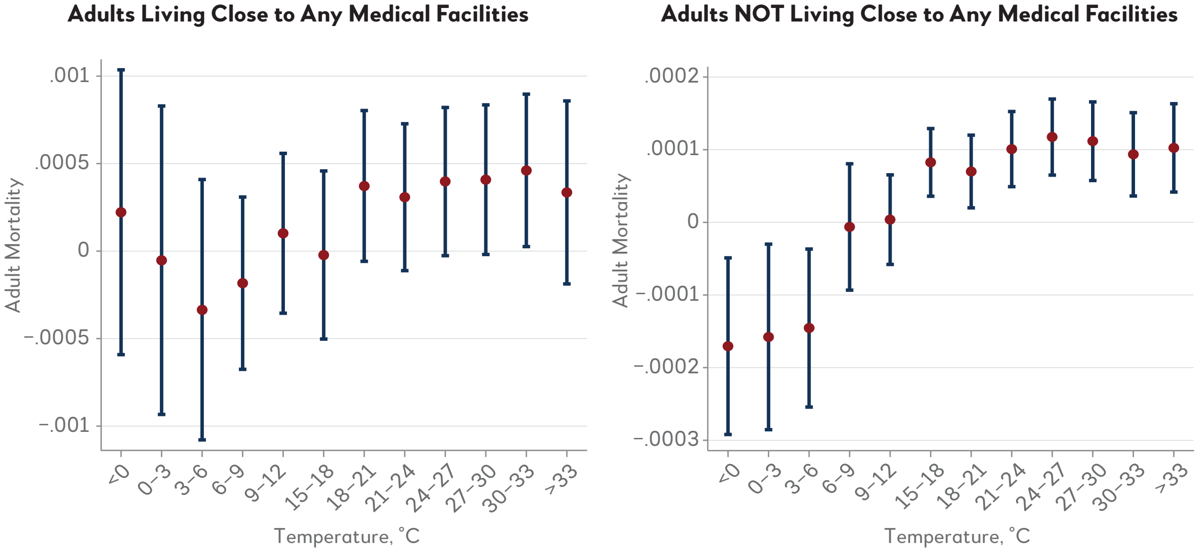
Healthcare systems are the first line of defense in managing heat-related illnesses and preventing fatalities. However, the SSEA region faces significant challenges in healthcare access due to insufficient healthcare facilities and trained medical professionals. Most countries in these regions have fewer than two hospital beds per 1,000 people, which falls well below the Organisation for Economic Co-operation and Development (OECD) average of 4.6 beds per 1,000 population. The shortage extends to medical professionals, with the number of doctors per 1,000 people varying widely across the region, from as low as 0.2 in Cambodia to 2.5 in Singapore. Even at its highest, this figure remains below the OECD average of 3.6 doctors per 1,000 people [OECD & WHO (2022)].

The insufficiency of health facilities directly impacts the proximity of populations to medical care. This is particularly problematic in rural and remote areas, where the scarcity of healthcare facilities often means that residents must travel long distances to access even basic medical care [Douthit et al. (2015)]. During extreme heat events, the demand for medical care, including emergency responses and long-term management, rises dramatically [Wondmagegn et al. (2019)]. The following section examines how proximity to medical facilities influences the ability to mitigate the health impacts of extreme heat on both adults and infants.

Figure 33 highlights the role of medical facilities in mitigating the health impacts of extreme heat on adults by comparing those living near medical facilities with those who do not.

Adults Living Close to Medical Facilities: The left panel shows that individuals residing near medical facilities exhibit a positive relationship between extreme heat and mortality at temperatures above 21°C. However, the coefficients are statistically insignificant in many cases, as indicated by the

Figure 33: Medical Facilities and Health Impact of Extreme Heat (Adults)



Source: AIIB staff estimates.

Notes: Left chart shows the effects on adults living close to medical facilities; right chart shows the effects on adults not living close to medical facilities.

overlapping confidence intervals. This suggests that living close to medical facilities may mitigate some heat-related risks, as extreme heat has a less pronounced effect on mortality compared to the mortality rate for those without access to medical facilities.

Adults NOT Living Close to Medical Facilities: The right panel, on the other hand, demonstrates a more significant positive relationship between extreme heat and mortality for those not living near medical facilities.

The relationship becomes significant at lower temperature thresholds (above 15°C), and the coefficients remain consistently positive and increase as the temperature rises, indicating a higher mortality risk due to heat. This highlights the increased vulnerability of individuals without proximity to medical care.

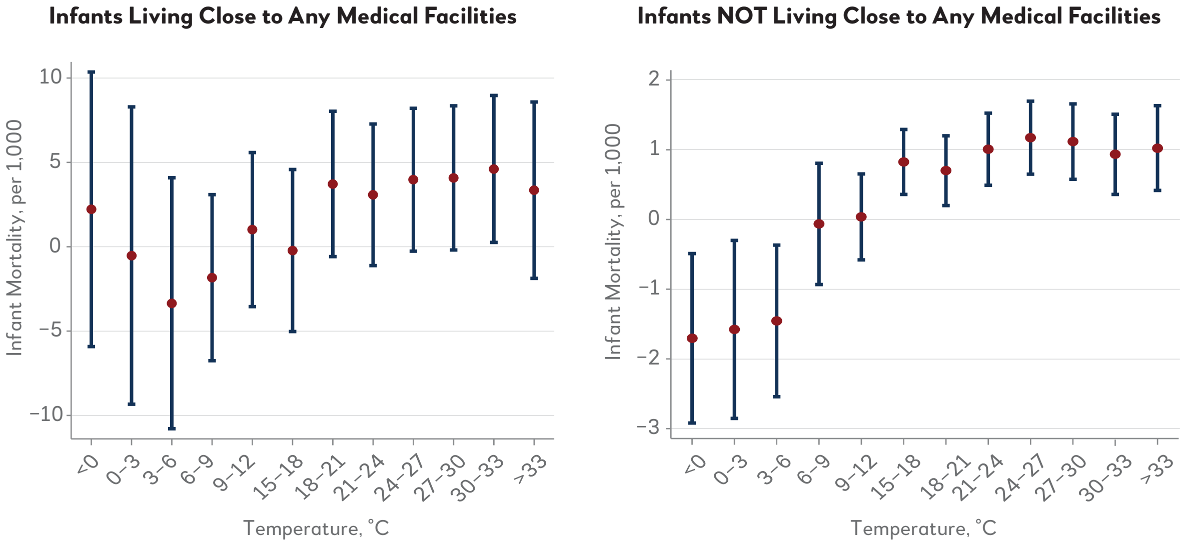
Overall, the graph underscores the crucial role of medical facilities in mitigating the health impacts of extreme heat. Individuals living close to medical facilities are more likely to receive timely treatment for heat-related conditions such as heatstroke, dehydration and other complications, which can significantly reduce the risk of mortality during heatwaves. Proximity to healthcare services also improves access to health information, preventive care and resources, such as guidance on avoiding heat exposure and recognizing early symptoms of heat-related illnesses, promoting more proactive health management. Additionally, many healthcare centers and hospitals are equipped with cooling systems, providing a refuge from extreme heat, making it more likely that people living nearby will use these spaces as cooling shelters during heatwaves.

Figure 34 presents similar findings regarding the role of medical facilities in mitigating the health impact of extreme heat on infants, comparing those living near medical facilities with those who do not.

Infants Living Close to Medical Facilities: The relationship between temperature and infant mortality appears less significant for infants living near medical facilities, as evidenced by the wide confidence intervals overlapping with zero across most temperature ranges. Even at higher temperatures, there is little notable impact on infant mortality, suggesting that proximity to healthcare facilities may reduce the risk of heat-related infant deaths.

Infants NOT Living Close to Medical Facilities: For infants not living close to medical facilities, there is a more pronounced positive relationship between temperature and mortality, particularly for

Figure 34: Medical Facilities and Health Impact of Extreme Heat (Infants)



Source: AIIB staff estimates.

Notes: Left chart shows the effects on infants close to medical facilities; right chart shows the effects on infants not close to medical facilities.

temperatures above 15°C. The coefficients increase consistently as temperatures rise, indicating a higher risk of infant mortality due to extreme heat for those without easy access to healthcare services.

Access to medical facilities acts as a critical buffer against the harmful health effects of extreme heat in both adults and infants, with proximity to healthcare providing enhanced protection against heat-related mortality. However, the mitigating effects appear stronger for infants than adults living near healthcare services, as evidenced by the near-insignificant impact on mortality for infants with access to medical care. This provides concrete evidence of the life-saving potential of timely access to healthcare during extreme heat events, which is especially vital for vulnerable populations like infants.

4.6.3 Heat-related Mortality: by Access to Electricity

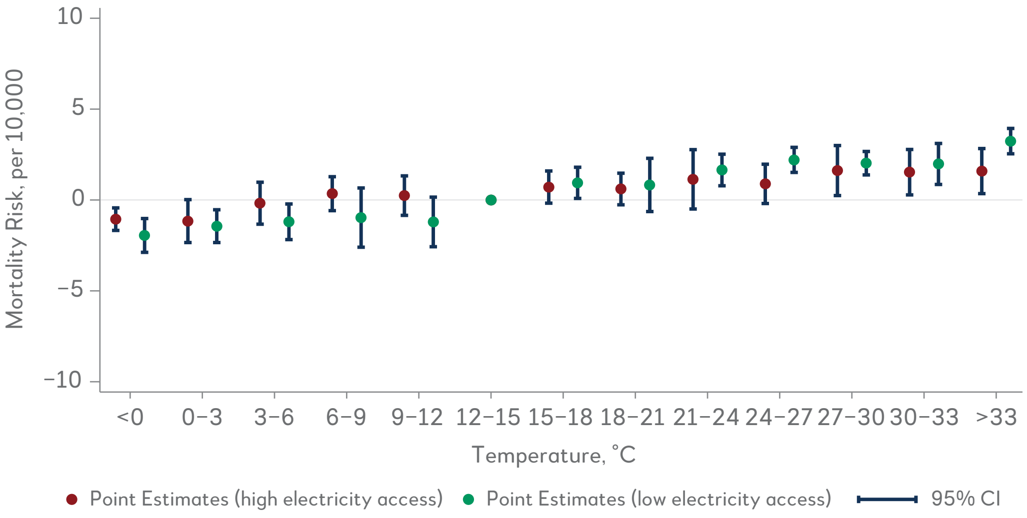
Electricity enables access to lifesaving cooling solutions such as air conditioning, fans, and refrigeration for medications, all of which are crucial during extreme heat events [Malik et al. (2022); Sahakian (2014); Ogle et al. (2016)]. Understanding the percentage reduction in mortality linked to electricity access demonstrates the tangible benefits of energy infrastructure in protecting vulnerable populations from heat-related deaths. The following section measures the effect of electricity access on mitigating extreme heat impact, using data from DHS household surveys.

Figure 35 reveals significant differences in how populations with high and low electricity access experience the health impacts of extreme heat. For populations with high electricity access, mortality risk increases gradually. It becomes significant only at higher temperatures (above 27°C), with the confidence intervals excluding zero, indicating a strong impact of high temperatures on mortality risk. In contrast, for populations with low electricity access, there is a substantial increase in mortality risk at lower temperature thresholds (above 21°C), and the overall risk is significantly higher compared to those with high electricity access. This highlights the crucial role of electricity access in mitigating the health impacts of extreme heat.

4.6.4 Heat-related Mortality: by Access to Public Transportation

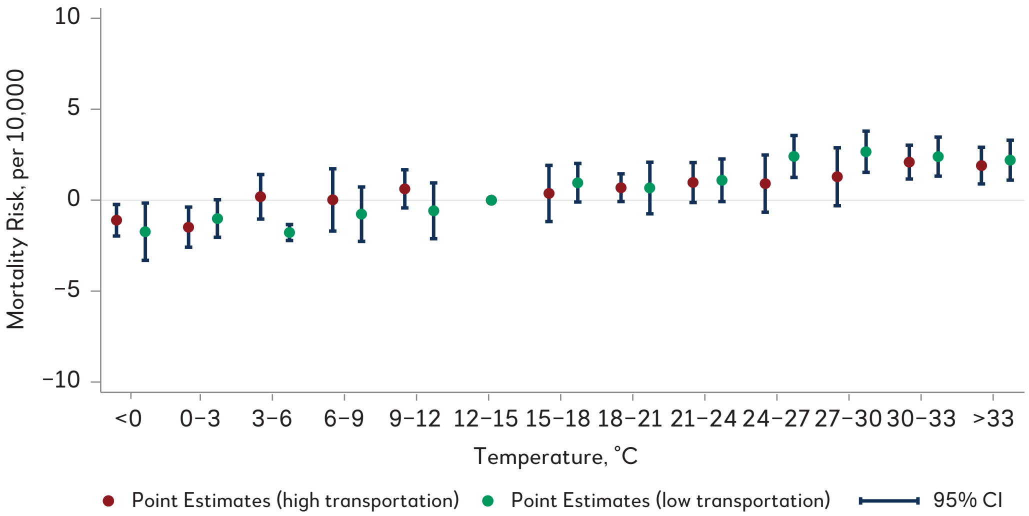
Access to public transportation reduces direct exposure to extreme heat by providing an alternative to walking or outdoor activities during peak temperatures. Reliable public transport also allows people to quickly reach medical facilities, cooling centers, or other safe locations, which can be lifesaving during heatwaves [Dvir et al. (2022)]. Additionally, well-designed public transport systems can decrease reliance on personal vehicles, thereby contributing to long-term heat mitigation strategies

Figure 35: Electricity Access and Health Impact of Extreme Heat



Source: AIIB staff estimates.

Figure 36: Public Transport and Health Impact of Extreme Heat



Source: AIIB staff estimates.

[Bleviss (2021)]. The following section assesses the impact of transportation infrastructure on mitigating the health effects of extreme heat.

Figure 36 highlights significant differences in the impact of extreme heat on populations with varying levels of public transportation access. For those with high access, mortality risk shows minimal change at moderate temperatures, with no statistically significant increases. The risk only becomes significant at higher temperatures (above 30°C) and remains lower compared to populations with limited transportation access. This suggests that those with low public transportation access are much more vulnerable to the health impacts of heatwaves, given the fewer options available to avoid extreme heat or reach essential services.

4.6.5 Heat-related Mortality: by Access to Green Space

Green spaces, like parks and urban forests, offer natural cooling and can potentially reduce the risk of heat-related illnesses [Zölch et al. (2016)]. They also promote physical activity and improve mental well-being [Nutsford et al. (2013)]. However, rapid urban growth in SSEA regions has resulted in fragmented and unevenly distributed green areas. For instance, in cities like Jakarta, Metro Manila, and Kuala Lumpur, green space has decreased from 45 percent to 20 percent over the past 25 years due to rapid urban expansion [Muhamad Nor et al. (2021)]. The situation is further exacerbated by commercial pressures and local governments' tendency to construct multipurpose buildings on existing green spaces [Sahakian et al. (2020)].

The following section explores the impact of green spaces, represented by the Leaf Area Index (LAI), which measures the density of leaf material in specific environments, on reducing heat-related health risks.[8]

Figure 37 reveals the differing impact of extreme temperatures on mortality risk for populations residing in areas with high and low Leaf Area Index (LAI), which reflects the density of green spaces. For populations living in areas with high LAI, mortality risk begins to rise at temperatures above 24°C but at a somewhat slower rate compared to those in low LAI areas. The risk only becomes statistically significant at high temperatures (above 30°C). Overall, populations in high LAI areas experience slightly smaller increases in mortality risk at higher temperature ranges. The potential role of green spaces in reducing heat-related risks requires much more extensive research.

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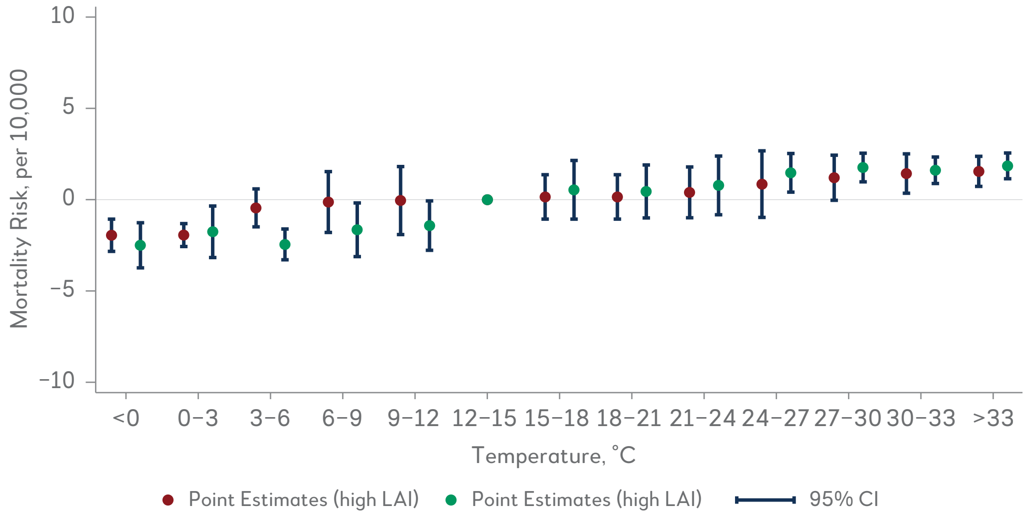
[8] For more details about the Leaf Area Index (LAI), see: https://gcos.wmo.int/en/essential-climate-variables/lai.

Figure 37: Green Space and Health Impact of Extreme Heat



Source: AIIB staff estimates.

4.7 Chapter Concluding Remarks

This chapter presents a comprehensive analysis of the impact of extreme heat on mortality rates in eight South and Southeast Asian countries, focusing on how various types of infrastructure can mitigate these effects. The study examines the relationship between high temperatures and mortality rates among the general population, elderly individuals, and infants while also investigating the role of medical facilities, electricity access, transportation networks and green spaces in reducing heat-related mortality.

The research provides crucial and novel quantification of heat-related mortality risks in the SSEA region. For the overall population, one additional day of temperatures exceeding 30°C annually increases the death risk by 1.6 per 10,000 (compared to a reference temperature of 12-15°C). The effect is more pronounced among the elderly over 60, where the risk rises to 4.2 per 10,000. Infants are found to be the most vulnerable, with one extra day above 30°C raising the death risk by 21.8 per 10,000—14 times the risk for the general population. Moreover, in utero exposure to extreme heat is also critical, with one additional day above 30°C associated with an increase of 17.8 infant deaths per 10,000 live births.

Another key contribution of this study is highlighting the understudied potential of various infrastructure interventions in reducing heat-related health risks. The results suggest that rural populations are more vulnerable to extreme heat than urban populations, likely due to inadequate infrastructure. Statistically, individuals with access to medical facilities, electricity and public transportation are less affected by extreme heat. Additionally, green infrastructure, which integrates nature-based solutions into urban planning and built environments, is a critical adaptation measure for mitigating the health impacts of extreme heat. There is also a need to consider more heat shielding measures for homes and workplaces (including retrofitting existing ones).

This research contributes to our understanding of the relationship between extreme heat, mortality, and infrastructure, providing valuable insights for policymakers, urban planners and public health officials in developing effective strategies to protect vulnerable populations from the increasing threat of heat-related health risks. The differences in vulnerability across age groups call for targeted interventions, focusing particularly on protecting infants and the elderly during extreme heat events. The higher vulnerability of rural populations highlights the need for improved infrastructure development in these areas to enhance heat resilience. The research highlights the importance of investing in key infrastructure—medical facilities, electricity networks, public transportation and green spaces—as a strategy to mitigate heat-related mortality. It also opens avenues for further research into how different types of infrastructure contribute to heat resilience and how these can be optimized in various geographical and socioeconomic contexts.

CHAPTER 5

CHEMICAL HAZARD AND HEALTH

LEAD – AN OLD POISON WITH NEW CHALLENGES

Highlights

- Lead is a widespread multi-system toxin that affects our bodies and brains; lead exposure in humans is responsible for 1.6 to 5.5 million deaths every year.
- One in three children worldwide has elevated blood lead levels (BLLs) above the World Health Organization (WHO) reference level for clinical intervention. Almost all of these children live in low- and middle-income countries. Each year, lead exposure globally is estimated to be responsible for the loss of 765 million IQ points, resulting in USD1.4 trillion in income losses, comprising 1.6 percent of global GDP.
- There are many sources of lead exposure from the use of lead in infrastructure, including lead-acid batteries for vehicles and green energy storage; lead paint; lead pipes and plumbing fixtures; specialty construction materials; and legacy pollution from prior use of leaded petrol, which has now been globally eliminated.
- Lead pollution and exposure can be dramatically reduced through investments in recycling facilities, sound recycling practices for lead-acid batteries, supported by appropriate regulation, capital investment, and operational financing on both the supply and demand sides.

5.1 Lead and Why It Is Widely Used

Lead is a multisystem toxin that hurts bodies and brains. Between 1.6 and 5.5 million people die annually due to lead exposure, and the toll is higher than malaria and HIV combined [see Vaduganathan et al. (2022); Larsen and Sánchez-Triana (2023)]. At the same time, through its neurotoxic effects, lead exposure impairs IQ. The social and economic implications of these losses are staggering—by one estimate adding up to USD6.0 trillion for every additional year of exposure.

These harms are considerable because lead is easily mined and recycled, with widespread use at the global level. Humans have done so since antiquity. Its applications are manifold: lead pipes have carried water across global cities, starting in ancient Rome; lead shielding protects telecommunication cables; lead acid batteries are used as starter batteries in all vehicles and deep cycle applications in energy storage for off-grid solar home systems and electric three-wheelers in low- or middle-income countries (LMIC); leaded gasoline has powered automobiles for most of the 20th century; and lead paint adorns the walls of homes, businesses and public spaces. This widespread use of lead occurs despite risks recognized for over 2000 years.

There is no safe level of lead, and even low exposure levels can cause devastating cognitive deficits, behavioral problems, cardiovascular disease risk and other health problems, with relatively large effects at the population level [EPA (2024)]. Children are most vulnerable. Since the late 1970s, growing global awareness about lead's danger has prompted efforts to phase lead out from petrol, paint, and, to a lesser extent, other sources of human exposure. As of 2021, all countries have eliminated the use of leaded petrol in automobiles—although it is still used to power small-engine aircraft—and as of 2022, at least 94 countries have regulations on lead paint [see UNEP (2021); Science (2023)].

While lead has many applications, at least 85 percent of lead production is now used for lead-acid batteries [ILZSG (2023)]. These batteries often have a short lifetime, typically from three to five years for car starter batteries, around five years for solar applications and two to three years for electric three-wheelers. Lead in lead-acid batteries is almost 100 percent recyclable, and the frequent need for battery replacement, combined with the high value of lead, encourages recycling, making lead-acid batteries a successful example of a circular economy in developed countries. In the long-term, demand for lead-acid batteries will likely slow, given the transition to lithium-ion technologies, which represented just 14 percent of the overall market (by energy output) in 2015 but are projected to comprise 81 percent by 2030. Demand for lead-acid batteries will continue to grow in the immediate future.

Continued economic demand for lead is reflected in commodity prices and ongoing mining operations. Since 2010, commodity prices have remained relatively stable at about USD2,000 per metric ton. Globally, 4.5 million metric tons of lead were newly mined in 2023, with production concentrated in China (42 percent), Australia (10 percent), Mexico (6 percent), the United States (6 percent) and Peru (6 percent) [Klochko (2024)]. Refined lead usage has held steady at roughly 12 million metric tons annually since 2013. As of 2020, the total global market volume for recycled lead was over seven million metric tons. In other words, lead remains a significant part of our economy.

Lead is used in all countries. However, stringent regulations and enforcement regimes for lead are in place in most high-income countries, greatly reducing the risk of human exposure and environmental contamination. Lead exposure and elevated blood lead levels are far more common and severe in LMICs, where formal and environmentally safe recycling facilities and used battery and lead supply chains are typically not in place and where regulation, enforcement, surveillance and awareness remain relatively low. The estimated average blood lead levels in many LMICs exceed 5 micrograms per deciliter, the reference level at which the WHO recommends clinical intervention [Pure Earth (2024)]. Globally, there are an estimated 800 million children with elevated BLLs—almost all of whom live in LMICs [UNICEF (2020)].

5.2 Effects and Burden of Lead Exposure

Estimates are that preindustrial humans had blood-lead levels of just 0.016 micrograms per deciliter, about 300 times lower than the current WHO reference level for public health intervention [Smith and Flegal (1992)].

Current evidence does not indicate a minimum threshold for the toxic effects of lead exposure. Increasingly, it is recognized that levels of lead exposure previously considered relatively low can be harmful, with the severity rising with higher doses [EPA (2024)].

In humans, lead exposure is most common via inhalation or ingestion of environmental lead or contaminated objects or via in utero fetal exposure during pregnancy. Less commonly, lead exposure can occur through dermal contact, mucous membranes or direct penetration of a foreign lead object, for example, gunshot wounds [Bonnifield and Todd (2024)]. Some of the lead that enters the human body is absorbed into the blood and distributed to bone, teeth and soft tissue storage. Lead that remains in blood circulation is processed by the kidneys and excreted, with a half-life of about 35 days. BLLs, measured in micrograms per deciliter, are the most common biomarkers of ongoing or recent lead exposure.

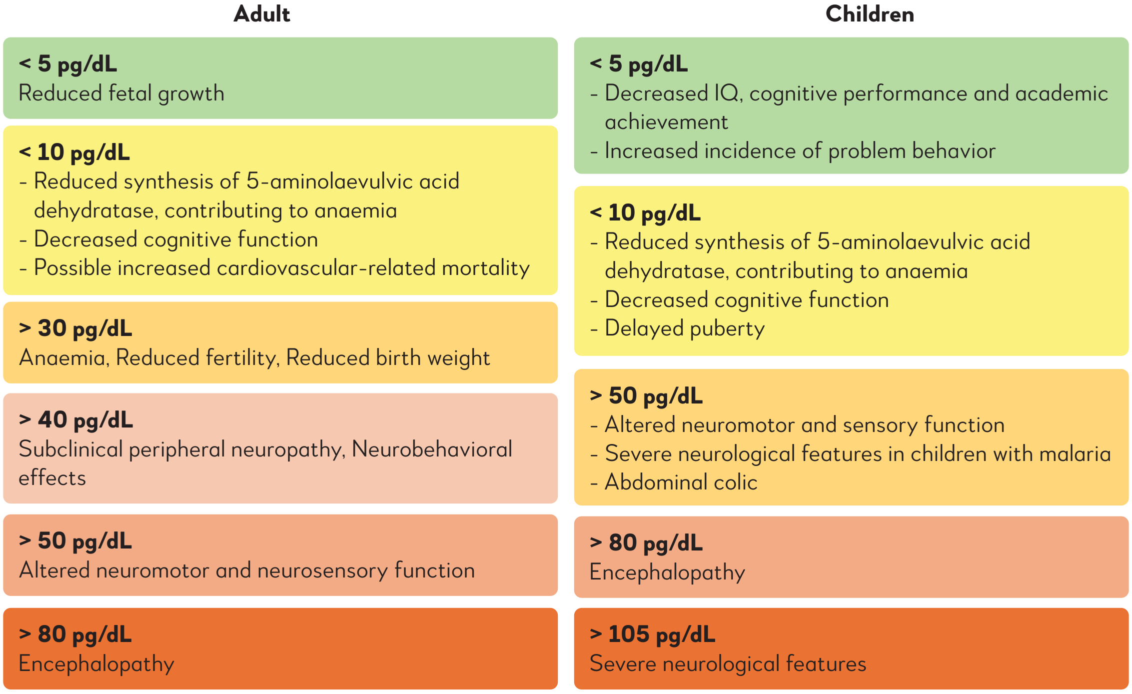
Lead is a multi-system toxin in humans, with adverse causal impacts on the nervous, cardiovascular, renal, reproductive and hematological systems, with likely causal evidence of adverse effects on the musculoskeletal system and immune function. The health effects of lead become progressively more severe at higher levels of exposure (Figure 38). They can be crudely categorized into clinical lead poisoning, which has clear symptomatic manifestations and can be deadly, and sub-clinical lead exposure, which may not present obvious symptoms but has measurable impacts at the population level.

Subclinical lead exposure is less immediately severe but far more common, thus ultimately responsible for most disease burden from lead exposure at the population level. Even low-level lead exposure impedes proper brain development and function; in children, even lead levels under 5 micrograms per deciliter—previously considered low—are known to result in decreased IQ, problem behavior and attention deficits (Figure 38). In adults, lead exposure (alongside other heavy metals) is also recognized by the American Heart Association as a "significant contributor to cardiovascular disease worldwide." Metanalysis results suggest that relatively higher risk to lead (top versus bottom third in study population) results in a 43 percent increased risk of cardiovascular disease, 85 percent increased risk of coronary heart disease and 63 percent increased risk of stroke [Lamas et al. (2023)].

Several groups—children, pregnant women and workers with occupational exposure—are particularly vulnerable:

- As of 2019, elevated lead levels (>5μg/dL) are estimated to affect approximately one in three children or 800 million children worldwide [UNICEF (2020)]. Children absorb about 40-50 percent of ingested lead into blood, compared to just 5-10 percent in adults, and have relatively little body mass over which to distribute ingested or inhaled lead. Children are more likely to eat non-food items and engage in hand-to-mouth behavior [see Kaji and Nishi (2006); WHO (2023)]. Lead exposure in early childhood impedes normal cognitive development and is causally linked to cognitive deficits, attention deficits, hyperactivity and impulsivity [EPA (2024)].
- Pregnant women are a population of concern for two reasons. First, during pregnancy, blood lead can be transferred via the placenta to

Figure 38: Association of Subclinical and Clinical Effects with Blood Lead Concentrations



Adult

< 5 pg/dL
Reduced fetal growth

< 10 pg/dL
- Reduced synthesis of 5-aminolaevulvic acid dehydratase, contributing to anaemia
- Decreased cognitive function
- Possible increased cardiovascular-related mortality

> 30 pg/dL
Anaemia, Reduced fertility, Reduced birth weight

> 40 pg/dL
Subclinical peripheral neuropathy, Neurobehavioral effects

> 50 pg/dL
Altered neuromotor and neurosensory function

> 80 pg/dL
Encephalopathy

Children

< 5 pg/dL
- Decreased IQ, cognitive performance and academic achievement
- Increased incidence of problem behavior

< 10 pg/dL
- Reduced synthesis of 5-aminolaevulvic acid dehydratase, contributing to anaemia
- Decreased cognitive function
- Delayed puberty

> 50 pg/dL
- Altered neuromotor and sensory function
- Severe neurological features in children with malaria
- Abdominal colic

> 80 pg/dL
Encephalopathy

> 105 pg/dL
Severe neurological features

Source: WHO (2021).

the developing fetus with lasting damage. Second, pregnant women are susceptible to higher BLLs than their non-pregnant peers due to the remobilization of stored lead from the skeletal system—which itself can subsequently be transferred to the fetus.

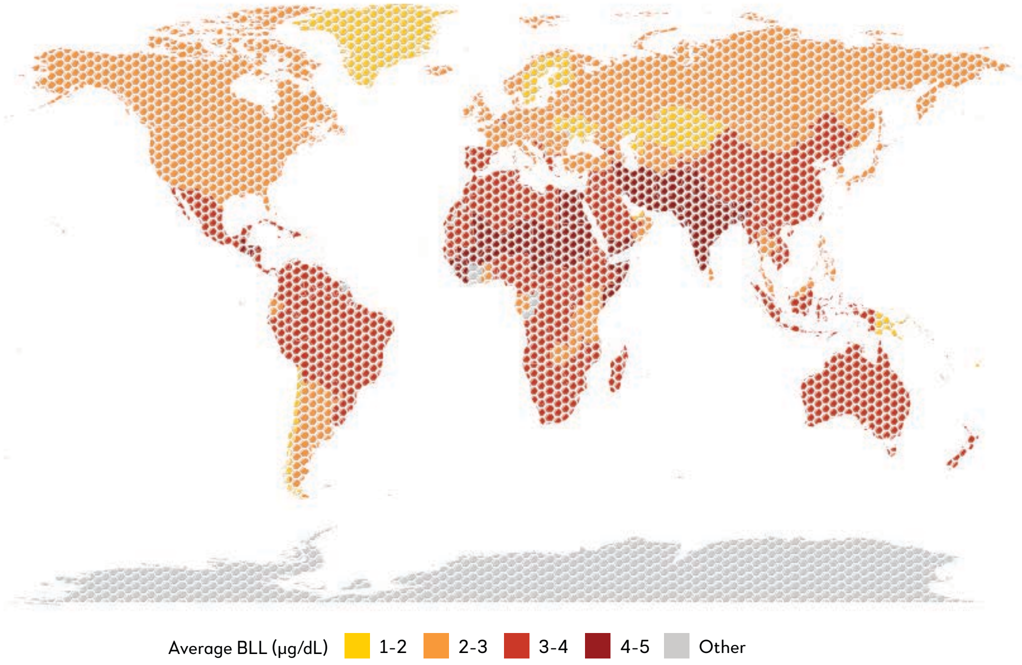
- Several categories of workers are more vulnerable to occupational lead exposure. These include but are not limited to individuals working in construction/demolition, infrastructure maintenance, renovation/remediation, mining, smelting, battery and e-waste recycling, auto repair, painting, welding, electronics, and ceramic and crystal manufacturing, as well as soldiers, police, hunters, and other individuals who work with firearms. Between 1995 and 2010, there were 14 studies measuring worker BLLs in LMIC battery recycling plants, finding average BLLs as high as 112.5 micrograms per deciliter (in Nigeria) and an arithmetic mean of 64 micrograms per deciliter across study settings [Gottesfeld and Pokhrel (2011)].

5.2.1 Burden of Lead Exposure

The burden of lead exposure is overwhelmingly concentrated in the Global South, specifically Latin America, Africa and developing Asia (Figure 39). BLLs are lowest in North America, Western Europe and Australia/New Zealand, which have generally implemented stringent lead control regulation and enforcement.

In Asia, only two countries (China and Georgia) have conducted representative national BLL measurement exercises as of early 2024. Nevertheless, existing evidence and global estimates suggest that elevated lead levels are common in the Global South (Figure 39). Lead exposure is considered particularly severe in South and Central Asia; in most countries within these subregions, it is estimated that average childhood BLLs exceed 5µg/dL [Pure Earth (2024)].

Figure 39: Estimated Average Blood Lead Levels by Geographical Location



Source: Institute for Health Metrics and Evaluation - Global Burden of Disease 2021.

Notes: Top 20 countries across the world with the highest average blood lead levels (BLL): Niger (7.125), Afghanistan (7.005), Haiti (6.755), Somalia (6.471), Guatemala (6.181), Yemen (6.165), Chad (6.117), Nepal (6.027), Egypt (5.907), Mali (5.841), Sudan (5.804), Burkina Faso (5.766), Honduras (5.519), Iran (5.399), El Salvador (5.378), Guinea (5.353), Bhutan (5.292), Bangladesh (5.268), Pakistan (5.249), Sierra Leone (5.232). Top 10 countries across Asia and Pacific with the highest average BLL: Afghanistan (7.005), Nepal (6.027), Bhutan (5.292), Bangladesh (5.268), Pakistan (5.249), India (5.034), Timor-Leste (4.628), Lao PDR (4.431), China (4.204), Myanmar (4.148).

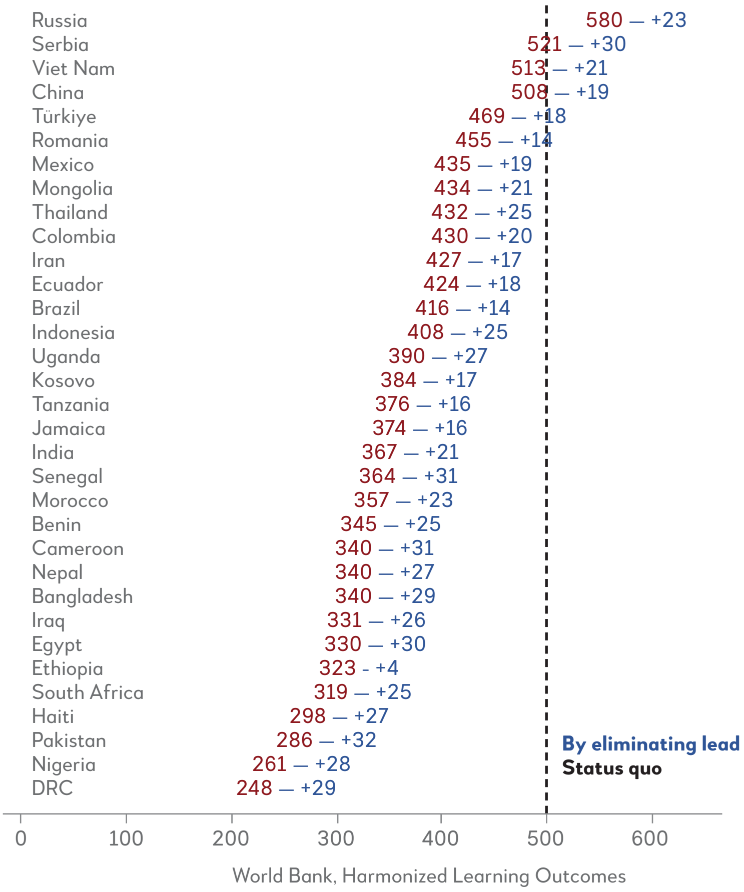
Four Asian countries—India, Bangladesh, Pakistan and China—are home to well over half of all children with elevated BLLs over 5µg/dL worldwide. High average BLLs in children with no particular risk factors relative to the rest of the population have been measured in Pakistan (9.3µg/dL), Bangladesh (7.9µg/dL) and Nepal (6.7µg/dL) [Ericson et al. (2021)].

At the global level, a recent meta-analysis finds that lead exposure may explain a fifth of the gap in learning outcomes between developed and developing economies (Figure 40). At the country level (where data exists), lead exposure can explain the loss of 32 points on World Bank Harmonized Learning Outcomes in Pakistan, 27 points in Nepal, 26 points in Iraq, 25 points in Indonesia, 21 points in Mongolia and Viet Nam, and 19 points in China [Crawfurd et al. (2024)]. According to a recent World Bank analysis, each year of lead exposure globally is estimated to be responsible for the loss of 765 million IQ points, driving USD1.4 trillion in income losses, comprising 1.6 percent of global GDP. In South Asia, the estimated losses are larger at 3.5 percent of regional GDP [Larsen and Sánchez-Triana (2023)].

There are two major studies estimating lead-attributable mortality. The first estimate, from the Institute for Health Metrics and Evaluation at the University of Washington, finds that 1.6 million annual deaths can be attributed to the hypertensive effects of lead exposure, and this burden accounts for 1.2 percent of global disability-adjusted life years each year [Vaduganathan et al. (2022)].

The second estimate, from the World Bank, attributes 5.5 million annual cardiovascular deaths to global lead exposure, inclusive of all cardiovascular mechanisms; 70 percent of these annual deaths (3.4 million) occur in South Asia, East Asia, and the Pacific [Larsen and Sánchez-Triana (2023)].

Figure 40: Simulated Effect of Eliminating Blood Lead on Learning Outcomes



Source: Adapted from Crawfurd et al. (2024).

Using these two estimates as a possible range's outer bounds implies that lead exposure accounts for 8 to 27 percent of global cardiovascular mortality (20.5 million annual deaths) [Lindstrom et al. (2022)].

5.3 Sources of Lead and Exposure

There are three broad exposure pathways: indirect exposure via environmental contamination in water, air or soil; direct occupational exposure, e.g., direct exposure because of work in a lead-containing industry; and direct consumer/user exposure, e.g., direct exposure because of using, eating, drinking or otherwise interacting with a lead-contaminated product.

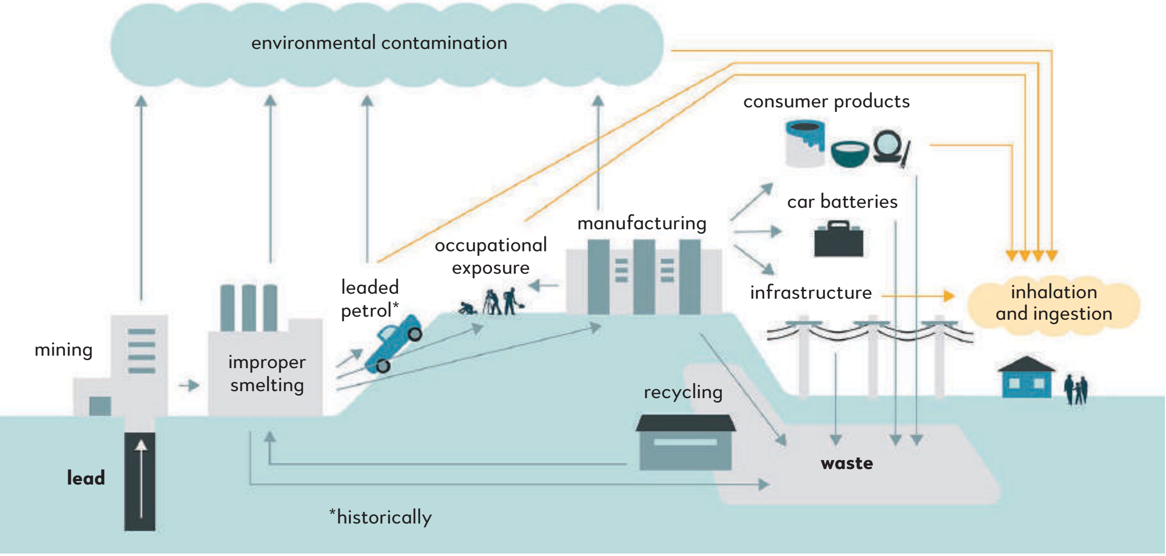
The lifecycle of lead in the environment is complicated and can create risks for all three pathways of lead exposure along different points of production, use and disposal (Figure 41). Exposure risks begin when lead is first extracted, and miners of lead ores are among the occupational groups most susceptible to lead exposure.

Once extracted, ores are subject to several processing stages, including at high temperatures, which can produce substantial lead emissions if uncontrolled. Environmental contamination from mining and smelting can last for decades, even after mining activity has been suspended. For example, Kabwe, Zambia, was the site of large-scale lead mining until 1994; over two decades later, 100 percent of sampled children still had elevated lead exposure, with many suffering from severe exposure [Yabe et al. (2015)]. Small-small-scale mining and refining of other metals can also create contamination risks and severe lead exposure. For example, gold mining in northern Nigeria in 2010 resulted in the deaths of over 400 children from lead poisoning [MSF (2012)].

Refined lead is then deployed across various use cases, including in climate infrastructure. Historically, lead was added to gasoline as an "anti-knocking agent," driving mass environmental contamination, particularly in dense urban areas and along major roadways. Exposure risk from leaded gasoline has significantly abated since its global phase-out (except for small aircraft aviation), but some legacy environmental contamination remains in place. In recent years, lead pollution associated with transport is primarily driven by lead's use within lead-acid batteries. They are increasingly used for green energy storage and electric mobility, for example, within off-grid solar energy systems and to power electric bicycles, scooters, and tuk-tuks [see Pure Earth (2024); Klochko (2024)].

Lead-acid batteries must be frequently replaced and recycled, each time requiring secondary smelting and processing of the constituent lead.

Figure 41: Sources and Pathways of Lead Exposure



Source: Bonnifield and Todd (2024).

In many LMICs, the safety conditions under which such recycling occurs are poorly regulated and enforced, with informal and substandard formal recycling operations creating severe environmental contamination and occupational exposure risks.

Lead is also non-corrodible, stable and malleable, which has driven its use in pipes, other plumbing components, telecommunications cable shielding and specialist construction (e.g., roof flashing and other purposes). Lead pipes were widespread in LMICs and high-income countries (HICs) before the dangers of lead exposure were fully understood, and there is some evidence of continued installation of lead infrastructure components in LMICs, such as lead plumbing in Madagascar.

Lead contamination in drinking water is predominantly a result of corrosion in lead-containing components within water supply systems, particularly in aging infrastructure where lead pipes, solder and fixtures are still in use. Studies show that across 261 rural water systems in three West African LMICs, lead exceeds WHO guideline values in 9 percent of drinking water samples [Fisher et al. (2021)]. Even in HICs, lead pipes remain in service due to the high replacement costs.

A final crucial infrastructural application of lead is in paint, particularly as a pigment in the form of lead chromate. Despite a global campaign to introduce controls, more than half of countries have no recorded legislation on the production or use of lead paint, and studies by the International Pollutants Elimination Network (IPEN) and others have found that lead paints are widespread in these countries, including at extremely high concentrations [IPEN (2020)]. Paints with high concentrations of lead have also been identified on the market in some LMIC settings where they are de jure banned, suggesting weak or inconsistent enforcement even where regulations exist [LEEP (2023)]. In some cases, strict lead regulations apply to residential or decorative paints, but industrial, infrastructural and/or automobile applications are either unregulated or less strictly regulated [SAICM (2024)].

Beyond infrastructural sources, lead exposure can occur through contaminated food, consumer products and household items, including spices, cookware, cosmetics and folk medicines, particularly in regions like South and Central Asia [see Forsyth et al. (2024); Fellows et al. (2022); Sargsyan et al. (2024)].

Some forms of lead contamination within environmental media are also common. Lead is rare in natural water sources like rivers and aquifers; nevertheless, pollution from industries such as battery manufacturing, mining and smelting can introduce it into water supplies [Raj and Das (2023)]. Similarly, soil near roadways, buildings, and industrial sites often contains elevated lead levels due to past use of leaded gasoline, lead-based paint, industrial emissions, and ongoing contamination from industrial operations like smelting and battery manufacturing [Levin et al. (2022)]. The lead-contaminated soil can become airborne, contributing to indoor dust, which closely correlates with elevated blood lead levels in children [EPA (2024)]. Emissions from ore and metals processing and piston-engine aircraft operating on leaded aviation fuel have contributed significantly to lead levels in the air. The highest air concentrations of lead are usually found near lead smelters. Once deposited in the soil, the lead-laden dust can be remobilized into the atmosphere, perpetuating human exposure.

The impact of lead contamination extends beyond water, soil and air, affecting plants, animals and ecosystems. Plants absorb lead through their roots from contaminated soil and through their leaves from polluted air. The accumulation of lead in excess can cause up to a 42 percent reduction in the growth of roots [Collin et al. (2022)]. Once inside the plant system, lead ions are transported via the xylem, leading to accumulation in various plant tissues.

Lead-contaminated soil and water harm plants and further endanger animals and humans by allowing the lead to move from soil to crops, thereby entering the food chain. Lead exposure in domestic and wild animals mirrors the exposure patterns observed in humans. Domestic pets, particularly dogs, are highly vulnerable to lead poisoning, often showing elevated blood lead levels in homes with lead contamination.

Similarly, urban wildlife, such as pigeons and house sparrows, suffer from high lead exposure due to foraging in polluted areas, leading to reproductive and neurotoxic problems and increased mortality [Gillings et al. (2024)]. Grazing animals like sheep and cattle are also affected, especially near roadways or urban areas, where lead exposure correlates with higher lead levels in their milk, adding additional risks to human health [Johnsen and Aaneby (2019)].

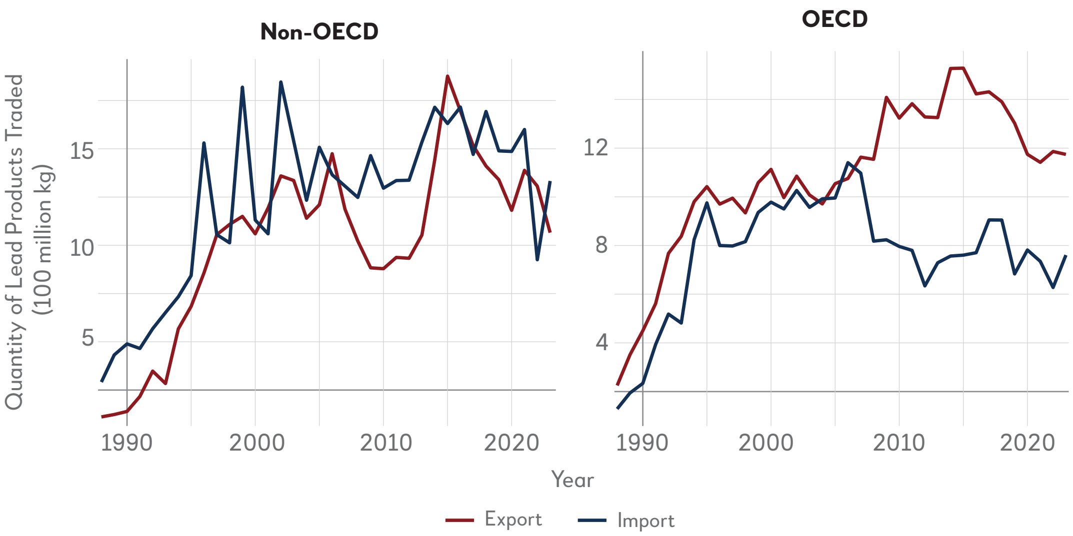
Furthermore, climate change and extreme weather patterns influence the cycle of lead exposure. For instance, lead exposure in children, often called "summer disease," peaks during the warmest months, a trend observed consistently across different populations and locations [Pure Earth (2024)]. This seasonal rise is driven by higher temperatures, lower soil moisture and increased bioavailability of lead, coupled with behavioral factors such as more outdoor playtime and open windows in homes. With global temperatures projected to rise by 1.5°C between 2030 and 2052 and the expected increase in the frequency of summer heatwaves, this seasonal risk is likely to extend, especially in urban areas where heat islands exacerbate the effects.

5.4 Lead Acid Batteries and the Green Energy Transition

Renewable energy transition has increased globally in the last two decades, exponentially increasing electricity production from renewable sources. Given the crucial role of batteries in renewable energy storage and grid balancing, the growth of battery trade worldwide has followed a similar trend. The last decade has seen a sharp increase in the lithium battery trade, but the trade of refined and unrefined lead globally remains steady. The disaggregated analysis in Figure 42 demonstrates that imports of lead products have decreased in countries under the Organisation for Economic Co-operation and Development (OECD) members but remain at high levels in non-OECD members. Despite newer battery technologies with higher energy density than lead, lead acid batteries remain the economical choice of battery in emerging markets, even in deep-cycle operations such as e-mobility and renewable energy storage.

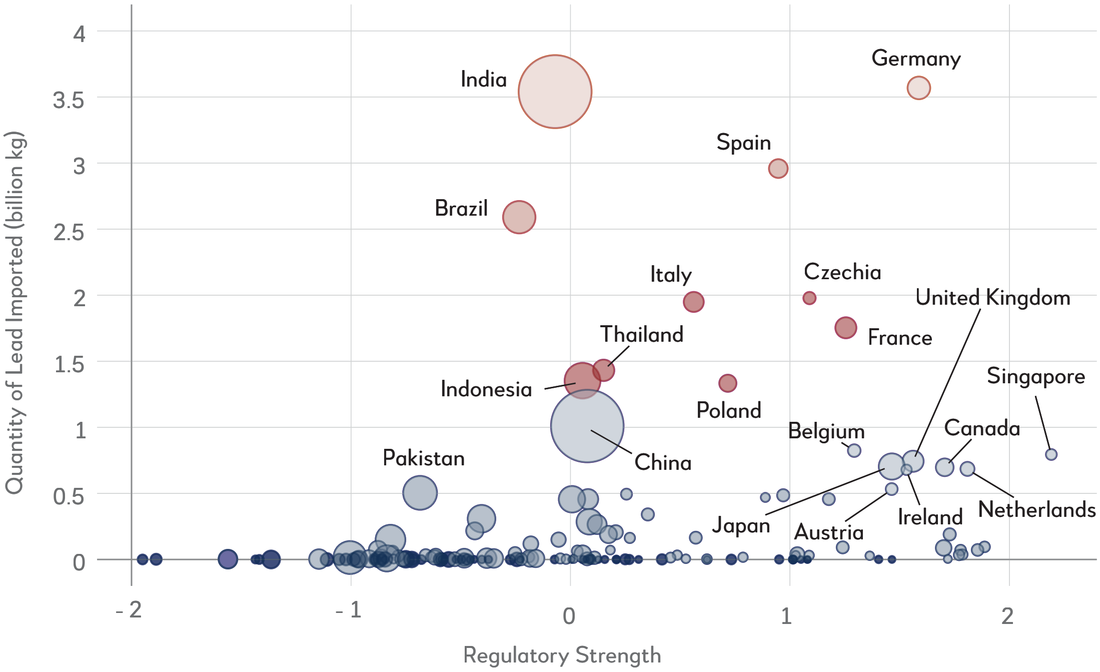
Further, as Figure 43 shows, many countries with weak regulatory scores (as measured by the World Bank) imported high volumes of lead between 2000 and 2023, including many LMIC countries. Environmental standards and safe lead handling and recycling capability in the countries will likely correlate with their overall regulatory strength. Indeed, blood lead levels from the Institute for Health Metrics and Evaluation's Global Burden of Disease data are highly negatively correlated with the regulatory capacity measures used in the plot (correlation of −0.5, $p < 0.001$). The high volume of lead imports and use in countries with few resources to safely handle and recycle lead can result in catastrophic health outcomes that may persist through generations.

Figure 42: Trade of Lead Products, OECD and Non-OECD Members (1988–2023)



Source: UN Comtrade Data.

Figure 43: Quantity of Lead Imported and Levels of Regulatory Strength (2000–2003)



Source: UN Comtrade Data; World Bank DataBank.

Lead-acid batteries (LABs) come in different types (sealed and unsealed) and sizes (4 voltage to 12 voltage) with varied power capacities. Due to their portability, versatility and relative affordability, LABs have expanded beyond automotive applications, including energy storage from solar or instant power supply, telecommunication towers and industrial uses. In many LMICs, LABs are widely used as reliable backup power sources, particularly in rural and remote communities where electricity is only intermittently available due to energy shortages.

Lead acid batteries are easy to recycle economically, creating a thriving circular economy of batteries and lead worldwide. Lead is a commodity traded on the London Metal Exchange and has significant value, especially considering the income levels in LMICs. As a result, used lead acid batteries have a high salvage value (ranging from 10 to 50 percent of its value depending on the market and type of battery) and are almost always sold to a shopkeeper or a scrapper by the owner. The shopkeeper or the scrapper directs the used batteries (ULABs) to a recycler. In the HIC countries, the forward supply chain of batteries and the reverse supply chain of scrap batteries and lead is highly regulated and entails strict enforcement of environmental standards and heavy penalties. In LMICs, however, there is a thriving informal sector where batteries are recycled in a crude and environmentally irresponsible manner. The local existence of formal recycling facilities also does not guarantee safe recycling; many formal facilities are highly polluting, and they are often underused relative to their own capacity and the informal sector due to unequal tax treatment or cost structures.

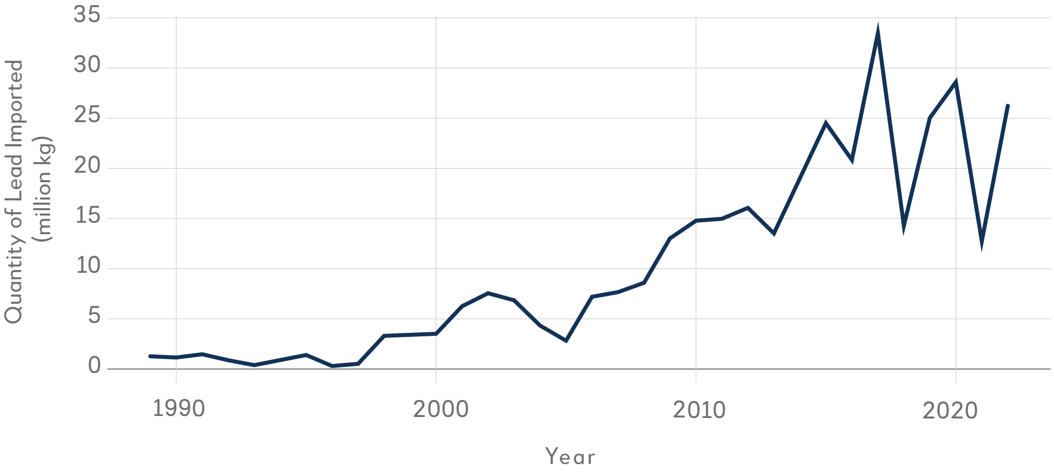
Recent studies in LMICs have found a direct link between unsafe recycling of lead acid batteries and low birth weight in newborns as well as terminated pregnancies, with more studies underway [see Tanaka et al. (2022); Kundu et al. (2024); Rahman (2023)]. Box D provides a case study for Bangladesh.

Box D: Battery Recycling and the Green Energy Transition in Bangladesh

Lead poisoning in Bangladesh is a major concern. It is estimated that more than 35 million children in Bangladesh have blood lead levels above 5µg/dL, and over 9.7 million children exceed 10µg/dL [UNICEF and Pure Earth (2024)]. There are many reasons for high lead levels in Bangladesh, and the relative attribution of lead exposure to various sources remains unknown. Yet one source of lead exposure stands out for its volume and climate connections: the production, use and recycling of lead-acid batteries.

Bangladesh is one of the most climate-vulnerable countries. As an emerging economy, its demand for energy has also increased significantly in recent years, and the transition to renewable energy is thus a critical national priority. As part of this transition, energy storage, including lead-acid batteries, plays a critical role. Over 3 million e-rickshaws (local three-wheelers to carry passengers to short distances) operate with lead-acid batteries—an e-mobility revolution. Lead-acid batteries have also been widely used for uninterruptible power supplies (UPS), backup systems for telecommunication networks and other electric vehicles to provide 'last-mile' connectivity. Each lead-acid battery contains approximately 14-21 kilograms of lead, depending on its size. Bangladesh generates 90,000 tons of used lead batteries annually (the estimate is based on the six-month life cycle of the battery), 77 percent of which originate from the e-rickshaw industry [see UNICEF and Pure Earth (2024); Rahman (2023)]. To meet growing demand, Bangladesh also continues to import rapidly growing quantities of lead-based products (Figure D1).

Figure D1: Growth in Lead Imports, Bangladesh (1989–2022)



Source: UN Comtrade Data, Bangladesh National Revenue Board Data.

Despite increasing imports, the battery industry in Bangladesh is highly dependent on local lead supply due to high import tariffs on lead (exceeding 30 percent) and lead-acid batteries (over 80 percent). This demand, alongside the rapid consumption and turnover of lead-acid batteries, creates a large market for battery recycling, which overwhelmingly occurs within the informal sector.

Over 1,100 informal and illegal ULAB recycling operations in Bangladesh employ more than 100,000 people. Although inadequate semi-formal and formal recycling facilities are available, they are underused because the operation cost of these semi-formal recycling facilities is higher than informal recycling, and local battery manufacturers are more inclined to source cheaper recycled lead.

Figure D2 shows a simplified supply chain of informal LAB recycling in Bangladesh. These processes result in a 70 percent recovery rate of raw lead. The remaining 30 percent leaks into the environment or landfill because of inefficient and manual smelting. The battery cases are often reused, and after multiple reuses, they are replaced with new cases. Thus, despite the informal process, material circularity in the LABs in

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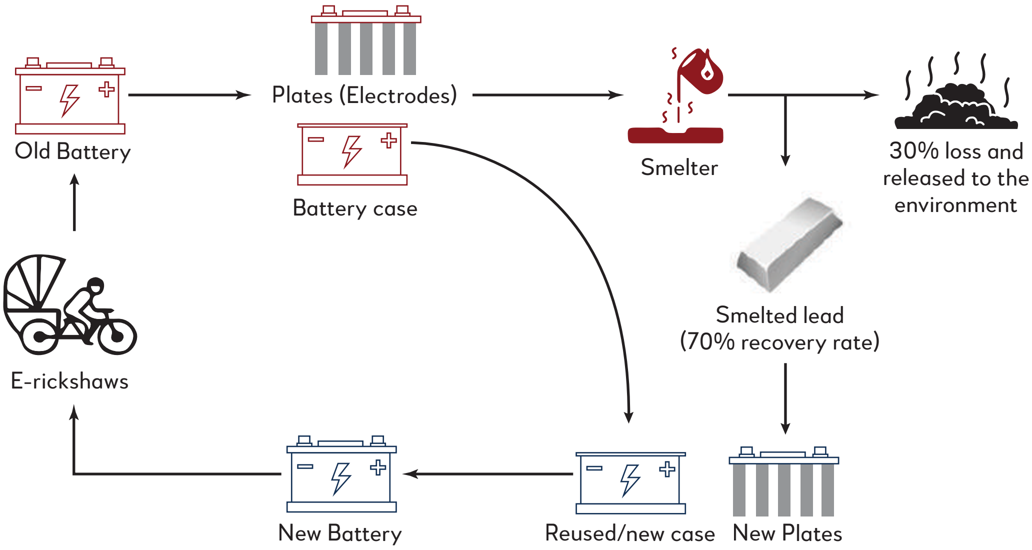
Box D *continued*

Figure D2: Simplified Supply Chain of Informal LAB Recycling in Bangladesh



Source: Zaman and Pacini (2024).

Bangladesh is quite high. However, the quality of lead acid batteries in this application is poor because of the informality of the sector, the lack of product standards and the low demand for high-quality batteries due to financial constraints of the vehicle owners. As a result, e-rickshaw batteries in Bangladesh have an artificially short life of less than a year, which increases the rate of recycling and lead emissions, as well as the cost of purchasing and using e-rickshaw batteries.

The substandard and unsafe battery recycling practices have severe health and environmental consequences. Often, workers do not use proper personal protective equipment (PPE), putting them at elevated risk of severe lead poisoning. Risks extend to the surrounding communities, as informal recycling operations often occur near residential areas, accumulating lead dust in high-risk areas such as playgrounds, homes and streets. This dust can be stirred up and inhaled or swallowed, posing significant health risks.

While groundwater contamination from lead in recycling is not expected due to its non-solubility, lead dust can spread through stormwater runoff, wind and workers' clothing, impacting a wider area. This pollution has led to animal deaths and community protests, often resulting in temporary compensation but no lasting solutions, as recyclers relocate to new sites to continue their hazardous activities [Pure Earth (2020)]. The continuous exposure to toxic pollutants leads to a persistent public health crisis, particularly for vulnerable populations living nearby, creating a cycle of poor health outcomes and reduced quality of life.

A conservative estimate indicates that Bangladesh's informal ULABs and battery industry contribute around 1 billion to the local economy and create jobs, yet the negative externalities far outweigh the benefits. With sound management and regulation, there is potential to sustain and expand the industry's economic benefits through formalization while dramatically reducing the attendant health and environmental harms. For example, current recycling practices result in low-quality lead, and local batteries do not last as long as would otherwise be expected, meaning that e-rickshaw operators pay comparatively high energy costs per kilometer. Better recycling processes can increase the current 70 percent lead recovery rate and improve the quality of recycled lead, thereby increasing battery quality and affordable energy access for the marginal poor in Bangladesh.

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Box D *continued*

The formalization of Bangladesh's electric three-wheeler battery and lead market thus requires urgent policy attention, including an appropriate and enforced national regulatory framework for e-mobility and handling battery waste and lead. By devising effective tax and tariff policies, the government can incentivize environmentally responsible recovery and recycling of lead by formal recyclers. Currently, battery recycling is governed by the Lead-acid Battery Recycling and Management Rules from 2006, which have significant weaknesses. Although Bangladesh Environment Conservation Act 1995 allows regulation, monitoring and the provision for penalties (imprisonment of a maximum of 10 years or fines up to 10 lac - USD9,113), enforcement is weak, highlighting the need for stricter monitoring (perhaps through digital and technological solutions) and comprehensive regulatory frameworks. By formalizing the sector, improving battery and vehicle standards, and investing in charging infrastructure, the electric three-wheeler sector can attract financing from local institutions such as the BRAC Bank and Grameen Bank.

Additionally, there are opportunities to secure funding under a public-private-partnership from regional and international financial bodies, including MDBs like the Asian Development Bank, the Asian Infrastructure Investment Bank, and the World Bank, as well as through bilateral cooperation organizations like the Japan International Cooperation Agency to formalize and modernize this sector through investments and policy dialogues.

5.5 Tools and Strategies for Tackling Lead Exposure from the Battery and Lead Industry

To support infrastructural development and a safe transition to green energy in LMICs, multilateral development banks (MDBs) have a significant role to play in creating robust and safe lead and battery markets and improving recycling facility standards and lead supply chains. A key part of this involves reducing informal recycling or illegal subcontracting. This can be achieved by improving the level playing field between formal and informal lead recyclers to increase the cost of informal recycling compared to formal recycling.

Formal recycling facilities typically require significant upfront capital. For example, a single state-of-the-art LAB recycling plant can require initial capital investment ranging from USD0.5 million to USD5 million, depending on size and capacity [GME Recycling (2023)]. The Battery Council International estimates that converting global ULAB recycling to formal systems could involve investments of over USD1 billion, including both capital investments in facility infrastructure and the operational financing required to maintain compliance with environmental standards. Investments from MDBs can directly tackle lead exposure in LMICs by:

- Supporting the building of formal and efficient recycling facilities that operate with the highest air and effluent treatment standards. Higher recycling yields from efficient facilities can make formal facilities more cost competitive.
- Formalizing the reverse supply chain and providing low-cost financing for those holding ULAB inventory. Doing so would make the formal sector more competitive. Capital investment in formal recycling facilities is insufficient unless the operating costs of the formal recyclers are sufficiently low to capture market share from informal recyclers. The largest operating costs for formal recyclers are the collection and storage of large quantities of ULABs. Energy costs, taxes and regulatory costs also tend to be high for formal recyclers, which decreases their competitiveness.
- Ensuring the formal sector meets environmental standards. Formal recyclers may have efficient air and water treatment plants but may avoid turning them on because of high energy costs. To ensure the formal sector abides by environmental standards, especially if they receive financing support or other benefits from the government, there needs to be accountability and transparent accounting of the amount of scrap lead smelted, the amount of lead refined and the number of batteries manufactured, which should corroborate with energy and tax payments.

Investments supported by or conditional on the use of technology-backed traceability of materials and energy use in the facilities can help ensure compliance without strong regulatory oversight.

- Providing low-interest green financing to bring battery manufacturing and recycling in LMICs within the formal sector. For example, in Bangladesh, a research team from Georgetown University and Stanford University is working with BRAC Microfinance to test a new business model where high-quality batteries—manufactured with formally recycled lead—are provided on loan to end users [Kundu and Plambeck (2024)]. At the time of purchase, the manufacturer also buys back the used batteries at market price. Low-interest loans to microfinance organizations to support the financing of batteries manufactured by responsible manufacturers can improve industry practice.
- Financing new business models. Green financing can also support the adoption of higher-cost but more efficient battery technologies such as lithium-ion through lease and swap arrangements, which decrease the upfront cost of buying the technology and smoothen the cost over a long period of time for the end users. These models also hold the manufacturers accountable for the performance of their products over a longer period, alleviating quality concerns that are prominent in LMICs where product standards and customer protection laws are not implemented or enforced.

As an example, the African Development Bank "Desert to Power" initiative that support renewable energy (which uses batteries) across Africa includes funding safer battery disposal and recycling practices. Similar initiatives could involve USD20 million investments or more per country, depending on infrastructure needs [Mkoka (2022)].

In the longer term, a gradual transition towards using lithium-ion batteries (LiB) should be considered and supported. LiBs offer significantly higher energy density (almost 4-7 times greater), faster charging, superior performance in harsh conditions, and longer life cycles (nearly double) [see Garimella and Nair (2010); Grey and Tarascon (2017)]. Sodium-ion batteries are another alternative and have the potential to replace LABs and provide affordable and safe energy alternatives [Skyllas-Kazacos et al. (2011)]. However, the lower price of LABs, at nearly one-third of the cost of LiBs, suggests a continued role in supporting developing countries' immediate energy transition [see Habib et al. (2019); Muzir et al. (2022)]. Therefore, investment opportunities in LMICs by multilateral development banks should strategically adopt an integrated approach, mitigating health risks and pollution from the battery manufacturing and recycling industries while also fostering the growth of emerging markets such as LiB or Sodium-Ion batteries for e-mobility and the green energy transition [UNICEF (2020)].

Alternative battery options bring new challenges, including gaining consumer confidence, achieving market penetration within a reasonable time, and ensuring technical and customer services and the necessary soft and hard infrastructure. In contrast with LABs, LiBs are highly dependent on virgin resources (minimal global availability). Geopolitical circumstances often influence lithium's price as a prime global commodity and critical mineral. Thus, a consistent supply chain of lithium is crucial, and lithium recovery from the end-of-life LiB plays a crucial role in the greater sustainability of LiB. A substantial investment is also needed in supply chains, research, and development to make these technologies more affordable and accessible. This is particularly important in mobilizing private capital and encouraging public-private partnerships to invest in cutting-edge battery technology and infrastructure in LMICs [see Pure Earth (2020); Biswas et al. (2021)]. Investment in cross-border initiatives should also be considered, such as regional recycling hubs for lithium-ion batteries.

5.6 Chapter Concluding Remarks

The health, welfare and environmental costs of lead contamination are incredibly high and merit a robust government response. While this chapter has focused primarily on the role of lead-acid batteries, this should fit into broader government policies supported by MDBs and other partners to reduce and mitigate all sources of human lead exposure. First, this implies that governments must strictly limit the use of lead in infrastructure, paint, food and consumer goods through robust regulatory and enforcement regimes. Second, governments must create the conditions for safe deployment of lead in cases where its use remains necessary, most notably by establishing the infrastructure required for safe lead-acid battery recycling. Finally, governments must build the health system and laboratory capacity to monitor blood lead levels; detect and address sources of lead poisoning in individuals and communities; and empower families and communities to protect themselves through increased awareness of lead hazards.

CHAPTER 6

THE GRAND PANDEMIC

ANTIMICROBIAL RESISTANCE IN ASIA[9]

Highlights

- Antimicrobial Resistance (AMR) is one of the most significant global public health and development issues, and the threat is rising. The World Health Organization (WHO) estimates that AMR was directly responsible for 1.27 million deaths globally in 2019, and the World Bank estimates that AMR could lead to an additional USD1 trillion in healthcare costs globally by 2050.
- Model estimates show that investing in effective AMR prevention and control measures, together with a range of best-practice policy interventions, could help sustain the increase in life expectancy. On the other hand, if AMR is not controlled, it has the potential to reduce life expectancy and lead to significantly higher disease burdens.
- The total cost of AMR per year up to 2050 is estimated to be USD13.0 billion in Indonesia (or USD42 per capita), USD20.0 billion in Brazil (or USD88 per capita), USD82.2 billion in India (or USD53 per capita) and USD85.4 billion in China (or USD59 per capita).
- In all four countries, infection prevention and control measures, such as enhancing hand hygiene and environmental hygiene in hospitals, are associated with the greatest benefits for health systems and economies. However, there is significant variability across countries, reflecting differences in the levels of access to healthcare services, the cost of delivering healthcare services, and state capacity to implement interventions.

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[9] This chapter is the product of collaboration between AIIB and the OECD.

6.1 Antimicrobial Resistance: A Growing Threat to Global Health

6.1.1 AMR Likely Large Impact

When AMR occurs, antimicrobials such as antibiotics become less effective, increasing the risk of severe disease and death and raising the likelihood of others becoming infected. The WHO (2024) estimates that AMR was directly responsible for 1.27 million deaths globally in 2019 and contributed to 4.95 million deaths.

While AMR affects populations in all countries and at all income levels, its causes and consequences are more prevalent in low and middle-income countries, which often lack the infrastructure and capacity to implement policies necessary to mitigate it. The threat is particularly significant in Asia; in 2019, AMR was the cause of an estimated 700,000 deaths in the WHO's Southeast Asia and Western Pacific Regions [WHO (2024)]. This accounted for more than half of the global deaths caused by AMR.

Women are more likely to be affected by AMR due to biological and occupational factors. Overall, women are 27 percent more likely to receive antibiotics throughout their lifetime than men. Women also tend to be more exposed to infections, including through childbirth, abortion and menstrual hygiene. In addition, occupations that tend to be more commonly held by women, such as healthcare, involve more risk of infection [WHO (2022)]. Gautron et al. (2023) have also used intersectionality to consider how gender and other socio-economic characteristics in low- and middle-income countries can determine how at risk an individual is from AMR.

Unless properly addressed, AMR is also likely to have significant economic impacts. There are several transmission mechanisms through which AMR can affect the economy—e.g., more prolonged and costly healthcare for affected patients, loss of productivity of patients and caregivers, effect on livestock health and worsening of agricultural productivity. The World Bank (2017) estimates that AMR could lead to GDP losses of USD1 to 3.4 trillion by 2030 and USD1 trillion in additional healthcare costs by 2050. The extent of these costs can create relatively strong business cases for governments to invest in policy and infrastructure solutions that combat AMR; however, robust analysis is needed to drive change.

6.1.2 An Emerging Governance Framework

The nature of AMR means that it does not respect country or regional boundaries—it is a global issue that requires global governance and regional cooperation. To coordinate an international response to AMR, the WHO works closely with the Food and Agriculture Organization, the United Nations Environment Programme and the World Organisation for Animal Health as part of the Quadripartite. At the 2015 World Health Assembly, countries adopted the Global Action Plan on AMR, which committed countries to develop National Action Plans (NAPs) with a One Health approach to tackling AMR. The One Health approach requires countries to develop, implement and coordinate actions in relevant sectors, including the human, animal, food, and environmental sectors. As of November 2023, 178 countries had developed NAPs, which set out national multisectoral governance mechanisms, operational plans including budgets, and domestic and external resources.

At the United Nations General Assembly High-Level Meeting on AMR in September 2024, global leaders approved a political declaration that set clear actions and targets, including reducing the aforementioned 4.95 million deaths associated with AMR annually by 10 percent by 2030. The declaration includes several specific actions, including funding NAPs of at least 60 percent of countries by 2030 [UNEP (2024)].

6.1.3 Interlinkages with Planetary Health

AMR is also closely interlinked with planetary health, with the climate, biodiversity, and the environment impacting its prevalence. There are three main interlinkages highlighted by Tigges et al. (2024): (a) antibiotics polluting soils and water sources, which can affect human and animal health; (b) higher temperatures globally leading to increases in bacterial infections and vector-borne diseases, which in turn increases in antibiotic use; and (c) large population movements following extreme weather events, leading to overcrowding and spread of infection. Policymakers and investors should understand such interlinkages when designing infrastructure projects and policy programs.

Evidence reveals that current warming is occurring roughly 10 times faster than the average rate of warming after an ice age.[10] One million animal and plant species are now threatened with extinction, many within decades, more than ever before in human history.[11] While AMR is a natural evolutionary process of microbes, acceleration of the occurrence and spread is driven by anthropogenic impacts.

Increased temperature has been identified as an independent variable associated with increased AMR infections: temperature is a key variable influencing bacterial processes, including horizontal gene transfer, a major mechanism for the acquisition of antibiotic resistance. Storms and floods, the frequency and severity of which are intensified by climate change, are already displacing populations, damaging healthcare services and disrupting wastewater management, leading to more cases of water born disease in affected areas. In Pakistan, for example, unprecedent flooding has led to a surge of skin and eye infections, diarrhea, malaria, typhoid, and dengue fever in 2022. It is also likely to be associated with significant spread of AMR bacteria, and the transferable genes that confer resistance, as animal and human feces contaminated potable water throughout numerous communities.[12]

Deforestation by mining, logging, ranchers, intensive monocrop agriculture and road construction destroys not only carbon sequestration capacities but also nutrient cycling which leads to disturbance of the extraordinary diversity of micro-organisms in soil.[13] Melting permafrost due to increasing temperature can unlock gases, such as carbon dioxide and methane, as well as ancient viruses and bacteria.[14] Scientists report that melting artic glaciers produce conditions for algae to bloom turning sun-reflecting glaciers into sun-absorbing hotspots. These in turn, induce ecosystem and geo-planetary impacts which further deteriorates remaining natural carbon sink function as well as potentially increasing methane production.[15] Intensive use of antibiotics in livestock production that make up approximately 70 percent of global sales, as well as biocides and heavy metals which can remain in the environment may reduce microbial biodiversity and induce AMR in bacteria.[16]

The complexity of the AMR, climate change and biodiversity loss interlinkages require further scientific research. Meanwhile all three global issues are contributing towards a point of no return of unrecoverable depletion of common resources. The World Bank estimated that AMR could result in USD1 trillion additional healthcare costs by 2050, and USD1 trillion to USD3.4 trillion GDP losses per year by 2030. Improving public awareness, surveillance, and laboratory capacity, comprehensively financed national action plans with civil society engagement, access to clean water, sanitation and hygiene (WASH), infection prevention and control (IPC), ensured access to essential medicines of assured quality and immunization, regulated rational use of medicines including in animal husbandry, proper patient care, effective diagnostic and research and development for new antibiotics can all play a part.

6.2 The Health and Economic Impacts of Antimicrobial Resistance: Evidence Thus Far

Several critical studies have analyzed the impact of AMR. The Review on Antimicrobial Resistance, published in 2016, was a major study commissioned by the United Kingdom Government [O'Neill (2016)]. The study estimated that, by 2050, 10 million lives a year and a cumulative USD100 trillion of economic output were at risk due to the rise of drug-resistant infections, with most of

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[10] See more here: Evidence | Facts – Climate Change: Vital Signs of the Planet (nasa.gov)

[11] See more here: UN Report: Nature's Dangerous Decline 'Unprecedented'; Species Extinction Rates 'Accelerating' - United Nations Sustainable Development (May 2019)

[12] See more here: Antibiotic resistance in the environment - PMC (nih.gov) (Nov 2021)

[13] See more here: The soil crisis: the need to treat as a global health problem and the pivotal role of microbes in prophylaxis and therapy - Timmis - 2021 - Microbial Biotechnology - Wiley Online Library

[14] See more here: What is Permafrost, Melting Effects, and How to Stop it (nrdc.org)

[15] See more here: Soils as sources and sinks for atmospheric methane (cdnsciencepub.com); Methane Production in Soil Environments—Anaerobic Biogeochemistry and Microbial Life between Flooding and Desiccation - PMC (nih.gov)(Jun 2020)

[16] See more here: Antibiotic resistance in the environment - PMC (nih.gov) (Nov 2021)

the direct and much of the indirect impact falling on low and middle-income countries. Other global studies include those led by the Global Research on Antimicrobial Resistance (GRAM) Project.[17] GRAM published its first report in 2020, estimating that AMR directly caused 1.27 million deaths in 2019–more than HIV/AIDS or malaria–and that resistant infections were associated with 4.95 million deaths.

The Organisation for Economic Co-operation and Development (OECD) has published several studies on AMR [OECD (2018)]. In 2023, it published a new study that highlighted the importance of embracing a One Health framework–targeting people, animals, agrifood systems and the environment [OECD (2023)]. The study found that every USD1 invested in a mixed One Health policy package would generate benefits worth USD5 through reduced healthcare costs and increased productivity. More recently, it published an updated study of the regional impacts of AMR, including in Asia, to support the UN General Assembly High-Level Meeting on AMR.

Several studies have also examined the health and economic impact of AMR in Asia. In 2023, analysis by the WHO (2023) and Hong Kong, China, projected that AMR would lead to 5.2 million deaths in the Western Pacific region from 2020 to 2030, with patients estimated to spend 172 million extra days in hospital. The study estimates that AMR would cost the region a cumulative total of USD148 billion (nearly 10 percent of total health expenditure in the region in 2019) over the ten-year period.

6.3 Applying a Standard Model to Estimate Antimicrobial Resistance Impacts for Select AIIB Members

This chapter summarizes the results and key findings from an analysis aiming to calculate the health and economic impact of AMR in four AIIB members: Brazil (BRA), China (CHN), Indonesia (IDN) and India (IND). The analyses were carried out for the period 2023 to 2050.

Analyses were performed using the OECD Strategic Public Health Planning for AMR (SPHeP-AMR) model, adapted to the context of the members included in the analysis. Previous versions of the model have already been used for similar analyses on AMR in different countries/regions.[18] For the current analysis, the model uses the list of priority antibiotic-bacterium pairs in Table 10, covering infections with significant environmental and zoonotic reservoirs. The selection of infective

Table 10: Pathogens Included in Model

Pathogens	Strain Characteristics	Setting	
		Healthcare	Community
Acinetobacter spp.	*Acinetobacter spp.* excluding isolates with resistance to carbapenem and/or fluoroquinolones	x	
	Acinetobacter spp. with resistance to carbapenem	x	
	Acinetobacter spp. with multidrug resistance (i.e., three or more of piperacillin ± tazobactam, fluoroquinolones, ceftazidime and aminoglycosides) excluding carbapenem	x	
Enterococcus faecalis (E. faecalis) & Enterococcus faecium (E. faecium)	*E. faecalis* and *E. faecium* excluding vancomycin-resistant isolates	x	
	E. faecalis and *E. faecium* resistant to Vancomycin	x	

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[17] The Gram project is a partnership between the University of Oxford and the Institute for Health Metrics and Evaluation (IHME) at the University of Washington.

[18] This chapter does not report a detailed description of the model or technical information of how the analyses were carried out as these aspects are addressed in a companion online document [OECD (2023)] with a methodological focus. Boxes 1.3, 3.1 and 6.1 in the OECD (2023)'s recently released publication 'Embracing a One Health Framework to Fight Antimicrobial Resistance,' also contain summarized descriptions of the model.

Table 10 *continued*

Pathogens	**Strain Characteristics**	**Setting** **Healthcare**	 **Community**
Escherichia coli *(E. coli)*	*E. coli* excluding isolates with resistance to third-generation cephalosporins and/or carbapenems	x	x
	E. coli. with resistance to carbapenem	x	x
	E. coli with resistance to third-generation cephalosporins excluding carbapenem	x	x
Klebsiella pneumoniae *(K. pneumoniae)*	*K. pneumoniae* excluding isolates with resistance to third-generation cephalosporins and/or carbapenems	x	x
	K. pneumoniae with resistance to third-generation cephalosporins excluding carbapenem	x	x
	K. pneumoniae with carbapenem resistance	x	
Mycobacterium tuberculosis *(M. tuberculosis)*	*M. tuberculosis* excluding isolates with multidrug resistance (i.e., at least isoniazid and rifampin) and extensive drug resistance (i.e., isoniazid, rifampin, plus any fluoroquinolone and at least one of three injectable second-line drugs: amikacin, kanamycin or capreomycin)		x
	M. tuberculosis with multidrug resistance (i.e., at least isoniazid and rifampin) excluding extensive drug resistance		x
	M. tuberculosis with extensive drug resistance (i.e., isoniazid, rifampin, plus any fluoroquinolone and at least one of three injectable second-line drugs: amikacin, kanamycin or capreomycin)		x
Pseudomonas aeruginosa *(P. aeruginosa)*	*P. aeruginosa* excluding isolates with carbapenem resistance and/or resistance to three or more of piperacillin ± tazobactam, fluoroquinolones, ceftazidime and aminoglycosides	x	
	P. aeruginosa with carbapenem resistance	x	
	P. aeruginosa with multidrug resistance (i.e., three or more of piperacillin ± tazobactam, fluoroquinolones, ceftazidime and aminoglycosides) excluding carbapenem	x	
Salmonella spp.	*Salmonella spp.* excluding isolates with resistance to fluoroquinolones, cephalosporins and resistance to three or more of ampicillin, chloramphenicol, streptomycin, sulphonamides and/or tetracycline		x
	Salmonella spp. with resistance to fluoroquinolones		x
	Salmonella spp. with multidrug resistance (i.e., three or more of ampicillin, chloramphenicol, streptomycin, sulphonamides and/or tetracycline, and/or cephalosporins) excluding fluoroquinolones		x
Staphylococcus aureus *(S. aureus)*	*S. aureus* excluding methicillin-resistant Staphylococcus aureus (MRSA) isolates	x	x
	Methicillin-resistant *S. aureus* (MRSA)	x	x
Streptococcus pneumoniae *(S. pneumoniae)*	*S. pneumoniae* excluding isolates with single penicillin resistance and combined resistance to penicillins and macrolides		x
	Penicillin-resistant *S. pneumoniae* excluding macrolide-resistant isolates		x
	S. pneumoniae with combined penicillin and macrolide resistance		x

agents reflects expert advice based on the disease burden, policy priorities and data availability. Some infections considered in the model can be both hospital- and community-acquired and resistant to multiple antibiotics.

Monetary results presented in the main document are expressed in USD, with 2020 as the base year. Presenting the results in USD does not eliminate price differences across countries. Adjusting for purchasing power parity eliminates the price differences across countries with an international dollar with the same purchasing power as the USD in the United States and, therefore, would provide a more appropriate basis for comparing cost results across countries.

The key findings on the health and economic burden of AMR were calculated based on the assumption that all resistant infections are completely eliminated and that the infections are not replaced by susceptible infections. For the intervention analyses, the OECD SPHeP-AMR model was fed with data to simulate the impact of scaling up different interventions to tackle AMR consistent with a One Health policy approach. The design features of the multi-sectoral policies are described below:

- Policies to optimize the use of antibiotics in human health
- Strengthen antimicrobial stewardship programs by scaling up hospital-based programs involving the creation of multidisciplinary teams that provide antibiotic stewardship and the scaling up of monitoring and surveillance systems.
- Financial incentives entailing a nationwide pay-for-performance program to optimize antimicrobial use in community settings by rewarding prescribers with bonuses for achieving pre-set antibiotic prescribing targets.
- Policies in human health to reduce the incidence of infections
- Enhance hand hygiene by scaling up facility-based interventions to enhance hand hygiene practices among health workers.
- Enhance environmental hygiene by scaling up a bundled intervention that aims to improve environmental hygiene practices in hospitals.
- One Health policies to reduce the incidence of infections
- Improve farm hygiene entailing the scaling up of a procurement program that facilitates the purchase of personal protective equipment in farm settings by farmers and professional visitors like veterinarians.
- Improve food handling practices entailing the scaling up of a food safety control training program targeting food service workers in food establishments, coupled with visual reminders and regular audits based on checklists.
- Improve water, sanitation and hygiene (WASH) entailing enhanced access to improved latrines and waste management.

Table 11 describes the key model parameters associated with each intervention to tackle AMR. It is essential to recognize that these model parameters and assumptions impact the estimated impact of the modeled interventions. The modeled interventions can be implemented in hospitals and community settings. They will have a greater or lesser effect depending on several factors, including, for example, the baseline burden of infections and the level of implementation of the intervention in an individual country. In practice, interventions targeting highly prevalent infections and with lower levels of implementation at the baseline are more likely to show a higher impact.

The interventions are modeled based on evidence from the peer-reviewed academic literature. Most evidence on the effectiveness of the modeled interventions was retrieved from the OECD (2023) publication 'Embracing a One Health Framework to Fight Antimicrobial Resistance'. The evidence for the efficacy of WASH [Cha et al. (2020)] is based on the cited reference. Baseline intervention coverage estimates are taken from the Tracking AMR Country Self-Assessment Survey (TrACSS) [WHO (2023)], which is a survey jointly administered by the WHO and the other members of the Quadripartite. The target coverage numbers are based on WHO global targets. The interventions are assumed to be implemented starting in 2023, and their effects will be calculated through to 2050.

Table 11: Inputs Used to Model Selected Policy Interventions to Tackle AMR

	Policies to optimize the use of antibiotics in human health			**Policies in human health to reduce the incidence of infections**		**One Health policies to reduce the incidence of infections**		
	Strengthen ASPs	**Financial incentives**	**Scale up rapid diagnostic testing**	**Enhance hand hygiene**	**Enhance environmental hygiene**	**Improve farm hygiene**	**Improve food handling practices**	**Improve WASH**
Setting	Hospital	Community	Community	Hospitals	Hospitals	Farms (Community)	Food establishments (Community)	Community
Target population	Health workers	Health workers	Health workers	Health workers	Health workers	Farm workers and professional visitors	Food service workers	Children <5 years
Target infection	Resistant hospital infections	Resistant community infections	Resistant community infections	Resistant and susceptible hospital infections	Resistant and susceptible hospital infections	Resistant and susceptible diarrheal infections	Resistant and susceptible diarrheal infections	Resistant and susceptible diarrheal infections
Intervention effectiveness at individual level	30% decline in antibiotic use	8% decline in antibiotic prescribing	32% reduction in immediate antibiotic prescribing in adults and 46% in children <18 years of age	33% reduction in risk of infection among people who comply with enhanced hand hygiene practices compared to those who do not	26% reduction in risk of infection among people who are exposed to enhanced environmental hygiene practices compared to those who do not	12% reduction in risk of infection among people who use PPE compared to those who do not	29% reduction in microbial count	29% reduction in longitudinal prevalence of diarrhea in children <5 years of age
Intervention effectiveness over time	Observed immediately and sustained over time	Observed immediately and sustained over time	Observed immediately and sustained over time	Observed immediately and sustained over time	Observed immediately and sustained over time	Observed immediately and sustained over time	Observed immediately and sustained over time	Observed immediately and sustained over time
Intervention coverage (business-as-usual scenario) (%)	IND: 28	0 for all members	0 for all members	IND: 32	IND: 28	IND: 0	IND: 0	IND: 52
	IDN: 28			IDN: 39	IDN: 34	IDN: 10	IDN: 10	IDN: 51
	CHN: 38			CHN: 46	CHN: 41	CHN: 40	CHN: 20	CHN: 67
	BRA: 33			BRA: 32	BRA: 28	BRA: 0	BRA: 40	BRA: 50
Target coverage (%)	80	70	25	70	70	70	70	90

Notes: BRA=Brazil, CHN=China, IDN=Indonesia, IND=India.

6.4 The Cost of Inaction on AMR, Significant Upsides If AMR Is Eliminated

6.4.1 AMR Could Impact Life Expectancy

Without effective control, AMR will lead to a reduction in life expectancy at birth. Conversely, the absence of AMR will provide a further boost to life expectancy. Using the elimination scenario in the model, life expectancy is estimated to be 1.7 years higher in Brazil and Indonesia, 0.9 years higher in China and 2.3 years higher in India for the projection period up to 2050. Correspondingly, the number of life years (LYs) will increase significantly as a result (see Figure 44).

6.4.2 AMR Negatively Impacts Years and Quality of Life

In addition to its impact on mortality, resistant infections impact quality of life by increasing the number of years lived with disease or disability. This can be combined with LYs to derive the disability-adjusted life years (DALYs). The greater the number of LYs lost or DALYs, the higher the overall burden of AMR on mortality and morbidity. Figure 45 shows the average number of LYs and DALYs that can be potentially gained with the elimination of AMR, normalized per 100,000 persons to account for population differences.

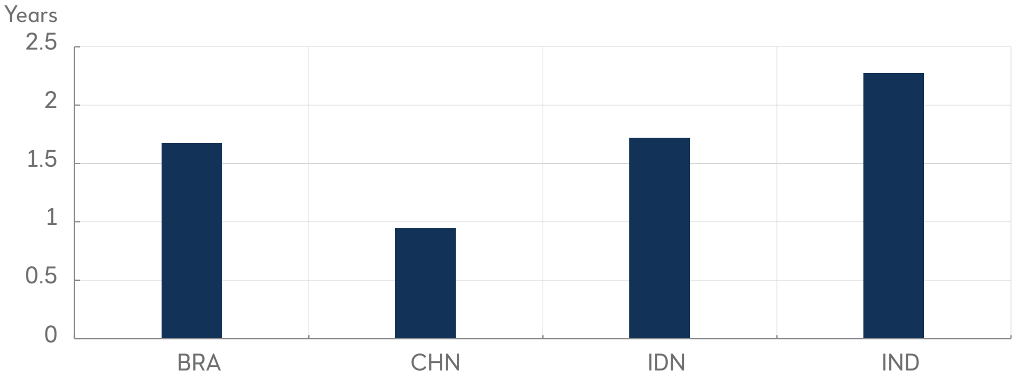
6.4.3 AMR has a Substantial Economic Impact

Infections caused by antimicrobial-resistant pathogens resistant to antimicrobials are generally more expensive to treat than susceptible infections. Treating complications from resistant infections often requires more intensive medical procedures, advanced laboratory tests and extended hospital stays. Health providers may need to resort to more costly and aggressive therapies, including second-line treatments or combinations of antimicrobials, to manage these infections.

Overall, the healthcare systems of the members included in the analysis could spend billions of dollars per year between 2023 and 2050 due to AMR, which substantially straining healthcare budgets. There is great variability across countries, reflecting the differences in the cost of delivering healthcare, levels of access to healthcare services and the size of the overall population.

Beyond the health sector, AMR depresses economic activity through reduced workforce participation and productivity. This translates into substantial financial losses. There is substantial cross-country variation in the potential financial losses, reflecting the burden of resistant infections and wages in each member as well as population and human capital. Differences in labor policies, such as retirement age, may also influence the results, though these effects are challenging to isolate, given that such policies are only indirectly captured by the model through the input data.

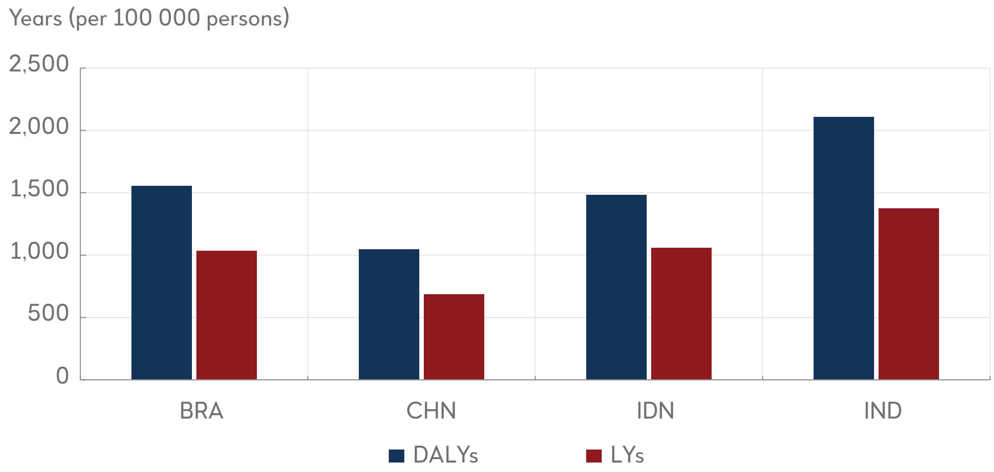
Figure 44: Total Reduction in Life Expectancy at Birth Due to AMR (Up to 2050)



Source: OECD analysis based on the OECD SPHeP-AMR model.

Notes: BRA=Brazil, CHN=China, IDN=Indonesia, IND=India.

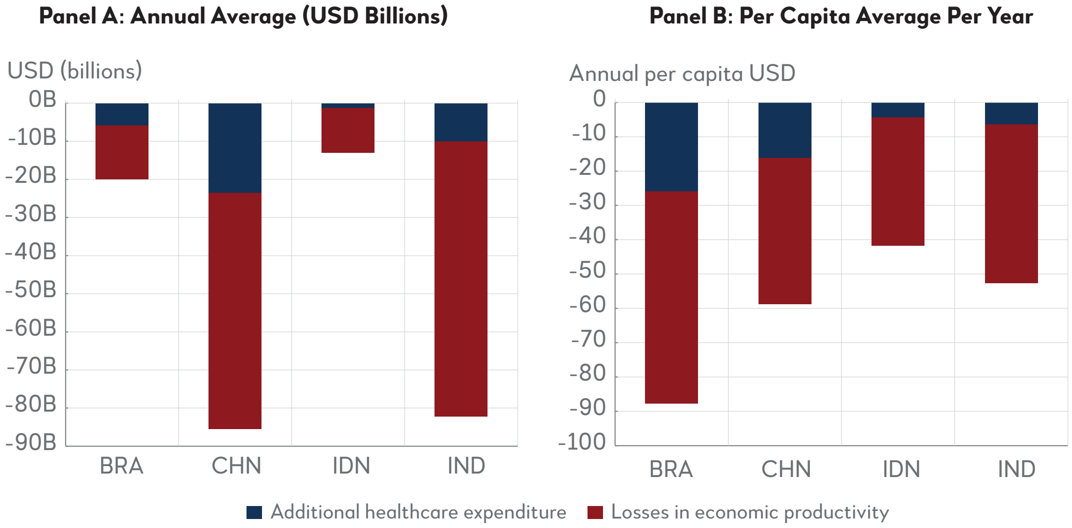
Figure 45: Average Annual Life Years (LYs) and DALYs Lost to AMR (2023 and 2050)



Source: OECD analysis based on the OECD SPHeP-AMR model.

Notes: BRA=Brazil, CHN=China, IDN=Indonesia, IND=India. DALYs: disability-adjusted life years; LYs: life years.

Figure 46: Model Estimated AMR Losses



Source: OECD analysis based on the OECD SPHeP-AMR model.

Notes: BRA=Brazil, CHN=China, IDN=Indonesia, IND=India.

Taking these effects together, Figure 46 summarizes the overall economic impact of AMR. Panel A, Figure 46, shows the average estimated financial losses per year due to AMR between 2023 and 2050 from (1) additional healthcare expenditures and (2) losses in economic productivity as a result of a reduction in full-time equivalents (FTEs) in USD.

The total cost of AMR per year up to 2050 is estimated to be USD20.0 billion in Brazil (or USD88 per capita), USD85.4 billion in China (or USD59 per capita), USD13.0 billion in Indonesia (or USD42 per capita) and USD82.2 billion in India (or USD53 per capita). This can be assumed to be the total cost of AMR. Panel B, Figure 46, shows the corresponding estimates adjusted per capita. In all four members, more than 70 percent of this estimated cost is due to financial losses associated with reduced labor market output.

6.5 Reducing the Burden: Which Policy Interventions are Most Effective?

6.5.1 Policies that Lead to Life Years and Quality of Life

Implementing all eight modeled interventions is expected to improve the number of LYs lived. The effectiveness of all interventions on morbidity, as measured in DALYs, surpasses their effectiveness on mortality, as measured in LYs gained. The magnitude of intervention effectiveness varies across the four countries.

This variation can be due to several reasons, such as the underlying burden of infections and baseline and target coverage of an intervention (see Table 11). In general, infection prevention and control measures such as enhancing hand hygiene and environmental hygiene in hospitals, strengthening antimicrobial stewardship programs in hospitals, and scaling up the use of rapid diagnostic tests with accompanying prescribing guidelines in community settings, are estimated to promise some of the greatest savings in LYs and DALYs gained across all four members. Improving food handling practices and WASH are also associated with relatively high gains in Indonesia and India, likely due to the burden of diarrheal infections in these countries. This is less the case in Brazil and China. In China, improving farm hygiene are estimated to offer the lowest gains in terms of LYs saved and DALYs gained. In Brazil, the least effective intervention is improving food handling practices. In both countries, the low effectiveness is likely to be the relatively high baseline level of coverage (40 percent) that each country holds in the respective interventions.

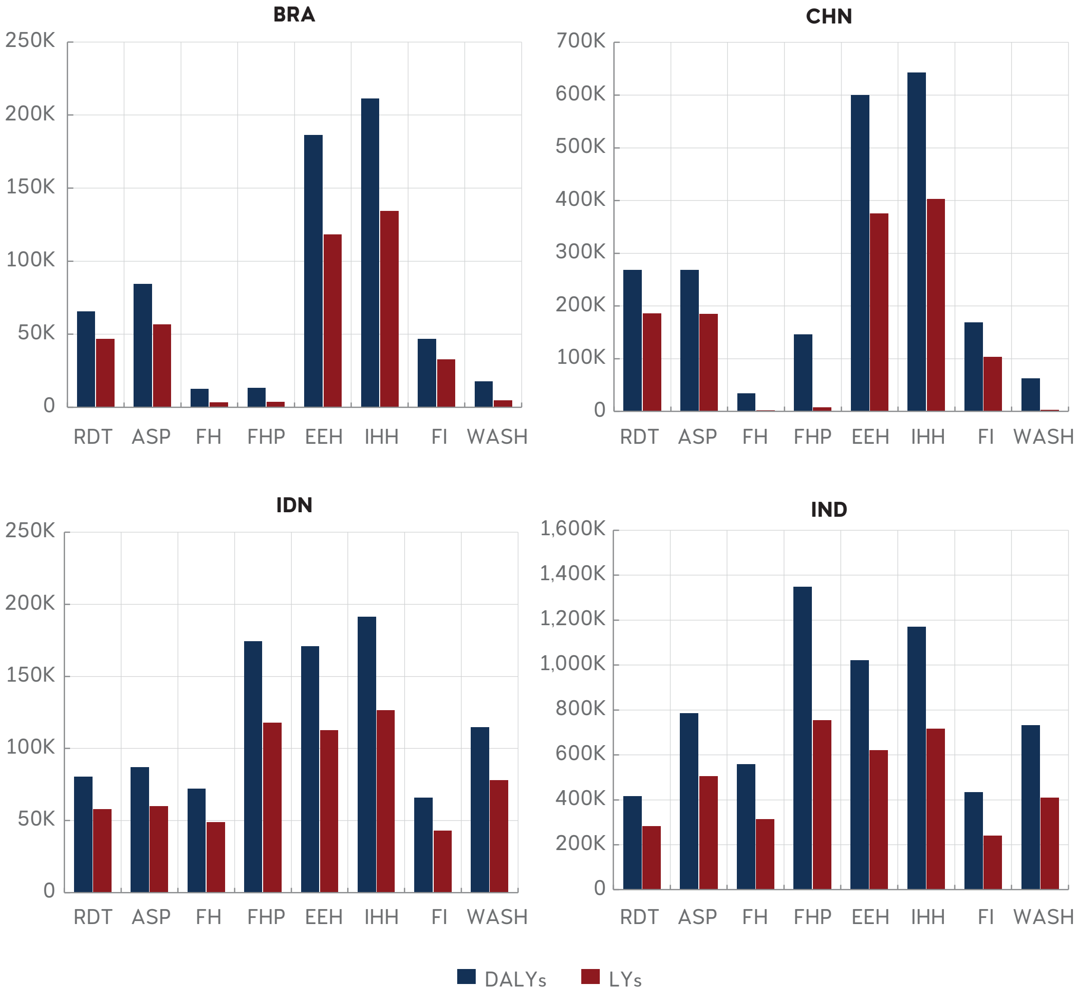
In India, improving hand hygiene practices is the leading hospital-based intervention and is estimated to save around 716,000 LYs annually on average (corresponding to 1.2 million DALYs gained). Improving food handling practices and WASH are associated with the highest gains for One Health interventions. Improving food handling practices saves around 754,000 LYs annually on average (corresponding to 1.3 million DALYs gained), while WASH is estimated to save around 410,000 LYs annually (corresponding to 730,000 DALYs gained). As explained above, the relatively high estimated gains from these interventions are likely due to India's burden of diarrheal infections. Figure 47 shows the average number of LYs saved and DALYs recovered due to AMR averted per year between 2023 and 2050 associated with the modeled interventions. Figure 48 reports the results per 100,000 population.

6.5.2 AMR Interventions Yield Large Gains

Implementing all modeled interventions is estimated to produce savings to the healthcare systems in all four countries, as they reduce the number of additional days spent in hospitals due to treating resistant infections. The magnitude of savings by interventions varies across countries. In general, infection prevention and control measures, such as enhancing hand hygiene and environmental hygiene and strengthening antimicrobial stewardship programs in hospitals, are expected to promise the greatest savings in healthcare expenditure. Improving farm hygiene is generally expected to offer the least savings in terms of this metric. In Brazil, for example, the healthcare system could save, on average, around USD576 million per year between 2023 and 2050 by scaling up the use of hand hygiene interventions in hospitals. Cross-country differences in savings in healthcare expenditure reflect the variation in the burden of infections (including their associated lengths of hospital stay), access to and cost of healthcare services.

The reduction in morbidity and mortality produced by the interventions also has a favorable impact on workforce productivity. Gains can be achieved primarily through increasing workforce participation, followed by reducing absence from work due to ill health and presenteeism. These productivity gains translate into overall financial gains. As with healthcare cost savings, enhancing hand hygiene and environmental hygiene in hospitals and strengthening antimicrobial stewardship programs in hospitals are associated with some of the highest estimated financial gains in productivity, while improving farm hygiene is associated with the lowest. In India and Indonesia, improving food handling practices and WASH is also associated with relatively high gains in productivity.

Figure 47: Annual Average LYs Saved and DALYs Recovered with AMR Averted (2023–2050)



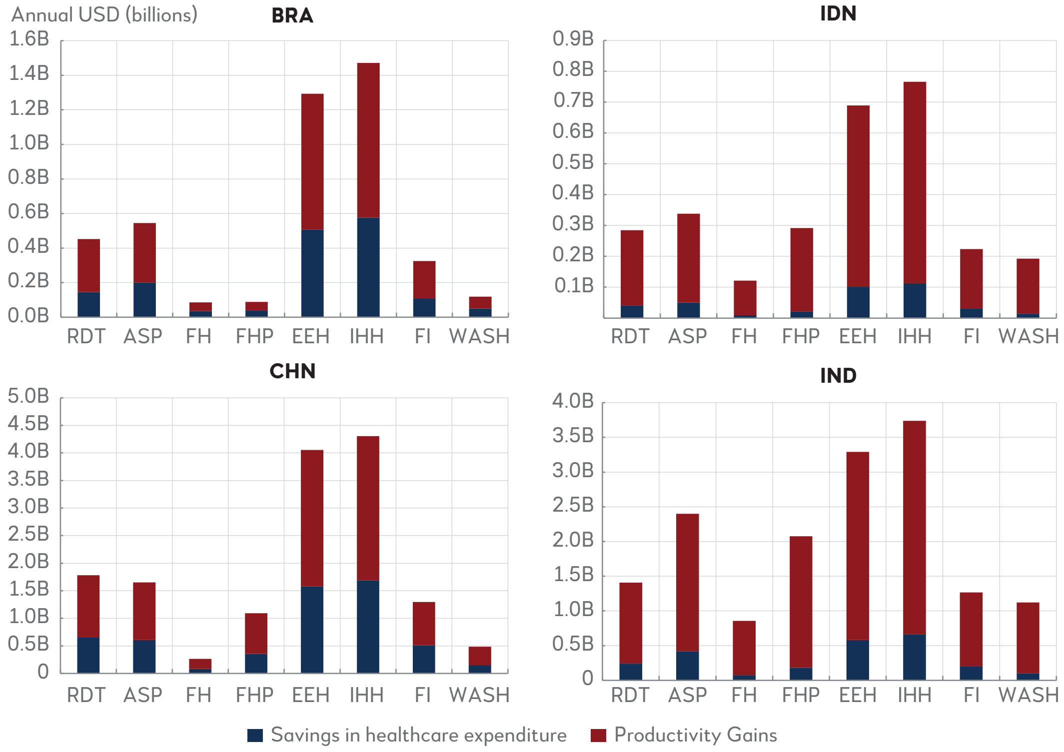
Source: OECD analysis based on the OECD SPHeP-AMR model.

Notes: K = thousands; ASP = Antimicrobial stewardship program; FH = Improving farm hygiene; FHP = Food handling practices; EEH = Enhancing environmental hygiene; IHH = Improving hand hygiene; FI = Financial incentives; WASH = water, sanitation and hygiene. Scales for each country differ.

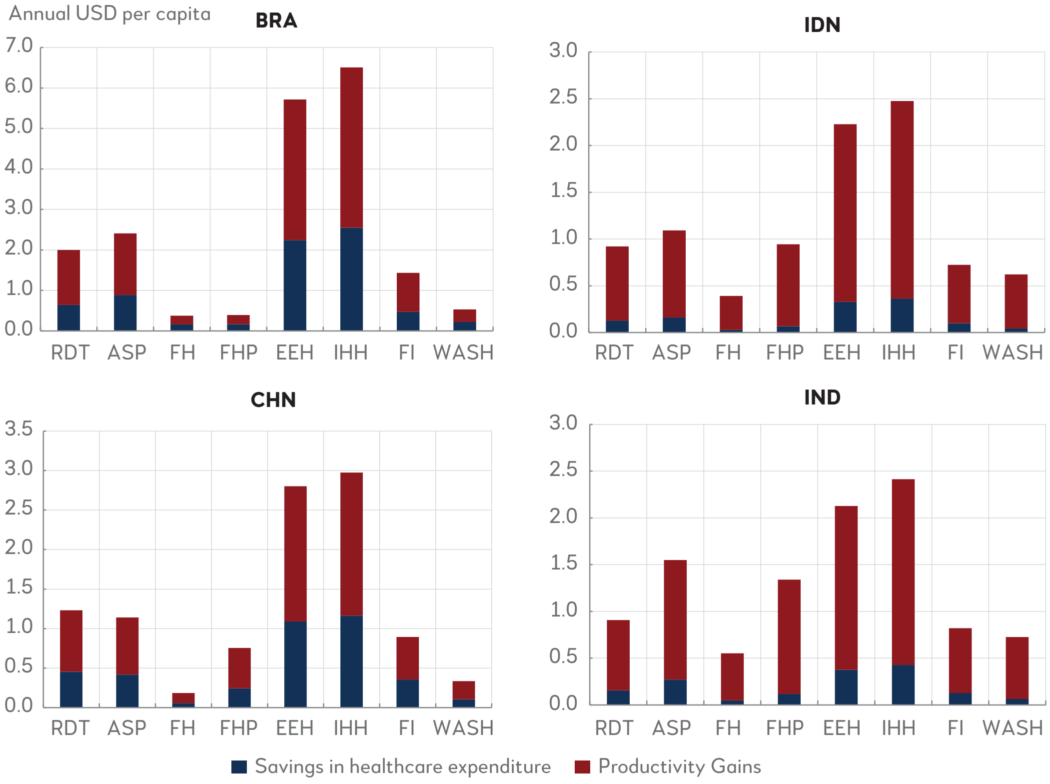
Taking these effects together, implementing all modeled interventions is expected to generate substantial benefits for the health systems and economies of the four members included in the analysis. The magnitude of the benefits varies across interventions and countries. On average, implementing all modeled interventions reduces yearly healthcare expenditure by USD338 million in Indonesia, USD1.5 billion in Brazil, USD2.2 billion in India and USD4.9 billion in China. The estimated gains in productivity exceed the savings in healthcare expenditure. On average, implementing all modeled interventions yields yearly productivity gains of USD2.3 billion in Indonesia, USD2.4 billion in Brazil, USD8.2 billion in China and USD12.5 billion in India. As described above, in all four members, infection prevention and control measures are generally associated with the greatest benefits for health systems and economies. Figure 48 shows the yearly average savings in healthcare expenditure and gains in productivity by avoiding AMR with the interventions between 2023 and 2050, expressed in USD. Figure 48B reports the results in per capita USD.

Figure 48: AMR Interventions and Productive Gains

A: Annual per capita, average per year, in USD



B: Annual per capita, average per year, in USD



Source: OECD analysis based on the OECD SPHeP-AMR model.

Notes: RDT = Rapid diagnostic testing capacity; ASP = Antimicrobial stewardship program; FH = Improving farm hygiene; FHP = Food handling practices; EEH = Enhancing environmental hygiene; IHH = Improving hand hygiene; FI = Financial incentives; WASH = water, sanitation and hygiene. Scales for each member differ.

6.6 Implications for Policymakers and Infrastructure Investors

6.6.1 The Role of Infrastructure

As highlighted above, AMR is an increasingly potent threat to sustainable development in Asia, with the potential to have significant economic impacts. The analysis in this chapter demonstrates that the degree to which countries in Asia can effectively address AMR will be a major determinant of their development pathways in the years leading up to 2050. This chapter also shows that there are several effective solutions to tackle AMR, and infrastructure investors and development finance institutions can have a role to play:

(i) **Direct investment in AMR infrastructure:** Key AMR infrastructure opportunities include WASH and the health sector. Within WASH, this could include projects to treat and dispose of sewage and wastewater as well as monitoring the presence of antibiotic-resistant bacteria in WASH systems. Within the health sector, this includes improving AMR laboratory capacity and diagnostic capability. The global financing needed to tackle AMR, including investments in diagnostic systems, infection control measures, and surveillance, is estimated to be around USD40 billion annually [O'Neill (2016)]. The market for rapid diagnostic tests for AMR-related diseases is expected to grow from USD4.4 billion in 2023 to USD7.6 billion by 2032 [Grand View Research (2023)]. The viability of infrastructure projects is likely to vary by country depending on several factors–including current investment in infrastructure, each country's capacity to deliver improvements and availability of private capital to support. Investment in areas with relatively lower coverage and capacity should lead to more impactful development outcomes. For example, the results of the analysis demonstrate that WASH projects are likely to be more impactful in India and Indonesia—where WASH systems tend to be more underdeveloped—than in China and Brazil. The declaration at the 79th United Nations General Assembly calls for sustainable national financing and USD100 million to support the development of AMR surveillance, diagnostics, and treatment infrastructure globally. However, large financing gaps exist [WHO (2024)].

(ii) **Integrating AMR components (policies or interventions) into more infrastructure projects:** Even if infrastructure does not directly target AMR, investors could add requirements to encourage the implementation of policies or interventions that tackle AMR. For each of the four AIIB members in the analysis, enhancing hand and environmental hygiene (specific interventions to improve practices among health workers) is consistently the most effective intervention in reducing AMR's health and economic burdens. Incorporating such interventions into general health infrastructure projects like hospitals would deliver significant health and economic benefits.

(iii) **Future Policy-based Financing (PBF) programs:** Funding national policy programs to implement some of the interventions modeled in this analysis would be another effective way to accelerate action on AMR. If the scale and urgency of AMR as a future health crisis—as estimated in this analysis—does materialize, then we may encounter more explicit AMR-focused PBF support in the longer term. PBF could also increase the scope of future infrastructure investment.

Other development finance institutions are already taking significant action on AMR. The World Bank, for example, is currently financing 63 projects across 40 countries, predominantly aimed at strengthening agricultural, health and WASH systems [World Bank (2024)]. Development finance institutions and infrastructure investors will increasingly need to work together in preparation for the high likelihood of increased demand for AMR financing from countries in the coming decades.

6.7 Chapter Concluding Remarks

AMR is the silent pandemic with very large economic impacts. The chapter's analysis shows that policy interventions in the health sector are still the most effective at tackling AMR, particularly those focused on infection prevention and control. However, in some members modeled, community-based interventions can also be effective. In India and Indonesia, for example, WASH and farm hygiene interventions reduce the health and economic burden of AMR significantly. Therefore, a multi-sector, planetary health approach to AMR—which combines actions through a policy mix in hospitals and community settings—is likely to be needed.

AMR is a cross-border issue that does not respect country or regional boundaries. Tackling AMR can be considered a global public good, with significant positive spillovers if countries progress the policy interventions highlighted in the analysis through their NAPs, such as better assessment of emerging threats through scaling up of rapid diagnostic testing. The recent political declaration made at the UNGA High-Level Meeting on AMR focused more on NAPs, with a target of 60 percent of countries having funded NAPs by 2030. Continued global governance, regional cooperation and multilateralism will be key to our success in the fight against AMR.

CHAPTER 7

NATURE AND HUMAN HEALTH

Highlights

- Species, from microbes to fungi to plants, are the fundamental building blocks of ecosystems and trace the complex ecological linkages between human health and nature.
- Ecosystems and species function as natural infrastructure, and investment in such natural infrastructure supports human health and well-being and sustainable economic development. The loss of species and their ecosystems likely impacts human health.
- The loss of keystone species can have major health impacts as documented in a recent study which found that the drop in vulture populations in India led to 100,000 additional human deaths per year.
- Mangroves provide valuable ecosystem services that improve human well-being and health by helping prevent damage to essential health infrastructure, accounting for large carbon sequestration and offering plant extracts with medicinal purposes.
- Proven strategies for biodiversity protection include habitat investments that positively impact human health. An example case study of certain species is an instructive example of the central role of natural infrastructure in protecting human health and biodiversity worldwide.

7.1 Why Nature Matters to Human Health

"With biodiversity loss, humanity is losing links in the web of life that provide important ecosystem services, forfeiting opportunities to understand the history and future of the living world, and losing opportunities for future beneficial bio-inspired discoveries and innovations." [National Science Foundation (2020)]

The nature crisis directly impacts human health [Abbasi et al. (2023)]. In fact, a thematic assessment of the nexus of biodiversity, water, food and health points to over 50 percent of global populations living in areas with the highest negative impacts on human health and health risks. These impacts are from the decrease in biodiversity and water availability and quality, food security and detrimental effects of climate change [IPBES (2024)]. Furthermore, the current economic and financial drivers incentivizing investments in activities that damage diversity and other nexus elements sum to around USD7 trillion, while only a small portion of this, approximately USD200 billion, is allocated to improving the state of nature. Note that there remains a lack of peer-reviewed research and data on the complex linkages between nature and health and more is needed.

Biodiversity and healthy ecosystems play a crucial role in shaping the environment around us, profoundly impacting human health outcomes. The variety of species in an ecosystem contributes to its resilience and stability, which directly influences human health. Healthy ecosystems provide access to clean air and water, food security and nutrition, economic opportunities, medicinal resources, protection from known and emergent infectious diseases, and physical and psychological well-being.

One approach to linking our understanding of nature and health, the ecosystem services approach, looks at the core biogeophysical characteristics and cycles associated with a given ecosystem type and relates these to human well-being. For example, a healthy forest provides humans with services ranging from carbon sequestration to water infiltration and from cleaner air to leisure spaces for stress reduction [see Groot et al. (2002); Hooper et al. (2005)]. Wetland areas, such as mangroves, serve as another example. Rich in biodiversity, wetlands can store, assimilate and transform contaminants from the land before they reach waterways. They are also highly effective at flood control and drainage [IISD (2025)].

These landscapes can stabilize the water supplies, purify sewage and recharge groundwater. Between 1980 and 2000, significant losses in biodiversity were reported globally. Approximately 25 percent of mangrove areas were lost, while 20 percent of coral reefs were destroyed, with an additional 24 percent at imminent risk and 26 percent facing long-term threats. IUCN (2019) has reported that the oxygen content of the ocean has declined by around 2 percent since the middle of the century, while land use change is estimated to have affected almost a third of the global land area from 1960 [Winkler et al. (2021)]. Concurrently, the WWF estimates that wildlife populations have declined by 69 percent in the last 50 years alone. These clear connections between health and nature point to healthy ecosystems: resilient systems that provide the services through which all these aspects of human health can exist and thrive [Groot et al. (2002)].

7.1.1 Prevention of Zoonotic Disease

One of the key means by which biodiversity influences human health is through the regulation of diseases. Diverse ecosystems are better equipped to control the spread of infectious diseases by naturally balancing the populations of different species. For example, a variety of plant species can support diverse habitats for animals that act as natural predators to disease-carrying pests like mosquitoes. By maintaining a balanced ecosystem, biodiversity can help reduce the prevalence of vector-borne diseases such as malaria and dengue fever. Research has consistently shown that human activities are the main drivers of infectious disease outbreaks. Human interference with natural ecosystems—through urban development, deforestation and resource extraction—disrupts the delicate balance that helps keep pathogens in check. These disturbances create opportunities for infectious organisms to thrive, raising the risk of human infection. An example is Lyme disease, a bacterium carried by ticks, which has proliferated due to the decline of wildlife such as wolves and other predators, resulting in a rise in deer and rodent populations that serve as hosts for ticks.

7.1.2 Climate Change Adaptation and Mitigation

Nature and biodiversity conservation is crucial for climate change adaptation and mitigation as well as human health, as discussed in several chapters of this report. Healthy ecosystems, like forests, wetlands and mangroves, act as buffers against climate extremes. Mangroves and coral reefs protect coastal areas from storm surges, while wetlands absorb floodwaters, reducing the human health impact of these extreme weather events and damage to essential health infrastructure. Furthermore, ecosystems play a critical role in regulating water cycles. Forests help maintain water quality and supply by filtering pollutants and regulating stream flows, reducing the exposure to unsafe drinking water, which is essential during droughts and extreme rainfall events. Diverse ecosystems are more resilient to changes and can better adapt to shifts in climate. A wide variety of species means that some will likely thrive even as conditions change, maintaining ecosystem functions that support human needs like agriculture and water resources.

Further, forests, oceans, grasslands and soils act as carbon sinks, absorbing CO_2 from the atmosphere and reducing the overall concentration of greenhouse gases. Conserving and restoring these ecosystems is one of the most effective ways to mitigate climate change.

Preventing deforestation and land degradation reduces emissions from the carbon stored in vegetation and soils. For example, when forests are cut down or peatlands are drained, they release large amounts of carbon stored for decades or centuries. Restoring natural ecosystems, such as reforestation, afforestation and peatland restoration, is an essential part of many climate action strategies, as well as improving the air we breathe and reducing a range of climate-sensitive diseases. These nature-based solutions help sequester carbon and enhance biodiversity and human health by reducing the risk of disease, disability and death. These ecosystems not only store significant amounts of carbon—both in plant tissues and in the soil—but also play a vital role in absorbing carbon dioxide from the atmosphere, helping to mitigate climate change effects. The consequences of climate change for nature are complex and can negatively influence human health.

7.1.3 Food Security and Nutrition

Furthermore, biodiversity also plays a critical role in ensuring food security and nutrition for human populations. Various plant and animal species are essential for supporting diverse and nutritious diets. Monocultures, where only a single crop is grown over large areas, are not only less resilient to pests and diseases but also provide limited nutritional variety. However, as diseases and pesticide resistance threaten these crops, we will increasingly rely on new varieties derived from wild plants. Therefore, it must be recognized that the health and productivity of the planet's food systems are directly linked to the diversity of species available. Indeed, diverse agricultural systems incorporating a range of crops and livestock can better withstand environmental stresses and provide a broader range of nutrients essential for human health [see Bernstein and Ludwig (2021); Bernstein and Ludwig (2008)].

The expansion of industrial agriculture often leads to land conversion, which can have devastating effects on remaining biodiversity. At times, in response to the biodiversity crisis driven by agricultural expansion, the number of protected areas has increased significantly, now covering about 11.5 percent of the world's land. While these areas are intended to safeguard ecosystems, they can limit access to resources for local communities, making it essential to balance conservation efforts with the needs of people who rely on biodiversity for their survival.

7.1.4 Mental Health and Well-being

In addition to physical health, biodiversity also has a significant impact on mental health and well-being. Numerous studies have shown that exposure to natural environments rich in biodiversity can have positive effects on mental health, reducing stress, anxiety and depression. Whether through hiking in a diverse forest or simply spending time in a biodiverse urban park, interacting with natural environments can improve mood and overall psychological well-being. Increasing biodiversity through habitat conservation can have positive mental and physical health benefits; these can accrue directly and indirectly from time spent in natural surroundings [see Pritchard et al. (2020); Lumber et al. (2017); Stier-Jarmer et al. (2021)]. Increasing the presence of nature in cities should be a priority for both physical and mental health. A recent report by CABE Space emphasizes the importance of open spaces, providing evidence of their numerous benefits for urban populations. It notes that exposure to nature can lead to significant health improvements, such as reduced blood pressure and lower stress levels. As cities grow, integrating nature into the urban landscape is essential to enhancing quality of life and addressing public health challenges.

7.1.5 Discovery of New Medicines

Moreover, biodiversity contributes to developing new medicines and treatments that benefit human health. Many plant and animal species contain compounds with medicinal properties that have been used for centuries in traditional medicine practices. For example, the rosy periwinkle plant has been instrumental in developing drugs that treat childhood leukemia and Hodgkin's disease. By preserving biodiversity and the genetic diversity of species, potential sources of life-saving medicines are less likely to be lost. Medicines derived from plants, animals and microorganisms play a crucial role in healthcare, but biodiversity loss significantly threatens this potential.

7.2 Infrastructure, Nature and Human Health

Environmental modifications through infrastructure, such as the construction of dams, barrages and canals, contribute to waterborne diseases. Construction of dams on rivers such as the Senegal River in West Africa significantly disrupted the region's ecosystem, leading to increased incidents of schistosomiasis, a snail-borne disease.

A rise in schistosomiasis cases can cause severe strains on healthcare resources. A study on another dam project highlighted the reduction in the daily flow of saltwater from the Atlantic Ocean, which was cut by half as it moved nearly 200 kilometers up the Senegal River. This significant decrease altered the river's salinity levels, impacting local ecosystems and agriculture that relied on a balance of fresh and saltwater. Communities dependent on fishing and farming faced challenges adapting to the changing environmental conditions. The impact of infrastructure on species, ecosystems and health highlights the need for integrated approaches to water management and disease prevention in regions where water is scarce.

As the evidence mounts for linking biodiversity and human health, the focus increasingly shifts to individual species. Global biodiversity research and policy are increasingly focused on species, particularly keystone species [Fenichel et al. (2023)]. This focus connects directly to questions of valuation, biodiversity credits and investment in natural systems. The Global Biodiversity Framework was endorsed by Multilateral Development Banks (MDBs) through the establishment of common principles for identifying and tracking nature-positive finance. These common principles aim to increase nature-positive finance by mainstreaming nature in MDB operations and investments systematically [Hoyer et al. (2023)].

Conventional infrastructure–the nexus of cement, steel and fossil fuels–encompasses elements like roads, bridges, pipelines, or seawalls. Natural infrastructure asks how strategies like coastal mangrove protection, reforestation, or coral reefs can produce productive outcomes while mitigating the negative ecological impacts and risks associated with conventional infrastructure.

Box E: New Research on the Importance of Keystone Species and Nature for Human Health

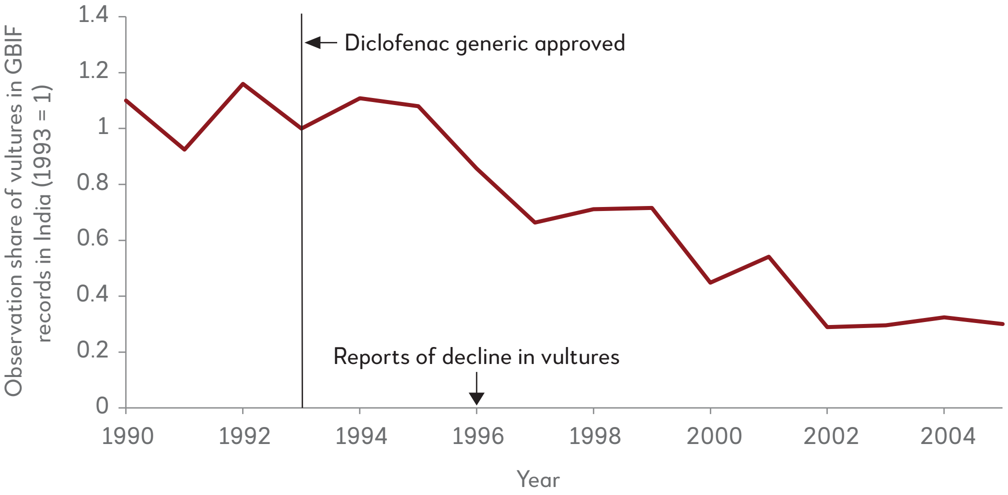
A recent United Nations Report assessed that 1 million of the roughly 8 million animal and plant species are in danger of becoming globally extinct. The risk of local extinction, where a species ceases to exist in a specific region, is thought to be even higher. Extinction leaves wildlife unable to perform its essential role in an ecosystem. In particular, the collapse of the population of keystone species—crucial for maintaining a functioning local ecosystem—can have severe social and economic consequences. The literature has previously said little about the costs of species extinction despite a growing focus on policy targeting the conservation of the natural environment. However, recent research from Frank and Sudarshan (2024) provides crucial insight into the extent of losses humans face from the functional extinction of a keynote species. The authors focus on the dramatic decline in vultures in India, a species essential for disease prevention.

Vultures as a keystone species

Vultures solely feed on carrion, the decaying flesh of deceased animals. The evolution of vultures to become effective scavengers led to their prevalence across India until the 1990s. In just a few years from 1995 onwards, the population of Indian vultures fell by more than 95 percent, leaving only a few thousand remaining (see Figure E1). The decline of these vultures is the fastest of any bird species in recorded history, emphasizing how much the ecosystem was damaged in such a short time.

In 2004, a study found that vultures can develop kidney failure and perish in just a few weeks after consuming carrion that contained the slightest residues of the diclofenac chemical [Oaks et al. (2004)]. Diclofenac is a common pain killer that Indian farmers also administered to livestock. The price of the drug dropped considerably following its patent expiration in the early 1990s as local copies flooded the market. Widespread veterinary use consequently began around this time. By 2000, all three species of vulture in India had been classified as critically endangered. Several Vulture Safe Zone initiatives exist today, accompanied by plans for trial releases from breeding centers. Despite the government banning diclofenac's veterinary application, evidence points to ongoing illegal administration. Vultures in India have failed to return to previous levels.

Figure E1: Decline in Observations of Affected Vulture Species



Source: Frank and Sudarshan (2024). The authors calculate the share of reports of diclofenac-affected vultures relative to other bird species that have non-zero observations each year. Original data from the Global Biodiversity Information Facility (GBIF) database [GBIF (2025)].

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Box E *continued*

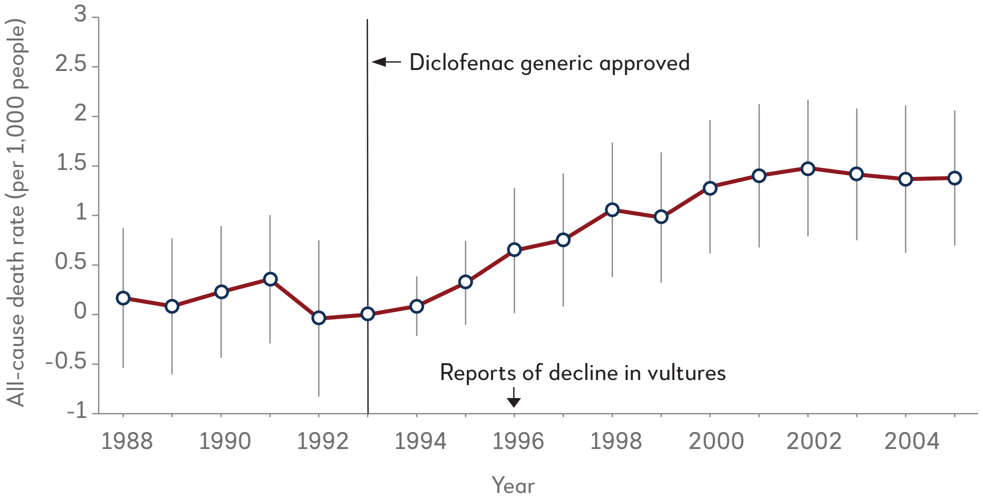
In low- and middle-income countries, where agriculture still constitutes a significant component of the economy, birds are strong substitutes for costly infrastructure such as animal incinerators for disposing of carcasses. In 2019, a livestock census reported over 500 million animals in India, the highest in the world. Due to a lack of vultures to effectively consume carrion, "animal landfills" began to pile up on the outskirts of urban areas. This attracts other mammalian scavengers, like feral dogs and rats, whose population grows at the expense of the vultures following less competition for carrion.

The impact on human health

Feral dogs in India are already a major threat to human health, especially to young children because of rabies. Feral dogs and rats are also vectors of infectious diseases and less efficient scavengers than vultures, meaning that their prevalence near carcass dumps leaves the local environment acutely vulnerable to contracting disease. These zoonotic diseases include anthrax and tuberculosis, which can be deadly, especially when there is a lack of health infrastructure. Moreover, pathogens can contaminate water supplies when these carcasses are thrown into rivers. Evidence of rabies cases rising after 1994 and higher water pollution levels in areas with fewer vultures support these channels. Overall, vultures dying out can have profound adverse sanitary effects on human health.

A difference-in-differences methodology was used to estimate the causal effect of a sharp decline in vultures on human health. This approach compares the change in human deaths in districts suitable for vulture habitation to those not before and after the 1994 domestic entry of diclofenac. Results indicate that the negative sanitation shock from vultures no longer effectively contributes to the ecosystem increase in human mortality by over 4 percent (see Figure E2). This is equivalent to over 100,000 excess deaths annually in the country, with an economic cost of USD69 billion through an India-specific value of statistical life. Accounting for an increased morbidity rate due to the prevalence of disease means that this figure may be a lower bound. There are additional economic costs from an increase in healthcare expenditure and productivity losses from illness. An earlier study analyzing the impact of the vulture decline had, in fact, estimated a cost of only around USD300 million in human health impact on the Indian economy. The broader scale of damages reflects the substantial shock resulting from the collapse in the vulture population.

Figure E2: All-Cause Death Rates Diff-in-Diff Estimation Results



Source: Frank and Sudarshan (2024). Estimation results from the differences-in-differences methodology showing coefficients and 95 percent confidence intervals. The regression includes all districts with balanced data from 1988 to 2005, as well as district and zonal council-by-year fixed effects.

Box F: Mangroves Case Study

Mangrove forests are natural infrastructure fringing tropical and subtropical coastlines. Mangrove trees develop extensive systems of below-ground and above-ground roots and dense vegetation, providing a three-dimensional protective habitat structure supporting other plants and a considerable diversity of associated animals and microorganisms. If well-managed, mangroves can provide an array of ecosystem services supporting human well-being, from physical protection of lives and property to nutrition, renewable supplies of raw materials, livelihood and employment, and mitigation against climate change. They are one of the best examples of natural infrastructure in the world.

Mangroves and health

Aquatic products from mangrove ecosystems (principally fish, crustaceans and mollusks) are typically high in protein and omega-3 fatty acids and rich in vitamins and minerals. These dietary components are vital to human health by preventing malnutrition and other health issues. For coastal communities, mangrove aquatic products are locally available and easily harvested by fishing or gleaning with simple hand tools. Non-aquatic foods from mangrove ecosystems are also readily available. Some mangrove leaves and herbs are edible, while the mangrove nipa palm is used to produce sugar and traditional food products, especially in Southeast Asia. Certain mangrove species also support bee populations, enabling the production of highly valued mangrove honey. Sheaves et al. (2015) highlighted the importance of mangrove fisheries for food security in tropical developing countries, where mangrove-dependent species often constitute 30-80 percent of small-scale fisheries catch in these regions. This daily available protein source is vital for preventing malnutrition, especially in children.

Along with their nutritional value, many mangrove species contain bioactive compounds that possess therapeutic properties. Dahibhate et al. (2019) identified over 200 bioactive compounds from mangroves, including alkaloids, terpenes and phenolic compounds. Many of these show promising pharmacological activities. Selected parts of some mangrove plants have been used traditionally as medicines. There is potential for further identification and utilization of mangroves both as a food source and a reservoir of future pharmaceutical agents. Mangroves also moderate the climate and promote clean air and water. They act as natural biofilters that break down or absorb environmental pollutants, such as nitrogen, phosphorus and heavy metals.

Economic value of mangroves

The world's mangroves cover about 147,000 square kilometers. Their estimated value ranges widely, depending on a country's GDP, area-specific coastal environment features, how mangrove resources are used and the valuation methods applied. Past values have typically averaged USD7,000 to USD12,000 per ha per year but are less for lower-income countries (e.g., USD1,938 to USD3,850 for mangroves in Pakistan). The UN Environmental Programme recently estimated the total economic value from USD33,000 to USD57,000 per ha per year. The carbon value of mangroves is now considered, with mangrove sequesters storing 3 to 4 times more carbon by area than other forest types. However, the coastal protection mangroves offer constitute the largest proportion (90 percent) of the value. Further work should be done to quantify the health benefits of maintaining the world's mangroves.

The Asian Infrastructure Investment Bank's 2023 Asian Infrastructure Finance Report explored whether mangrove depletion can lead to environmental damage using Indonesia as an example. Results suggest that an increase in mangrove coverage is correlated with a reduction in damaged amenities from tidal floods. For regencies experiencing mangrove depletion, the authors found a reduction of 0.2 units of damaged amenities for each percentage point increase in mangrove coverage within a five-kilometer buffer area, while for regencies with growing mangroves, the same increase corresponded to a reduction of 0.4 units. The analysis highlights how mangroves can significantly minimize damage and casualties in regencies at the greatest risk of tidal floods, where the poverty rate also tends to be higher than the national average (18.6 percent compared to 16.8 percent in 2008, for example). Therefore, protecting mangroves can help reduce economic damage, which is detrimental to well-being and limit mortality following extreme weather events. Incentives should be provided to local communities to manage mangroves and prevent further degradation and harm to human health.

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Box F *continued*

The hidden complexities of ecosystem conservation

While mangroves serve as critical natural infrastructure with extensive root systems and dense vegetation, implementing conservation strategies presents complex challenges that warrant careful consideration. Despite their proven value in providing ecosystem services, local communities often face immediate economic pressure that conflicts with preservation goals. For instance, in Southeast Asia, mangrove areas are frequently converted to aquaculture ponds, providing immediate income for impoverished coastal communities despite the long-term environmental costs [Richards and Friess (2016)]. These tradeoffs become particularly acute when considering human-wildlife conflicts, such as safety risks to local inhabitants and economic losses from protected species. The challenges are compounded by our limited understanding of ecosystem valuation and the linkages between conservation outcomes and human welfare. Research by Bennett et al. (2019) shows significant knowledge gaps in quantifying the socioeconomic impacts of conservation initiatives, particularly in developing regions where poverty alleviation and environmental protection objectives frequently intersect. There is a pressing need for more comprehensive research to better understand and navigate these tradeoffs, ensuring conservation strategies that can effectively balance ecological preservation with human development needs.

Box G: Urban Nature-based Solutions for Health Case Study

The healthy city approach leverages urban planning and design to promote health. Significant research has been conducted to explore the value of urban green spaces and nature for health and well-being. These spaces provide environmental benefits by mitigating urban heat (e.g., reducing air conditioning costs), cutting greenhouse gas emissions, providing habitat to sustain local biodiversity and managing stormwater. Additionally, they offer health benefits by providing opportunities for physical activity, social interaction and psychological restoration. Understanding the mechanisms through which these benefits are achieved is crucial [Bechauf (2022)].

Abbottabad Park Project - Pakistan

Abbottabad is a rapidly growing city in the Khyber Pakhtunkhwa province of Pakistan, currently facing numerous urban challenges. While the region has been experiencing both the growing frequency and strength of extreme weather events, green space in Abbottabad has declined over time, resulting in a higher incidence of the urban heat island effect and increased air pollution and flood risk. This has all been negatively impacting human health.

To counter these issues, the Khyber Pakhtunkhwa Cities Improvement Project [AIIB (2023)] has initiated the revitalization and expansion of Shimla Hill Park of Abbottabad, now renamed Sherwan Hill Adventure Park. By expanding and rehabilitating the park, the project aims to offer increased access to green spaces to help improve the physical and mental health of citizens while reducing air pollution and heat stress. The project also looks to mitigate flood risks, reducing the likelihood of waterborne diseases.

Economic analysis of the project’s outcomes

The International Institute for Sustainable Development applied their Sustainable Asset Valuation methodology (SAVi) in conducting a cost-benefit analysis and found that the expansion and rehabilitation of the park would have substantial health benefits [IISD (2024);IISD (2024)].

Overall, the Sherwan Hill Adventure Park expansion project is shown to be economically viable. The park expansion and revitalization will generate 1.41 Pakistani Rupees in return for each rupee invested when considering discounted values. When using undiscounted values, the Benefit-Cost Ratio is 2.49. The project’s net present value is positive, reaching PKR382.69 million over a 30-year period. The results

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Box G *continued*

indicate economic viability for the project (a 10 percent discount rate matching the average central bank rate is used). Health improvements are indeed among the largest co-benefits, which include physical activity, reduced heat stress and lower air pollution. The health benefits from increased physical activity, for example, are emphasized by the positive effect of increasing visitor numbers under an alternative scenario on the project's net benefits. Specifically, the value of avoided costs and benefits to human health amounts to 11 to 16 percent of the total investment, depending on the assumptions used and represents up to 13 percent of the total benefits generated by the nature-based infrastructure investment.

Table G1: Cost-benefit Analysis of the Abbottabad Park Project

	Undiscounted vaues	Discounted values
Total costs	**1,196.00**	**927.57**
Capital cost	808.00	797.70
Operations & Maintenance costs	387.84	129.87
Total added benefits	**2,910.00**	**1,290.37**
Income creation from reforestation jobs	3.94	1.61
Revenues from increased consumption	1,800.00	602.75
Health benefits of physical activity	274.76	86.29
Property value increase	800.00	591.39
Increased carbon storage	31.61	8.33
Total avoided costs	**62.40**	**18.63**
Health cost of heat stress	30.61	10.25
Health costs of air pollution	31.79	8.38
Net present value	**1,776.87**	**381.42**
Benefit-to-cost ratio	2.49	1.41
Internal rate of return	18.14%	18.14%

7.3 Investing in Nature for Health and the Role of Infrastructure

The links between functioning ecosystems and human health are evident, but how can ecosystems be made more resilient, protected from further deterioration and eventually restored to their full potential? Wildlife conversation and ecosystem restoration not only help protect endangered species but also improve human health outcomes. The 2023 Asian Infrastructure Finance Report Nature as Infrastructure argued that nature should be viewed as the most essential infrastructure for preserving life on Earth. There is a need to invest in and help manage nature to realize its true potential. Its full potential may never be fully known, but valuing natural capital and its various impacts on human health should be accounted for, including the possibility that a particular species of plant or fungi could have medicinal uses.

Nature as infrastructure starts from the view of ecosystems as systems sustaining life in a particular space. One can think of the large river systems of the world which have supported human civilizations for millennia. They deliver services to human beings, sometimes called ecosystem services, but the value of services extends beyond human beings. Nature-based solutions refer to solutions using nature to provide specific services. They help bridge the link between nature as infrastructure and health by focusing on a particular health benefit a natural environment may have. However, different ecosystem services often reinforce or even contradict each other. For example, a nature-based solution to flood management may help purify the water. Such a positive impact on health outcomes is sometimes called health co-benefits. Of course, the effect on health can also be harmful. For instance, wetland restoration could actually increase the prevalence of vector-borne diseases by becoming breeding grounds for mosquitos. Therefore, the total impact of nature infrastructure on health must be accounted for.

Infrastructure projects can target both the mitigation and adaptation of the fallout of an ecosystem. Relevant examples can be waste management and water sanitation initiatives. Projects incorporating measures that mitigate harm to ecosystems could also highlight the general benefits of conservation.

Real-world examples demonstrate how nature-based solutions can reduce costs, enhance resilience, and generate co-benefits for people and the planet. In Côte d'Ivoire, AIIB has launched its first infrastructure venture in Sub-Saharan Africa incorporating nature-based solutions to enhance climate resilience in road development. This project is particularly significant as road infrastructure in many parts of Africa is highly sensitive to the impacts of climate change, including extreme weather events and soil erosion. A key component involves tree planting along newly constructed and rehabilitated roads. This practice stabilizes soil, reduces erosion, and protects the road from damage caused by runoff during heavy rains. Additionally, the planted trees act as carbon sinks, offsetting some of the greenhouse gas emissions associated with road construction and operation. Beyond climate mitigation, the tree-lined roads provide shade, reducing the urban heat island effect in nearby settlements and improving thermal comfort for pedestrians and cyclists.

The World Bank has also incorporated nature-based solutions for disaster risk management. For example, in the Philippines, Metro Manila Flood Management Project supported by the World Bank is a comprehensive initiative to address chronic flooding in one of Southeast Asia's most densely populated urban areas. Frequent flooding in Metro Manila, exacerbated by climate change and rapid urbanization, has caused significant economic losses, displaced communities, and degraded public health and safety. The project rehabilitates natural waterways, wetlands, and creating green spaces that enhance the city's flood resilience. It involves clearing and desilting clogged canals while introducing vegetation along waterway banks. For example, mangrove restoration in adjacent coastal areas has bolstered natural defenses against storm surges and enhanced carbon sequestration. Another innovative feature is the development of multi-purpose green spaces, such as parks and recreational areas, that also function as flood retention zones during heavy rains.

To scale up investment, including private sector investments, development banks can leverage the emerging pool of instruments targeting nature and health outcomes. These include bonds linked to a conservation effort, such as the "Rhino Bond," as well as broader initiatives, such as the "Global Fund for Coral Reefs," which is a public-private partnership. Interest in species- and nature-related financial instruments, such as debt-for-nature swaps, is rising. It is increasingly clear that private sector finance can be effectively channeled to conservation efforts.

For example, in 2022, the World Bank issued the Wildlife Conservation Bond (WCB) to support South Africa's efforts to conserve endangered species. This five-year USD150 million instrument, often dubbed the "Rhino Bond," includes a potential performance payment from the Global Environment Facility, which will contribute to protecting and increasing black rhino populations in two protected areas in South Africa. The WCB was the first outcome-based financial instrument that channels investments to achieve conservation outcomes, in this case by promoting an increase in black rhino populations [World Bank (2022)].

Rand Merchant Bank (RMB) is now in the process of launching wildlife bonds to raise funds for the conservation of African wild dogs and lions. Inspired by the World Bank's WCB "Rhino Bond," RMB plans to issue USD233 million in five-year bonds between 2024 and 2025. The proceeds will be used to boost wild dog populations and reintroduce lions to protected areas in Africa [Sguazzin et al. (2023)]. The bonds aim to address biodiversity loss and promote sustainable wildlife populations, thereby benefiting both the environment and conservation-focused investors.

Sustainability-linked bonds (SLBs) increasingly incorporate Key Performance Indicators (KPIs) tied to nature protection, especially biodiversity. For instance, SLBs are now linking KPIs to biodiversity goals, with the market expected to accelerate the inclusion of these indicators. This shift represents a growing focus on protecting natural ecosystems as part of sustainability objectives [Ferraglioni (2023)].

Sovereign SLBs, which are specifically designed to link sovereign financing with climate targets by rewarding countries that meet their commitments, also use KPIs to align environmental objectives with national goals. For example, Chile's SLB includes KPIs related to environmental objectives specified in its updated Nationally Determined Contributions, ensuring that progress on biodiversity and natural resources is tracked alongside financial goals. These bonds set measurable sustainability performance targets, often connected to protecting ecosystems, reforestation and maintaining forest cover.

These KPIs can also account for the numerous health co-benefits from investing in climate and nature. A WHO report in 2011 explored the co-benefits of housing-related climate change migration. For instance, the transmission of communicable diseases can be reduced through low-energy and climate-friendly housing designs, while reducing exposure to extreme weather and improving air quality can limit the danger from non-communicable diseases. The World Bank's own "Climate and Health" Program is tasked with mitigating the spillover from climate change on human health. Its "3 by 3" framework again draws attention to the health co-benefits by recommending interventions to create health outcomes from mitigation in other sectors. Of course, KPIs can also be directly tied to the health impacts themselves, creating a robust strategy for combating the widespread impacts of nature degradation.

Banks are also increasingly integrating biodiversity and nature protection into their strategies to align with sustainability goals. They recognize the financial risks associated with biodiversity loss and are adopting "nature-positive" roadmaps. These strategies involve assessing and mitigating biodiversity impacts and embedding sustainability into lending and investment decisions [Martinez et al. (2023)]. Many banks now offer specialist advice to corporate clients on reducing their biodiversity footprints and promoting sustainable practices. Some institutions, like Bank Australia, have launched nature-positive products and committed to supporting conservation efforts. Incorporating biodiversity strategies also helps banks reduce risks in their portfolios, particularly by managing the environmental impact of projects they finance. This shift towards nature protection enables banks to contribute to global environmental goals while creating new value opportunities.

Recently, the Taskforce on Nature-related Financial Disclosures (TNFD) has devised recommendations to provide such financial institutions with a risk management and disclosure framework to manage and disclose nature-related issues. Its in-depth report views investing in health as a solid business practice and consequently emphasizes the human health and well-being co-benefits from supporting the recovery of an ecosystem [TNFD (2023)].

Moreover, nature-related risks and opportunities are difficult to quantify due to the absence of standardized data on biodiversity and ecosystem services. Institutions rely on evolving datasets, making it hard to fully assess their exposure to nature-related risks.

As a result, without precise measurement tools and robust data, financial institutions find it difficult to price nature-related risks properly, leading to undervaluation or mismanagement of nature's critical role in the economy.

7.4 Chapter Concluding Remarks

Biodiversity profoundly impacts human health outcomes in many ways, from disease regulation and food security to mental well-being and medicinal discoveries. Recognizing the importance of preserving biodiversity is not only crucial for the health of ecosystems but also for the health of human populations. The loss of species impacts human health and ecosystem resilience.

The loss of vultures in South Asia has been correlated to negative impacts on human health, loss of life and enormous economic implications. The plight of vulture populations is not unique. Keystone species like bats provide essential nutrients to a cave's food chain, while wolves prevent soil erosion by hunting elk that feed on vegetation by riverbanks. Safeguarding these vital species is crucial for maintaining the natural environment and protecting human health from diseases.

The mangroves provide an example of a plant species and ecosystem that demonstrate a natural infrastructure with great economic and health benefits.

Investing in nature-based solutions and promoting conservation efforts and sustainable practices that protect and enhance biodiversity can safeguard the environment and human health and well-being for generations to come.

CHAPTER 8

ONE HEALTH APPROACH TO ZOONOTIC DISEASES

CHALLENGES AND OPPORTUNITIES

Highlights

- Zoonotic diseases, which account for over 60 percent of emerging infectious diseases, pose significant threats to global public health, food security, and economic stability, underscoring the urgent need for integrated, multisectoral approaches to prevention and control.
- Preserving wildlife and nature, strengthening food safety, regulating wet markets, and investing in capacity building, including digital tools such as surveillance systems and digital platforms to help monitor health risks and facilitate faster response, are key to preventing future outbreaks and pandemics [UNEP (2020)].
- The One Health approach—integrating human, animal, and environmental health—is crucial for tackling pandemics, food security and environmental degradation. Effective implementation requires stronger coordination and data sharing between sectors to overcome barriers to timely outbreak detection and containment.

8.1 Interconnectedness of Human, Animal and Environmental Health in a Globalized World

In an interconnected world, the health of humans, animals and ecosystems is deeply intertwined. "One Health" is a multidisciplinary approach recognizing the interconnectedness of human, animal and environmental health. Additionally, the 2021 definition of One Health from the FAO, WOAH, UNEP and WHO advisory panel, the One Health High Level Expert Panel, includes action on climate change [WHO (2021)]. Around 60 percent of all emerging infectious diseases in humans are of zoonotic sources [Woolhouse and Gowtage-Sequeria (2005)], i.e., they are caused by pathogens transmitted from animals to humans in a process known as zoonotic spillover. Since the 1950s, zoonotic diseases, including Spanish Influenza, HIV and COVID-19, have resulted in an estimated cost of at least USD350 billion, along with an additional USD212 billion in direct economic losses [Bernstein et al. (2022)].

The COVID-19 pandemic has demonstrated the devastating impact a global pandemic can have on public health, economies and social structures. In a mere few months, the virus not only claimed millions of lives but also reversed years of progress in sustainable development. The pandemic has overwhelmed healthcare systems and left long-term health consequences for millions. Economically, it triggered the largest global contraction since the Great Depression, with a projected loss of USD22 trillion by 2025. The World Bank and WHO estimate that a USD31.1 billion annual investment is required to fund a future pandemic preparedness and response system. Currently a gap of USD10.5 billion per year exists between required investment, and existing and expected domestic and international pandemic preparedness response financing.

International financing, including important MDB financing could close the gap. Socially, the pandemic disrupted education for 90 percent of schoolchildren and pushed millions into extreme poverty, exacerbating inequality. Vulnerable populations, including women, informal workers and displaced people, have faced immense hardships. The pandemic's toll goes beyond statistics, as it has deeply affected livelihoods, well-being and global equity, underscoring the urgent need for stronger preparedness and response mechanisms [Sirleaf et al. (2021)].

As global concerns over pandemics, food security and environmental degradation increase, Southeast Asia has emerged as a region of critical focus due to its high population density, biodiversity and the prevalence of zoonotic diseases. Countries like Viet Nam, Thailand, Indonesia, and the Philippines are particularly susceptible to zoonotic diseases such as avian influenza, SARS and more recently, COVID.

Addressing animal health and environmental degradation is critical to mitigating the risk of emerging infectious diseases, including pandemics, originating from animals. By monitoring and improving animal health, the spread of zoonotic diseases can be detected and controlled at the source, preventing transmission to humans. Strengthening veterinary services, improving disease surveillance in animals and promoting sustainable livestock practices reduce the risk of zoonotic spillovers. This integrated approach not only safeguards human health but also protects ecosystems and promotes food security, making it a vital component in preventing future health crises.

Despite Southeast Asia's recognition of the importance of integrated approaches like One Health, the region faces substantial challenges in implementing these projects. These challenges range from institutional barriers, lack of coordination among various sectors, resource constraints, and socio-political factors to gender and inclusion issues. This section explores these challenges in-depth, focusing on multisector collaboration, governance and the lessons learned from recent One Health projects in the region.

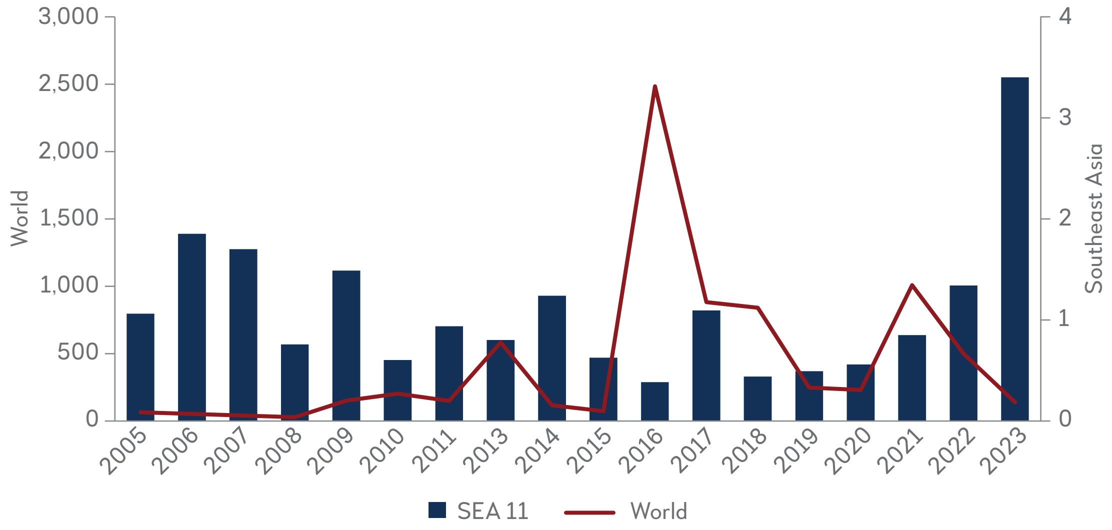
One Health is a collaborative, multisectoral and transdisciplinary approach that aims to achieve optimal health outcomes by recognizing the interconnection between people, animals, plants, and their shared environment. The concept is hardly new but has gained prominence due to the increasing global risks posed by emerging infectious diseases, climate change, and unsustainable agricultural practices.

Southeast Asia, a biodiversity hotspot with a high risk of zoonotic disease emergence, is an ideal region for One Health interventions. However, effective implementation of One Health strategies in the region is fraught with challenges.

Southeast Asia is home to over 600 million people and has diverse ecosystems ranging from dense tropical rainforests to mangroves and coral reefs. It is also one of the most biologically diverse regions globally, housing a wide variety of wildlife species. The region has already witnessed outbreaks of zoonoses like the Nipah virus, avian influenza (H5N1), and, more recently, COVID, which is believed to have originated from wildlife. In the last decade, more than 10 million outbreaks emerged in Southeast Asia (Figure 49).

Given this context, Southeast Asia is critical for One Health initiatives. Several countries have initiated One Health projects, focusing on early detection, surveillance and response to zoonotic diseases. However, the complexity of these projects has highlighted significant challenges related to governance, coordination among stakeholders, capacity-building and socio-economic factors.

Figure 49: Number of Zoonotic Disease Cases Globally and in Southeast Asia, Millions



Source: Global Animal Cases between 2005-2023, OIE-WAHIS. SEA countries include Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam.

8.2 Key Implementation Challenges

A fundamental requirement of the One Health approach is collaboration across various sectors—human, animal and environmental health. However, achieving this in practice is often difficult. Relevant Ministries often work in silos, with differing priorities, mandates and resource allocations. This lack of inter-sectoral communication and collaboration hinders the effective implementation of One Health initiatives. For example, in Indonesia, which has faced repeated outbreaks of avian influenza, the Ministry of Health, Ministry of Agriculture and environmental agencies have struggled to develop a unified response strategy. In 2017, the Government confirmed its commitment to advance One Health collaboration with five ministries by issuing a joint communique [FAO (2017)].

Many Southeast Asian countries face governance challenges that undermine the effectiveness of One Health interventions. Weak institutions, corruption and limited decentralization are common barriers. For instance, in countries like Cambodia and Lao PDR, public health systems are often underfunded and lack the capacity to manage cross-sectoral projects effectively [Lim et al. (2023)]. Decentralization in healthcare systems often leads to discrepancies in the implementation of One Health initiatives, as local governments may lack the necessary expertise or resources to manage complex projects that require coordination with national and international bodies [Abimbola et al. (2019)].

Another significant challenge in Southeast Asia is the lack of adequate financial and technical resources to support One Health projects. Many countries in the region are low- or middle-income, with limited budgets for public health, veterinary services and environmental protection. Consequently, there is often competition for resources between these sectors, making it difficult to allocate sufficient funding for integrated One Health approaches. For example, Viet Nam has successfully implemented One Health initiatives, particularly in response to avian influenza outbreaks [World Bank (2022)]. However, the country faces ongoing challenges related to funding and resource allocation.

While international donors have provided financial support for specific projects, there is a dearth of sustained investment in the infrastructure and workforce needed to implement long-term One Health strategies. This is a common issue across the region, where donor-driven projects often lack continuity once external funding ends [World Bank (2019)].

Cultural practices and socioeconomic conditions in Southeast Asia also pose significant challenges to One Health implementation. For instance, wet markets, where live animals are sold, are a common feature in many countries in the region. These markets can be hotspots for zoonotic disease transmission, but they are also vital to the livelihoods of millions of people. Shutting down or regulating these markets is a sensitive issue that requires balancing public health concerns with economic realities. In addition, poverty and inequality in many parts of Southeast Asia exacerbate the difficulties of implementing One Health projects. Marginalized communities, such as rural populations and indigenous groups, often have limited access to health services, and their traditional practices may conflict with modern health initiatives. For example, in Indonesia, which has faced repeated outbreaks of avian influenza, the Ministry of Health, Ministry of Agriculture, and environmental agencies have struggled to develop a unified response strategy. In 2017, the Government confirmed its commitment to advance One Health collaboration with five ministries by issuing a joint communique [FAO (2017)].

Gender and inclusion play a critical role in the success of One Health initiatives, yet these aspects are often overlooked. Women, in particular, play a significant role in agriculture and animal husbandry in Southeast Asia, making them key stakeholders in One Health projects. However, women are often excluded from decision-making processes, limiting their ability to influence health and environmental policies. In Thailand, for example, women are heavily involved in small-scale poultry farming, yet they have limited access to resources and training that would help them implement better biosecurity practices. Gender inequality in access to education and health services further exacerbates the situation, as women in rural areas may lack the knowledge and resources to protect themselves and their communities from zoonotic diseases [We World (2023)].

8.3 South-South Collaboration: Lessons Learned from One Health Projects in Southeast Asia

Despite the challenges, there have been notable successes in One Health implementation in Southeast Asia. Lessons from these successes can inform future efforts to overcome the abovementioned barriers.

One example is the Mekong Basin Disease Surveillance network, which has pioneered cross-border cooperation on disease surveillance in the region [Phommasack et al. (2013)]. The MBDS network has facilitated data sharing and collaboration between countries in the Mekong region, including Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam. This regional cooperation has been crucial in responding to outbreaks of avian influenza and other zoonotic diseases.

Another successful example is the Eco health project in Viet Nam, which took a community-based approach to disease prevention by involving local farmers in disease surveillance and control. By engaging local communities and incorporating their knowledge into disease prevention strategies, the project improved biosecurity practices and reduced the risk of disease transmission.

The success of these projects highlights the importance of community engagement, regional cooperation, and capacity-building in the effective implementation of One Health initiatives. However, these successes are often the exception rather than the rule, and much more needs to be done to scale up and sustain these efforts across the region.

One Health projects in Southeast Asia hold great potential to address the region's complex health challenges. However, the successful implementation of these projects is hindered by a range of factors, including poor coordination among sectors, weak governance, resource constraints and socio-cultural barriers. To overcome these challenges, a concerted effort is needed to strengthen multisector collaboration, build institutional capacity and ensure that One Health initiatives are inclusive and sustainable.

Furthermore, international cooperation and donor support will continue to be critical in supporting the region's efforts to implement One Health projects. However, long-term success will depend on the ability of Southeast Asian countries to build resilient health systems that can respond to emerging health threats in a holistic and integrated manner.

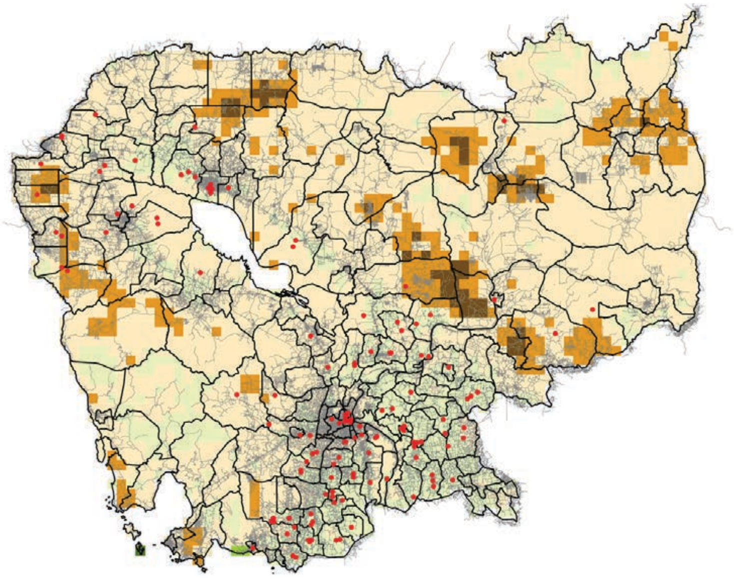
The lessons learned from past projects provide a valuable roadmap for future efforts. By addressing the challenges of multisector collaboration, governance, resources and inclusion, Southeast Asia can lead the way in implementing effective One Health strategies that protect the health of humans, animals and the environment. Box H provides an example of a project to strengthen zoonotic disease control for livestock in Cambodia.

Box H: Asian Infrastructure Investment Bank Cross-Border Livestock Health and Value-Chain Infrastructure Project

Cambodia faces increasing One Health threats, such as emerging infectious diseases, zoonoses, transboundary animal diseases, and antimicrobial resistance (AMR), intensified by factors like large human and animal populations and environmental change [Jones et al. (2008)]. Cambodia also contends with transboundary animal diseases like foot and mouth disease, African swine fever, and lumpy skin disease, causing economic shocks and food security challenges.

Zoonotic risks are driven by human-animal-environment interactions, with poorly regulated wildlife trade, AMR, climate change, urbanization, and deforestation playing roles [UNEP (2016)]. The legal and illegal wildlife trade within and beyond Cambodian borders combined with limited food safety measures, further exacerbates these risks [Cambodia Technical Working Group Presentation (2023)]. Food and Agriculture Organization (FAO) data shows that most of the reported cases of avian influenza found on birds occurred in the southern areas bordered by Viet Nam, with some other cases concentrated in northern areas bordered by Thailand (see Figure H1). These areas also have the densest road networks, with active cross-border land trade between Cambodia and its neighboring countries.

Figure H1: Deforestation and Avian Influenza Cases Locations (2002–2024)



Source: FAO EMPRES-i+ for avian influenza cases from birds. There are in total 196 avian influenza cases reported by FAO. Using Leaf Area Index (LAI) comparing 1981 and 2020, brown areas saw forest loss while green areas saw forest growth. Grey lines show the road network obtained from OpenStreetMap.

Establishing the One Health Strategy in Cambodia has been gradual, requiring ongoing political leadership, coordination and decisive action. While Cambodia effectively contained COVID-19 with an innovative vaccine rollout, certain areas still need attention. These include strengthening multisectoral collaboration, enhancing human resources and improving surveillance and laboratory capacities across some of the sectors.

The pandemic highlighted the fragility of laboratory systems, including those in Cambodia. While Cambodia did coordinate efforts for COVID testing, the pandemic exposed weaknesses like fragmentation and limited resources. NAHPRI, the national reference lab for animal health, has faced challenges such as funding constraints, outdated technology, and a shortage of skilled personnel.

To overcome these challenges, Cambodia needed to invest in laboratory infrastructure and human resources. Modernizing facilities and providing training programs will improve diagnostic and research capabilities. Collaboration with international research organizations can also bring in new technologies and foster local expertise development. To support Cambodia's ongoing effort, the Asian Infrastructure Investment Bank approved USD33 million in financing to the Ministry of Agriculture, Fishery and Forestry in 2023 to improve livestock, human and environmental health and create a more productive value-chain infrastructure. The Project will also help concerned government agencies prepare for emerging zoonotic disease outbreaks, food safety incidents, and address AMR.

Key challenges ahead:

Laboratory infrastructure and capacity. The shift in priorities post-COVID has seen a greater emphasis on human health laboratories, leaving animal health labs underfunded. NAHPRI, the key laboratory for animal health, struggles with staffing issues and limited permanent staff. The proposed National One Health Laboratory (NAL) may help centralize operations, but its long-term efficacy is uncertain without adequate human resources, training, and sustainable funding.

Data sharing and communication. Information sharing remains among the biggest barriers to successful One Health implementation. Particularly in animal health, stakeholders are reluctant to share test results, primarily due to economic concerns. The local farmers have little incentive to report animal health issues, making outbreak detection and testing difficult. Informal communication channels, such as social media platforms, are often used instead of formal data-sharing systems. This lack of transparency and formal coordination hinders the timely identification and management of disease outbreaks.

Resource constraints and funding imbalances. Although AMR initiatives are well-financed, there is a glaring lack of funding for food safety and environmental health aspects of One Health. Human resource shortages, especially in animal health laboratories, exacerbate the problem, with trained personnel often leaving for better-paying opportunities in the private sector. Furthermore, the cost of sustaining laboratory operations, particularly fieldwork and sample testing, remains high and unsustainable in the long run.

Multisectoral collaboration. Establishing the Inter-Ministerial Coordinating Committee in 2023 marked a critical step towards better governance of One Health initiatives in Cambodia. However, the IMCC-One Health and secretariat are acclimating to their roles and responsibilities and mechanisms for national and provincial coordination is still under discussion. The Ministry of Agriculture, Forestry and Fisheries; Ministry of Health; and Ministry of Environment still face challenges in effectively sharing data and collaborating on joint action plans. The country has developed a One Health strategy along with multisectoral plans for AMR and zoonoses, with food safety being the only remaining outstanding issue.

To fully realize One Health's potential, stronger institutional frameworks, increased investment in underfunded areas like food safety and enhanced capacity building, especially for animal and environmental health, are needed. By addressing these challenges, countries can build a more resilient and sustainable health system capable of managing interconnected health threats at the human-animal-environment interface.

CHAPTER 9

WHY HEALTH MEANS SO MUCH

CROSS-COUNTRY ESTIMATES OF HEALTH BURDENS ON THE LABOR FORCE

Highlights

- High-income countries lose around 0.2 percent of their labor force through premature mortality each year, while this rises to around 0.35 percent for developing economies. Higher male premature mortality in developing economies is a key driver behind this difference.
- Developing economies have lower average population morbidity due to younger demographics. For working-age groups, morbidity is on par or higher. Across all country samples, this chapter estimates that a 1 percentage point reduction in morbidity burden is associated with 3.3 and 4.6 percentage points increase for male and female labor force participation, respectively. Reducing morbidity burdens has sizeable labor force payoffs, particularly for females in developing economies.
- Extreme temperatures are associated with lower workforce participation. The indirect impact of infectious disease prevalence will be significant. The direct and indirect effects of higher temperatures appear to most affect developing economies and females.
- Healthcare systems in developing countries also need to prepare for aging, as morbidity burdens of noncommunicable diseases will rise in line with earlier experience from developed economies. Social infrastructure will need to be strengthened.

9.1 Health Impact on the Labor Force: Evidence Thus Far

How much labor force do countries lose through premature mortality and morbidity? Microeconomic studies primarily point to the positive effects of health on an individual's ability and willingness to work [see Pinto et al. (2024) for a recent review]. However, studies are largely country or context-specific (e.g., for certain demographics or certain diseases). This reflects the challenge of establishing this empirically at an aggregate level across countries.

Firstly, demographic transitions, changes in human capital, social norms, etc., can mask health effects on the labor force. Demographically advanced economies will likely see a lower labor force participation rate (LFPR), which is correlated with higher health burdens. On the other hand, higher education, a higher retirement age, and social support—typically seen in high-income countries (HICs)—are all known to delay retirement and raise participation. Country heterogeneity is a key challenge.

Secondly, reverse causality will pose an estimation challenge. Work can cause poor health due to occupational or other associated hazards. This is particularly relevant for developing countries where labor and environmental regulations may be less stringent or enforced. The lack of work can create its own health-related issues.

Thirdly, it can be challenging to define and construct aggregated measures of health. Objective health measures, however comprehensive, will not capture important unobserved factors at the individual, family or societal level. Subjective health measures, on the other hand, are prone to measurement, selection or justification bias.

Fourthly, female labor force participation is well-known to be U-shaped with respect to economic development, typically falling during early phases of industrialization before recovering in the latter stages [see Goldin (1995); Kristin and Paxson (2000); Ngai and Petrongolo (2017)]. Hence, female employment could be falling when health is improving or rising when health is worsening. Estimating health's impact on female participation is even more challenging as a result.

Without a large cross-country study, it becomes difficult to perform comparative analyses between country groups or estimate the impact of health on the global labor force. Localized or context-specific microstudies are also subject to general equilibrium critique.

This research builds on extensive micro literature on how health affects labor market participation [see Stephens Jr. and Toohey (2022); Pinto et al. (2024)]. The literature documents the substantive differences between countries, along racial and gender lines, between age groups and by disease types [see Bound et al. (1996); Schofield et al. (2013); Krueger (2017)]. Oster et al. (2013) find that lower life expectancy reduces incentives for human capital accumulation.

The research concerns the broader debate on health conditions and aggregate economic performance. Acemoglu and Johnson (2007) and Ashraf et al. (2009) find little aggregate impact of improved health–"drawing a macroeconomic conclusion directly from microeconomic evidence or the cross-sectional correlation is problematic… (and) unable to control for general equilibrium effects." Macroeconomic studies, on the other hand, "typically suffer from omitted variables bias and reverse causation." The researchers are careful to interpret that health improvement can be achieved with little impact on economic performance and argue for health as a humanitarian rather than an economic imperative

Other studies hold that health improvement has a significant aggregate effect on the economy. Swift (2011) argues that health's long-run effects are missed. While narrow in country coverage, the study finds that a 1 percent increase in life expectancy raises per capita GDP by 6 percent in the long run. Cole and Neumayer (2006) find that health can affect total factor productivity performance. Bloom et al. (2004) find a sizeable impact on GDP levels. Agénor (2008) argues that health infrastructure can affect both the production of goods and the expansion of health services.

Often, the debate centers around what is being measured as health and, more specifically, what is being missed. Bleakley (2009) argues that a single health outcome measure (e.g., life expectancy) misses the important effects of poor health, thus underestimating the effects of good health: "malaria can have subclinical morbidity that are poorly measured."

This chapter contributes by linking disability-adjusted life years (DALYs) to the LFPRs for a large group of countries.[19] Unlike life expectancy, DALY considers a wide range of health issues—mortality and morbidity—before aggregating these into standardized life years. Like Acemoglu and Johnson (2007), this chapter constructs plausible

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[19] Dalal and Svanström (2015) use DALYs to measure the cost of workplace injuries. Nurchis et al. (2020) leverage DALY to estimate the impact of COVID-19 in Italy.

instruments to overcome endogeneity, one of which exploits the U-shaped years lived with disability (YLD), and the second exploiting neighboring countries' YLDs. This chapter also follows the spirit of Blundell et al. (2023) who argue that subjective health measures instrumented by objective ones can improve estimates.

Finally, recent literature has focused on the effects of temperature, humidity and climate change on health and LFPR at the country level [see Liu et al. (2013); Zhang and Shindell (2021); Saudamini (2015); Li and Pan (2021); Liu (2020)]. Across country samples, this chapter further provides preliminary evidence that global average temperatures are positively correlated with infectious disease burdens.

9.2 WHO Disability-adjusted Life Years

9.2.1 WHO Global Burden of Disease Estimates

This is a well-established WHO dataset (2024). The DALY statistics provide standardized cross-country measures of overall disease burden, covering 2000, 2010, 2015, 2019, 2020 and 2021 (the latest two data years reflect the effects of the COVID-19 pandemic). This subsection provides further details of DALY together with some preliminary facts (I, II, III, etc.).

9.2.2 Years of Life Lost (YLL)

YLL is the sum of life years lost, measured against a benchmark. For example, if the life expectancy at birth is deemed to be 85 years, then five persons recorded with premature deaths at age 40 would each contribute to 45 life years lost, resulting in a total YLL of 225.[20] In this chapter, YLL is adjusted to record only the labor force lost in a particular year. From the example above, each premature death will be recorded as one life lost (as opposed to a lifetime loss of 45 years) to have a measure consistent with the annual flow impact on labor markets. Unless otherwise stated, all YLL statistics in this chapter have been adjusted to account for lives lost as they occurred and not in future years. YLL statistics have also been normalized by population to arrive at YLL rates (i.e., YLL per 100 population).

I. Developing countries' mortality or YLL rates have fallen significantly pre-COVID, mirrored by an increase in life expectancies

Based on population averages, YLL rates dropped significantly over the past two decades pre-COVID for developing countries and low-income countries (LICs) (Figure 50). Burundi and Malawi are LICs and achieved the most significant improvements in male and female mortality, respectively, with YLL rates decreasing by 1.3 and 1.2 percentage points from 2000 to 2021. Conversely, Cuba and Bosnia and Herzegovina, classified as upper-middle-income countries (UMICs), experienced the largest increase in male and female mortality, rising by 1 and 1.1 percentage points, respectively, over the same period. The decline in YLL rates is seen in tandem with a rise in life expectancy (Figure 51). In 2021, the United Arab Emirates recorded the lowest mortality rates among HICs, with a YLL rate of 0.17 for males and 0.14 for females. Among developing economies, Jordan achieved the best performance in YLL, with rates of 0.41 for males and 0.35 for females. The onset of COVID saw an increase in YLL for all country groups but more so for HICs and UMICs, though it is unclear at this stage whether mortality will remain high or revert to pre-COVID levels within a few years.

II. However, developing countries have higher mortality or YLL rates for key working-age groups, especially for males (even prior to COVID)

The broad convergence of developing economies' life expectancies and YLL rates towards HIC levels, even at lower income levels, is a significant global health achievement. However, this also reflects

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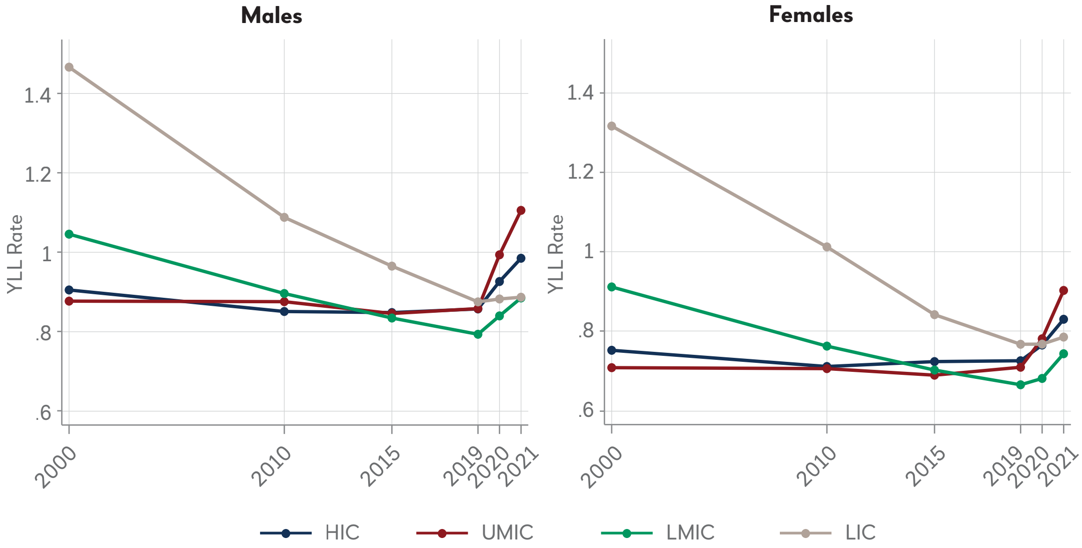
[20] In the earlier versions of DALY, future life years lost were discounted, and this was a subject of critique [see Anand and Hanson (1997). There is no such discounting in the latest DALY iteration, and all future life years lost are given the same weight. See WHO (2024).

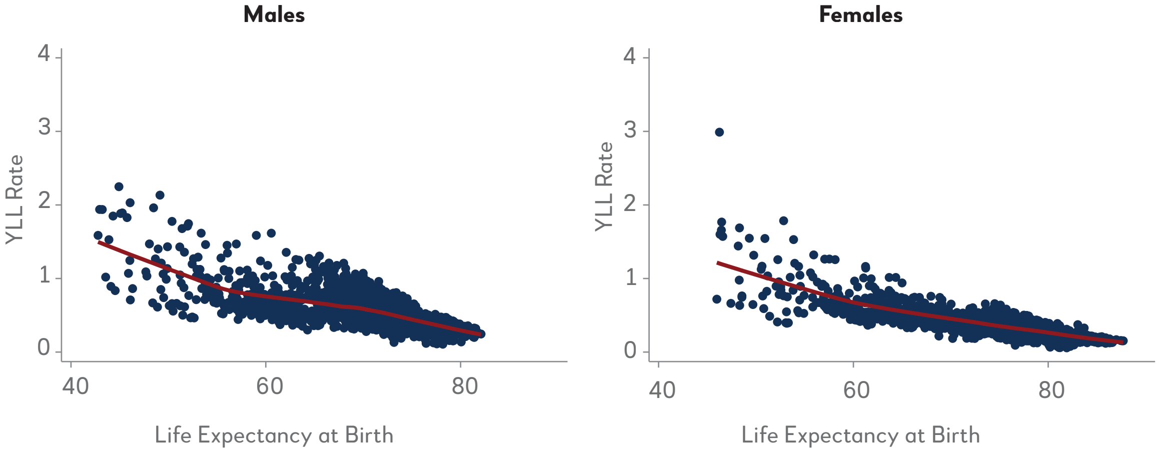
Figure 50: Average YLL Rates



Source: WHO and AIIB staff estimates.

Notes: YLL = Years of Life Lost; HIC = high-income country; UMIC = upper-middle-income country; LMIC = low- or middle-income countries: LIC = lower-income country

Figure 51: YLL Rates and Life Expectancy at Birth



Source: WHO and AIIB staff estimates.

Notes: Each data point above represents a country-year in the sample. Coverage includes working-age populations (15–69). YLL rate is defined as the total YLL of the working-age population divided by the working-age population for normalization across countries with different population sizes. The red lines indicate the respective LOWESS plots.

Table 12: Country Average of Adjusted YLL per 100 Population by Age and Gender Group

	15-29	30-49	50-59	60-69	70+
Males, 2021					
HIC	0.07	0.20	0.70	1.73	7.33
UMIC	0.15	0.42	1.36	3.05	11.47
LMIC	0.17	0.53	1.68	3.58	12.13
LIC	0.24	0.62	1.87	3.91	12.74
Females, 2021					
	15-29	**30-49**	**50-59**	**60-69**	**70+**
HIC	0.03	0.10	0.38	0.97	5.41
UMIC	0.07	0.24	0.79	1.87	8.25
LMIC	0.12	0.35	1.08	2.40	9.52
LIC	0.18	0.45	1.32	2.93	10.78

Notes: For each country, the (adjusted) YLL per 100 population is first computed for each cell represented by the age groups. An average is then obtained across economy categories (HIC, UMIC, LMIC and LIC). Taking an average of countries implies that countries with large populations do not dominate the data in each cell but rather provide an average across the cross-section of countries.

demographic composition. Zooming in on the key working ages of males, it becomes clear that the average YLL rates for key working-age groups in developing countries and LICs remain significantly higher than those in HICs.[21]

For males aged 30-49, a key working-age group, the average YLL in low or middle-income countries (LMICs) is 0.33 percentage points higher than that of HICs. For the group 50-59, the gap widens by almost 1 percentage point (Table 12). Simply put, the premature years lost are much higher for key working-age males in developing countries. Similarly, the YLL rates for females are also higher in key working-age groups for developing countries and LICs (though female gaps are relatively smaller compared to males). For example, for the age group 30-49, the LMIC gap is 0.25 percentage points. For the age group 50-59, the gap widens to 0.7 percentage points. These gaps between HICs, and developing economies and LICs are detected whether using pre-COVID data or during the pandemic.

9.2.3 Years Lost to Disability

The second component of DALY is the YLD, which measures disease and health burdens from various non-fatal causes. This is computed based on the prevalence of multiple diseases and health factors, weighted by disability weights derived from a large survey [Salomon et al. (2015)]. Thus, YLD has elements of both objective health measures (prevalence of each disease) and subjective weights (through the survey model).

III. Developing economies also have higher morbidity or YLD rates for working-age groups

For HICs and UMICs, YLD rates have trended upward in the past two decades (Figure 52). Korea and Bosnia and Herzegovina are UMICs. They saw the most significant deterioration in male and female morbidity, respectively, with their YLD rates increasing by 3.9 and 2.7 percentage points from 2000 to 2021.

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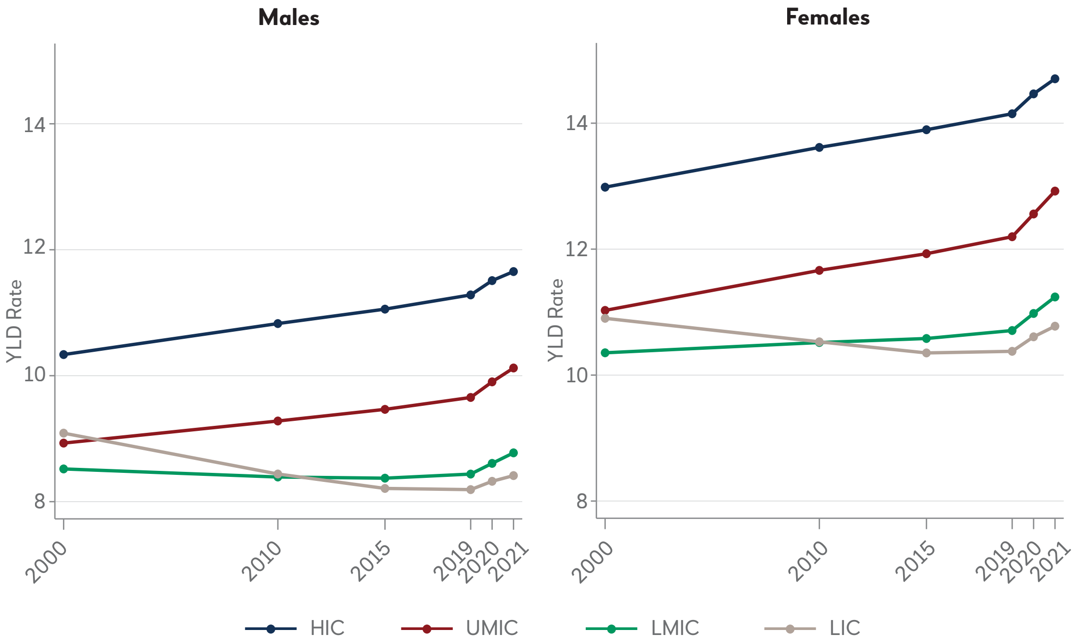
[21] Working-age groups are defined as those between 15 and 69 (that is, excluding age 70 and above).

Figure 52: Average YLD (per 100 Population)



Source: WHO and AIIB staff estimates.

Notes: YLD = years lived with disability; HIC = high-income country; UMIC = upper-middle-income country; LMIC = low- or middle-income countries: LIC = lower-income country

Table 13: Country Average of YLD per 100 Population by Age and Gender Group

	Males, 2021				
	15-29	**30-49**	**50-59**	**60-69**	**70+**
HIC	7.77	10.64	14.58	19.01	26.75
UMIC	7.38	10.72	15.37	19.64	26.72
LMIC	7.19	10.57	15.16	19.35	26.54
LIC	7.71	10.89	15.33	19.36	26.24
	Females, 2021				
	15-29	**30-49**	**50-59**	**60-69**	**70+**
HIC	10.67	14.31	17.42	20.82	28.56
UMIC	10.03	14.38	18.17	21.52	28.31
LMIC	9.81	14.45	18.23	21.75	28.75
LIC	10.50	15.42	18.79	22.14	28.62

Notes: For each country, the YLD per 100 population is first computed for each cell represented by the age groups. An average is then obtained across economy categories (HIC, UMIC, LMIC and LIC). Taking an average of countries implies that countries with large populations do not dominate the data in each cell but rather provide the average across the cross-section of countries.

HICs and UMICs record significantly higher YLD rates than LMICs and LICs, pre-COVID and during the pandemic. However, zooming in on age-specific YLD rates, HICs record lower disease burdens across most age groups (Table 13). In the younger working-age group (30-49), developing countries and LICs have similar or slightly higher morbidity compared to HICs. However, morbidity is noticeably higher for developing countries and LICs in older working-age groups (50-59 and 60-69). It is unclear at this stage whether this is a cohort effect such that YLD gaps will be ameliorated as existing younger (and presumably healthier) workers grow older or whether this represents a deeper health support issue in developing countries.

IV. Morbidity or YLD rate is a U-shape with respect to life expectancy–YLDs are higher when life expectancies become advanced.

The correlation between life expectancy and YLD is negative at lower life expectancy. However, at higher life expectancy, YLDs increase (see Figure 53). Across country samples, YLD rates are U-shaped with respect to life expectancy (and per capita income).[22] This U-shape is flatter for males and more distinct for females. This research exploits this U-shape relationship as an instrumental variable.

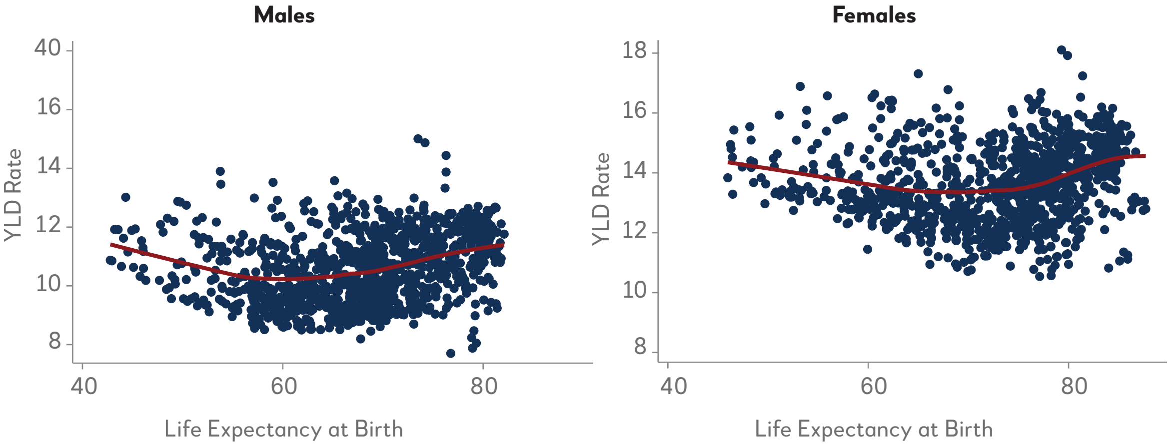
Specifically, the research pools together a large number of country-year samples and runs locally weighted regressions (LOWESS) between YLD and life expectancy (separately for males and females). With the LOWESS regressions, the predicted YLD (or PYLD) is constructed based on life expectancy.

9.2.4 Different Disease Burdens Across Economies

V. Infectious disease burdens decline while noncommunicable disease burdens rise with incomes

While we have discussed overall YLL and YLD rates thus far, the WHO dataset does provide a significantly more detailed breakdown by disease types. On average, disease burdens from infectious diseases decline with incomes, while the burdens from noncommunicable diseases rise with incomes. Over the past decade, DALY from infectious diseases has dropped significantly. Countries with

Figure 53: YLD Rate and Life Expectancy at Birth



Source: WHO and AIIB staff estimates.

Notes: Each data point above represents a country-year in the sample. Coverage includes working-age populations (ages 15–69). YLD rate is defined as the total YLD of the working-age population divided by the working-age population for normalization across countries with different population sizes. The red lines indicate the respective LOWESS plots.

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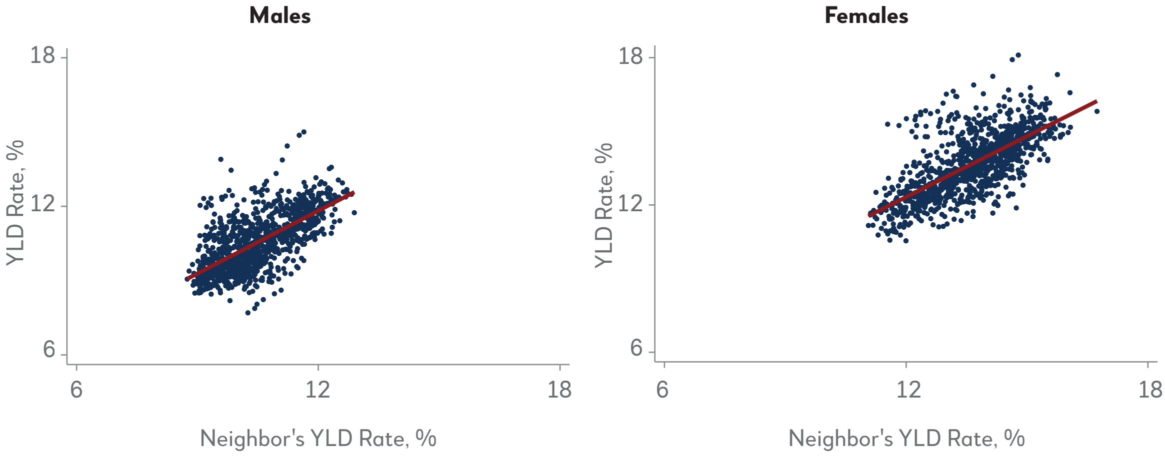
[22] Ashraf et al. (2009) use a linear model to fit YLD with life expectancy, though the age domain is restricted to lower age groups, thus avoiding the turning point of the U-shape.

Figure 54: Correlations between NYLD and YLD Rates



Source: WHO and AIIB staff estimates.

advanced demographics and incomes thus see higher YLD rates due to the rise in noncommunicable disease burdens. Appendix 3 provides further details on disease types for countries at different income levels, as well as preliminary evidence that infectious diseases rise with temperatures.

9.2.5 Distance and Nearest Neighbors

The research also leverages distances to nearest neighbors to construct a second set of instruments, NYLDs. Bilateral country distances are obtained from CEPII [see Gaulier and Zignano (2010); Mayer and Zignano (2011)].[23] Using this distance measure, the nearest three neighbors of every country are selected, and a weighted average YLDs of these neighbors are constructed. Inverse distance weighting gives the nearest (furthest) neighbor the highest (lowest) weight. The correlations between YLDs and NYLDs for males and females are provided in Figure 54.

9.2.6 Temperatures

Temperature data is collected from an open source provided by the University of Dayton.[24] This large dataset captures the daily average temperatures of various cities in every country from 2000 to 2019. The research computes the mean 1-percentile or P1, and 99-percentile or P99 temperatures recorded in every country. As will be seen later, average and extreme temperatures affect infectious diseases and labor force participation.

9.2.7 Labor Force Participation, Life Expectancy, and Other Measures

Labor force participation rates are obtained from the International Labour Organization. Before COVID, LFPR were quite similar across countries with different incomes for males, at around 70 percent. For females, average LFPRs are below 60 percent. Until 2019, LFPRs were declining for LMICs and LICs, whereas they were increasing in HICs and UMICs. Since 2020, LFPRs for both genders have markedly declined due to the pandemic's effects.

Data on life expectancy at birth for both males and females, age dependency ratio and GDP are sourced from the World Bank Open Data. Years of schooling are provided by Penn World Table (PWT) from the estimation methodology of Barro and Lee (2015). The complete list of variables is provided in Appendix 3.

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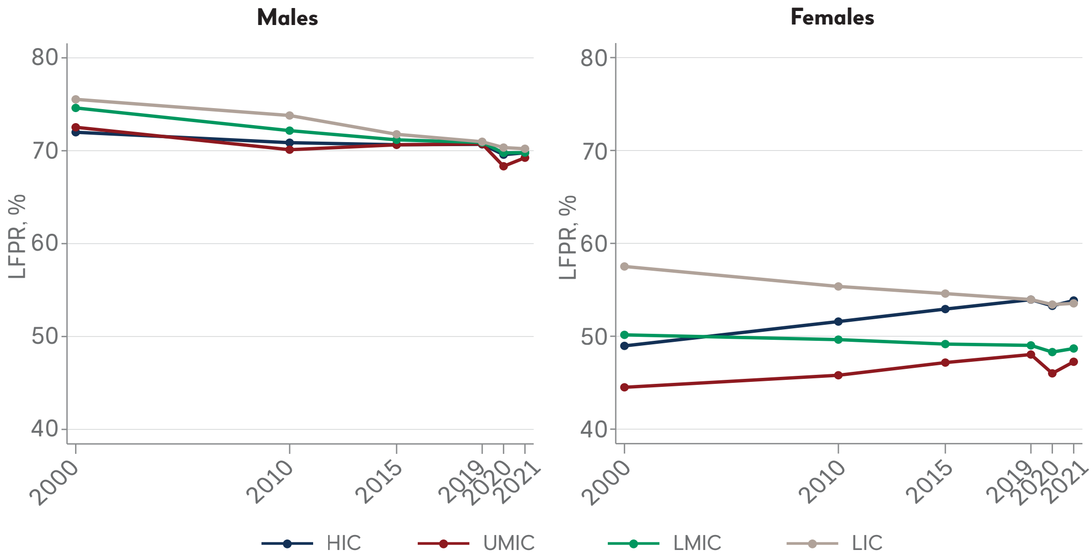
[23] Population-weighted bilateral distance is used (as opposed to the distance between country centroids or country capitals), as this would allow the NYLDs to better capture the correlation between neighbors' YLDs.

[24] https://www.kaggle.com/datasets/sudalairajkumar/daily-temperature-of-major-cities

Figure 55: LFPRs of Males and Females by Country Income Groups



Source: WHO and AIIB staff estimates.

Notes: LFPR = labor force participation rate

9.3 Estimating Premature Mortality Impact on the Labor Force

This section computes the percentage of labor force lost through mortality $\widehat{YLLR}_{i,t}$

$$\widehat{YLLR}_{i,t} = \frac{\sum_{n}^{N} YLL_{i,n,t} * LFPR_{i,t}}{\sum_{n}^{N} P_{i,n,t}}$$

where $YLL_{i,n,t}$ and $P_{i,n,t}$ are the YLL and populations of country i, age group n and time t. There are four age groups (N) included in this chapter, namely 15–29, 30–49, 50–59 and 60–69, which cover the key working age groups. There are six time periods (2000, 2010, 2015, 2019, 2022 and 2021).

In summary, $\widehat{YLLR}_{i,t}$ uses the raw YLL statistics from WHO, by country–year–age groups, multiplies with the country–year specific labor force participation rates, and then normalizes it by respective country–year working-age populations. This provides the estimated $\widehat{YLLR}_{i,t}$ across economies (Table 14).

In 2021, HICs lost 0.30 percent of the male labor force through premature mortality. The corresponding figures are 0.50 and 0.47 percentage points for UMICs and LMICs, respectively. Note that these figures capture the effects of mortality that occur in the year and do not account for the permanent loss caused by mortality. If one cumulates the effect of premature mortality across the productive lifetime of the person, the cumulative loss would, in fact, be larger. For females, the labor loss through premature mortality is lower for all country groups, and with a slightly smaller relative gap between HICs and the rest.

Table 14 provides the approximated labor force loss from mortality for males and females, respectively, and the combined effects on the whole labor force tare provided in Table 15. For 2021, HICs lose around 0.22 percent of the total labor force through premature mortality. The UAE, which had the lowest mortality rate in 2021, also experienced the lowest labor loss, estimated at just 0.09 percent. This average loss is 0.13 percentage points higher for both UMICs and LMICs and 0.18 percentage points higher for LICs. This reflects the effects of higher mortality for working-age groups and higher male participation in developing economies.

It is also worth noting that while country-to-country conditions might differ, the higher YLL rates for males in developing countries are observed across disease types (i.e., no one single prevalent factor). This suggests that public health policies must focus on male health more generally, potentially even the socio-economic factors affecting male health, rather than interventions for specific diseases.

Table 14: Estimated Male and Female Labor Lost as Percentage of Total Labor Force

	Males					
	2000	**2010**	**2015**	**2019**	**2020**	**2021**
HIC	0.34	0.29	0.28	0.27	0.28	0.30
UMIC	0.46	0.40	0.40	0.40	0.44	0.50
LMIC	0.56	0.47	0.44	0.42	0.43	0.47
LIC	0.72	0.56	0.52	0.48	0.47	0.49
	Females					
	2000	**2010**	**2015**	**2019**	**2020**	**2021**
HIC	0.12	0.11	0.12	0.12	0.12	0.13
UMIC	0.19	0.16	0.16	0.16	0.17	0.21
LMIC	0.33	0.25	0.22	0.21	0.21	0.23
LIC	0.49	0.40	0.32	0.28	0.28	0.30

Notes: The (adjusted) YLL per 100 population is first computed for each country. This is then multiplied by country-time specific LFPR and then expressed as a percentage of each country's total working-age population before averaging across country groups.

Table 15: Estimated Combined Labor Lost as Percentage of Total Labor Force

	2000	**2010**	**2015**	**2019**	**2020**	**2021**
HIC	0.23	0.20	0.20	0.20	0.20	0.22
UMIC	0.32	0.28	0.28	0.28	0.30	0.35
LMIC	0.44	0.36	0.33	0.31	0.32	0.35
LIC	0.60	0.48	0.42	0.38	0.37	0.40

Notes: For each country, the (adjusted) total YLL is first calculated and then expressed as a percentage of each country's total working-age population before averaging across country groups.

9.4 Estimating Morbidity Impact on the Labor Force

The chapter proceeds to estimate the impact of YLD on labor force participation. The main regression is given as:

Equation 6

$$LFPR_{i,t} = \alpha + \beta * YLDR_{i,t} + \theta * X_{i,t} + \varepsilon_{i,t}$$

where $YLDR_{i,t}$ is the YLD rate of country i at time t, the vector of fixed effects, $X_{i,t}$ the vector of controls and $\varepsilon_{i,t}$ the error term. Control variables include several demographic and educational metrics, specifically the average years of schooling, the age dependency ratio, life expectancy and the square of life expectancy (to assess the potential U-shaped impact on the LFPR).

The research aims to uncover the parameter β–how much YLD affects LFPR–across countries. A LOWESS regression is first carried out for each regional group to derive $\widehat{PYLDR}_{i,t}$, which serves as the first instrument (the instrument is U-shaped as mentioned). The second instrument is $\widehat{NYLDR}_{i,t}$, the (inverse) distance weighted average of YLDs of the three nearest neighbors. The chapter first provides the regression results using individual years data before showing the pooled ordinary least squared (POLS) results across years. This aims to provide readers with greater confidence in the underlying results. The regression of $YLDR_{i,t}$ on $\widehat{PYLDR}_{i,t}$ and $\widehat{NYLDR}_{i,t}$ is provided in Appendix 3.

Columns 1 and 4 of Table 16 show the naïve ordinary least squares (OLS) regressions with 2021 data on male and female samples, respectively. Columns 2 and 5 display the results using lagged life expectancy as the instrument. For both males and females, the lagged life expectancy IV estimates yield insignificant coefficients for YLD on labor force participation. As mentioned, this is due to the non-linear relationship between YLD and life expectancy. In particular, note that the U-shape YLD of females is especially sharp, which implies that simple use of life expectancy is unlikely to serve as a good instrument. Furthermore, the LFPR of females is also U-shape, as mentioned, making estimation even more challenging. The key lies in properly controlling for demographic factors.

Columns 3 and 6 of Table 16 show the respective regressions using PYLD and NYLD as instruments. For both males and females, the use of these instruments resulted in significant coefficients for both genders, with magnitudes of -2.5 for males and -3.6 for females. Higher education levels are particularly important in explaining female LFPR. For females, life expectancy has a negative coefficient, but the squared term is positive–i.e., these capture the U-shape over different stages of development. The OLS and IV estimates for males are not too

Table 16: Naïve and Instrumental Variable Estimations (Year 2021)

	(1)	(2)	(3)	(4)	(5)	(6)
	LFPR, Males, 2021			LFPR, Females, 2021		
	OLS	Lagged Life Expectancy IV	PYLD & NYLD IVs	OLS	Lagged Life Expectancy IV	PYLD & NYLD IVs
YLD (rate)	-2.707***	-2.223	-2.541***	-2.830***	0.742	-3.642***
	(0.610)	(2.541)	(0.769)	(0.825)	(5.782)	(1.138)
Education Level	0.311	0.182	0.294	1.718***	1.111	1.935***
	(0.420)	(0.777)	(0.446)	(0.504)	(1.093)	(0.501)
Dependency Ratio	-0.263***	-0.259***	-0.246***	-0.059	-0.048	-0.073
	(0.075)	(0.077)	(0.073)	(0.124)	(0.119)	(0.122)
Life Expectancy	-0.709	-0.633	-0.742	-10.043***	-9.028***	-10.819***
	(1.397)	(1.389)	(1.370)	(3.194)	(3.179)	(3.263)
Life Expectancy^2	0.005	0.004	0.005	0.066***	0.060***	0.071***
	(0.010)	(0.010)	(0.010)	(0.021)	(0.021)	(0.022)
Observations	142	142	142	142	142	142
R-squared	0.230	0.226	0.228	0.209	0.104	0.203

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 17: Summary of YLD Coefficients (with Instruments)

	LFPR, Males					
	2000	2010	2015	2019	2020	2021
YLD (rate)	-3.877***	-3.527***	-3.496***	-3.361***	-3.028***	-2.541***
	(0.896)	(0.900)	(0.921)	(0.779)	(0.810)	(0.786)
	LFPR, Females					
	2000	2010	2015	2019	2020	2021
YLD (rate)	-7.009***	-4.650***	-4.834***	-4.395***	-3.705***	-3.642***
	(1.689)	(1.354)	(1.373)	(1.364)	(1.166)	(1.163)

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

different but are significantly different for females. This underscores the more serious endogeneity concerns with female LFPR, which is expected.

Going beyond 2021 data, the year-by-year regressions using these PYLD and NYLD instruments are provided in Table 17. The estimated coefficients show a consistent decline over the years, decreasing from -3.9 in 2000 to -2.5 in 2021 for males and from -7 in 2000 to -3.6 in 2021 for females. Consistently, the YLD has a larger impact on the LFPR for females.

The above regression is also estimated using POLS. All regressions are reported with clustered errors at the country level. Male and female LFPR regressions are run and reported separately (Table 18). The key result that YLD is negatively associated with LFPR continues to hold in POLS across years, with the average coefficients being -3.3 and –4.6 for males and females, as seen in columns 1 and 4, respectively.

The chapter further provides regressions by country income groups to account for heterogeneity. The negative coefficient for males is larger and more significant for HICs, not for developing countries. It is the reverse for females, with developing economies accounting for the negative coefficient.

9.4.1 Further Results

This chapter provides preliminary evidence that higher temperatures are associated with higher infectious diseases, as well as how extreme temperatures have a direct negative impact on LFPRs. The fuller results and discussion are provided in Appendix 3.

9.5 Chapter Concluding Remarks

Developing economies have similar mortality rates on average with HICs, but this is due to demographic composition that masks the higher mortality rates in key working-age groups. HICs lose around 0.2 percent of labor force directly through premature mortality each year, while this rises to around 0.35 percent for developing economies. Higher male mortality in developing countries is not due to a

Table 18: Instrumental Variable Regressions (POLS) by Country Groups

	(1)	(2)	(3)	(4)	(5)	(6)
	LFPR, Males			LFPR, Females		
	All	HIC	Developing	All	HIC	Developing
YLD (rate)	-3.321***	-4.400***	-1.208	-4.562***	-2.177	-6.544***
	(0.766)	(1.369)	(1.172)	(1.227)	(1.538)	(1.595)
Education Level	-0.063	0.323	-0.221	2.170***	3.023***	1.667***
	(0.406)	(0.565)	(0.481)	(0.466)	(0.741)	(0.543)
Dependency Ratio	-0.182***	-0.363***	-0.034	-0.039	-0.019	-0.261
	(0.062)	(0.088)	(0.083)	(0.102)	(0.084)	(0.162)
Life Expectancy	-1.313	1.877	0.061	-8.329***	5.713	-4.740**
	(0.974)	(4.864)	(1.164)	(1.840)	(15.664)	(2.098)
Life Expectancy^2	0.010	-0.012	0.001	0.055***	-0.032	0.024
	(0.007)	(0.033)	(0.009)	(0.013)	(0.095)	(0.015)
Instruments	Y	Y	Y	Y	Y	Y
Year Fixed Effect	Y	Y	Y	Y	Y	Y
Observations	844	306	538	844	306	538
R-squared	0.156	0.556	0.050	0.194	0.306	0.224

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

specific disease type, and this suggests that policy needs to deal with male health generally. Closing the male mortality gap towards HICs would, on average, add around 0.1 percentage points back to the labor force annually. These losses are annual "flow" estimates. Cumulatively, these losses will significantly impact the size of the labor force over the lifetimes of individuals.

Developing economies today also have lower average population morbidity, but this, again, is in part due to younger demographic profiles. For working-age groups, morbidity is on par or higher for developing economies. The impact of morbidity on the workforce appears large, relative to mortality, in explaining cross-country LFPR differences. A 1 percentage point reduction in morbidity burden is associated with 3.3 and 4.6 percentage points increases in male and female participation, respectively. Box I provides an analysis of labor force participation in China based on health surveys.

In the future, morbidity is likely to pose even greater challenges. Increased life expectancy will add to noncommunicable disease burdens (given U-shape YLDs). Indeed, several developing economies are already experiencing rapid aging (e.g., China, Thailand, Sri Lanka etc.), a phenomenon of "getting old before getting rich." Without sufficient social support, labor force participation will have a knock-on effect as these societies age. For developing economies, female labor force participation seems more sensitive towards YLD. Box J provides a brief on the kinds of social infrastructure that would be required.

Healthcare systems are facing new threats. As the COVID pandemic has shown, many developing countries continue to have underdeveloped or under resourced healthcare. Climate change will also present new health hazards, with rising temperatures directly and indirectly impacting the labor force in developing countries. This chapter provides preliminary cross-country evidence that extreme temperatures are associated with lower workforce participation, corroborating with country- or sector-level studies in the literature. This chapter provides preliminary evidence that infectious disease prevalence positively correlates with average temperature. The direct and indirect effects of higher temperatures appear to affect developing economies and females the most. Global warming is only at the beginning. How health burdens change regarding global warming is a live issue requiring more study in the years ahead.

Box I: Health and Labor Force Participation in China

Poor health status negatively affects a worker's labor force participation [Burdorf et al. (2023)]. Meanwhile, long working hours also negatively impact health and lead to an increasing risk of stroke and other cardiovascular diseases [WHO (2021)]. This box shows the relationship between health and labor force participation at a micro level using data from the China Family Panel Survey (CFPS), a nationally representative, biennial longitudinal survey.

It follows the families in all the waves, covering health, education, employment and other topics. Labor force participation is measured by two dimensions, whether a person is in the labor market, i.e., whether the person exits from the labor market or not, and the number of hours a person works in a week. Table I1 shows the summary statistics of a 2020 survey. The sample is made up of roughly equal shares of males and females, as well as equal shares of rural and urban populations. Females work 43 hours a week on average (accounting solely for those who are working), compared with males who work on average 49 hours.

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Box I *continued*

Table I1: Summary Statistics of Health and Working Hours by Gender (2020 Wave Only)

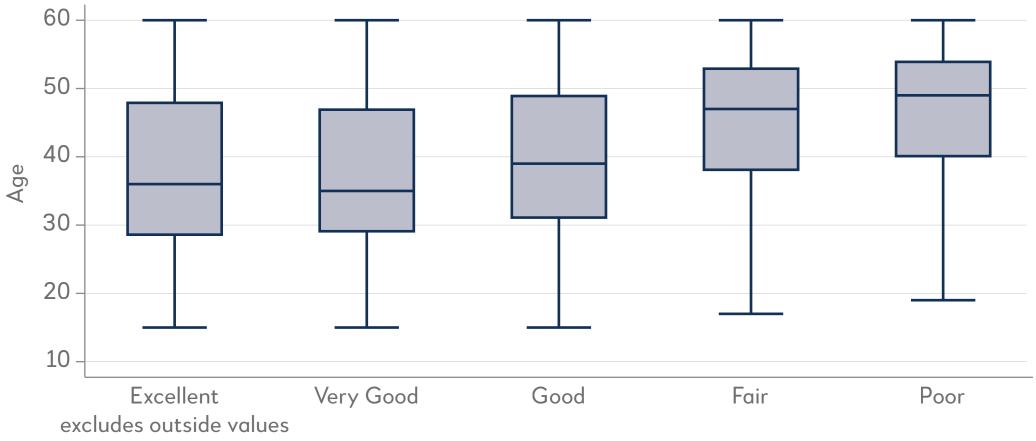
	Females		Males	
Number of respondents	9,779	46.10%	11,423	53.90%
Average working hours (hr/week)	43.06		49.16	
Age	45.29		45.57	
Self-assessed Health				
Excellent	1,238	12.70%	1,799	15.70%
Very Good	1,408	14.40%	1,905	16.70%
Good	4,069	41.60%	5039	44.10%
Fair	1,327	13.60%	1,397	12.20%
Poor	1,737	17.80%	1,283	11.20%
Urban or Rural				
Rural	5,103	53.80%	5,786	51.90%
Urban	4,531	47.60%	5,372	48.10%

Notes: Working population only

Health and labor market characteristics: Evidence from 2020 survey

Self-assessed health is a scale from 1 to 5, with 1 being "excellent" health and 5 being "poor" health. Self-reported health is negatively correlated with age (see Figure I1). Younger populations tend to have "excellent" and "very good" health. Meanwhile, the median age of people with "fair" and "poor" health is much older, at around 46-48. Another dimension of health is the incidence of hospitalization. In the 2020 cohort, around 10 percent of respondents claimed that they had been hospitalized in the past year, and this indicator is highly correlated with self-reported health. Figure I2 shows the distribution of working hours by health status. According to the 2020 data, people with excellent health work slightly over 50 hours per week. Meanwhile, median working hours for people with poor health is slightly less than 50 hours. The gap is narrow.

Figure I1: Health by Age Groups (Core Working Age Only, 15–60)



Source: China Family Panel Survey and AIIB staff estimates.

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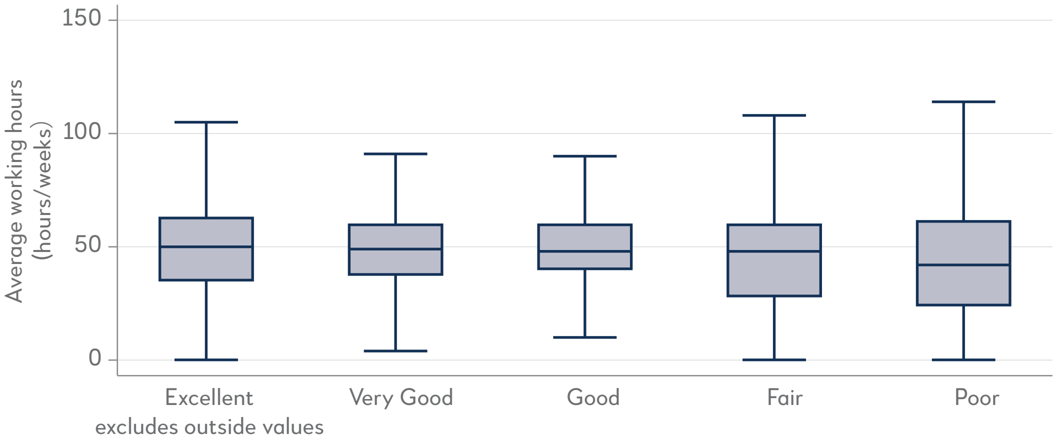
Box I *continued*

Figure I2: Health and Hours Worked per Week



Source: China Family Panel Survey and AIIB staff estimates.

Evidence from panel regressions

Panel data analysis utilizes the combination of different waves of the results. Due to data availability of certain labor force participation indicators, the waves used in the analysis are the years 2014, 2016, 2018 and 2020. The study follows the same group of respondents in each wave. By combining these waves, panel data fixed effect allows for controlling for endogeneity. There could be reverse causality—long work hours could lead to various physical and mental health conditions. To address this lag in health assessment, self-assessed health in the previous wave is used as an instrument. The health situation could also be endogenous. People with good health could be stronger and tougher physically and mentally, which is an advantage in the labor market and makes them qualify for more demanding jobs.

Table I2 provides estimates of the extensive margins of labor force participation—i.e., whether poor health leads to an exit from the labor market. It is a panel data fixed effect estimation with a linear probability model. Column 1 suggests that a unit increase in self-reported poor health leads to a 1.5 percent higher probability of exiting from the labor market, while column 3 suggests that being hospitalized leads to around an 8 percent higher probability of exit. There is little evidence of gender difference (columns 2 and 4). Using lag health status as an instrument, the results remain largely similar (see column 5).

Table I3 estimates the intensive margins of labor force participation—i.e., whether health affects work hours in the labor market. It shows the Tobit model estimation of two health measurements—self-assessed health and hospitalization on the weekly working hours. Results are quite consistent between males and females. Being hospitalized results in more than three fewer working hours per week. Using the self-assessment of health, a unit increase in poor health leads to roughly less than a working hour per week. The effects on males are larger. This could be due to more males in physically demanding jobs.

continued on next page

Box I *continued*

Table 12: Extensive Margin-Panel Data Fixed Effect Estimation

	(1)	(2)	(3)	(4)	(5)
			Working in the last week or not		
Self-assessed health	-0.015***	-0.015***			
	(0.002)	(0.003)			
Self-assessed health*gender		0.000			
		(0.003)			
Lag health as IV					-0.013**
					(0.007)
Hospitalization in the last 12 months			-0.078***	-0.080***	
			(0.006)	(0.011)	
Hospitalization*gender				0.010	
				(0.016)	
Urban	0.002	0.002	0.007	0.015	-0.003
	(0.008)	(0.008)	(0.009)	(0.011)	(0.010)
Age	0.035***	0.035***	0.035***	0.043***	0.032***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)
Age^2	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.443***	0.443***	0.388**	0.094	1.009***
	(0.153)	(0.153)	(0.155)	(0.173)	(0.166)
Year Fixed Effect	Yes	Yes	Yes	Yes	Yes
Province Fixed Effect	Yes	Yes	Yes	Yes	Yes
Observations	86,781	86,781	59,004	59,004	62,697
R-squared	0.012	0.012	0.015	0.018	
Number of respondents	35,175	35,175	31,337	31,337	31,420

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

continued on next page

Box I *continued*

Table 13: Intensive Margin–Tobit Model Estimation

	(1)	(2)	(3)	(4)	(5)	(6)
	Males			Females		
Self-assessed health	-1.290***			-0.855***		
	(0.160)			(0.183)		
Hospitalization in the past 12 months		-3.397***			-3.205***	
		(0.690)			(0.688)	
Lag health as IV			-1.778***			-1.469***
			(0.448)			(0.499)
Age	6.090***	6.204***	5.876***	6.648***	6.770***	0.033***
	(0.105)	(0.108)	(0.098)	(0.124)	(0.127)	(0.003)
Age2	-0.077***	-0.078***	-0.074***	-0.085***	-0.086***	-0.000***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.000)
Constant	-66.027***	-70.270***	-62.019***	-85.235***	-89.721***	-82.168***
	(2.713)	(2.775)	(2.582)	(3.243)	(3.317)	(3.083)
Year Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Province Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	49,333	45,354	49,300	49,144	46,287	49,129
Number of respondents	19,778	18,590		19,431	18,422	

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Box J: Social Infrastructure and Workforce Support for Demographic Shifts

As populations age, noncommunicable disease burdens will rise, along with broader economic implications. In many developing countries, this demographic transition will occur at lower national income levels than in developed countries decades prior. Hence, societies must be even more prepared regarding social infrastructure, healthcare systems, labor markets and regulatory frameworks.

The issue is multifaceted and intertwined. First, promoting the health and well-being of the elderly population is essential not only for their quality of life but also to enable them to remain engaged and productive. The participation of senior citizens will have a sizeable impact on the labor market and the overall economy. Second, the demand for long-term care (LTC) workers will inevitably increase. According to the OECD (2023), 80 percent of LTC workers are women, who earn 20 percent less than the economy-wide average. Gender roles will likely need to evolve in both directions—to raise female LFPRs in developing countries and empower them into various economic sectors while encouraging males to take on care responsibilities to relieve existing pressures. These, too, will impact families, communities and the labor force. Hence, healthcare and social infrastructure will need to evolve to accommodate these demographic changes and the evolving needs of society.

- **Bridging the labor gap.** The demand for LTC workers is expected to significantly outpace supply. To address this, policies are needed to upskill and improve working conditions in the LTC sector to improve sector productivity. Informal caregivers and those working in households should be supported and, where feasible, formally integrated into the economy.
- **Policies for inclusive labor force participation.** Addressing the disparities of underlying health conditions is crucial. To achieve inclusive labor force participation for people with chronic illness or disabilities and leave no one behind, policies are needed. At the global level, the ILO Global Business and Disability Network Charter was formed. The network showcases the best practices of companies and ensures that employment policies are inclusive of people with disabilities.
- **Solutions for the "middle".** Ageing needs are a continuum. However, developing countries cannot replicate the model of healthcare heavy or long-term care options as these would be financially unaffordable, nor can aging burdens be left entirely to individuals and families. The key lies in scalable social infrastructure for the "missing middle"—helping seniors with moderate needs via assisted living or community facilities. For instance, the rising demand for home renovations that cater to the elderly in China [People's Daily (2024)], success with intergenerational self-help clubs in Viet Nam [World Bank (2024)], and the boom in senior living markets in India [JLL (2023)]. Evidently, many countries are already experimenting with such middle options; successful models can be learned and scaled across.
- **Integrated initiatives.** Recognizing support for the elderly as an essential social infrastructure is increasingly vital. Sri Lanka and Mauritius have launched and implemented the Integrated Care for Older People approach, with the support of the WHO, aiming to promote healthy aging through comprehensive healthcare solutions at the national level [WHO (2024; 2023). Similarly, Hong Kong, China, has been working to become age-friendly to enhance the living conditions and social integration of the elderly [Woo et al. (2023)]. Initiatives like this can serve as blueprints for other economies to promote elder care.
- **Multilateral initiatives.** The UN Decade of Healthy Ageing is committed to reducing health disparities and improving the lives of older people, their families and communities. This initiative transforms societal attitudes towards aging, fosters age-friendly communities, provides person-centered integrated care and ensures access to quality long-term care for those who need it.

These infrastructure provisions and social initiatives will require substantial investments. Multilateral development banks can also help countries meet the challenges of demographic transition.

CHAPTER 10

CONCLUDING REMARKS

The report has made the case that human health is intimately linked to environmental factors such as air pollution, degradation of nature, the spread of disease vectors, heat, etc. Further integrating the health of other living beings and Earth's natural systems "as intrinsic components of human health" is needed [Antó (2024)]. It is important to flag the continuing contribution of the Lancet Countdown Asia reports to the climate, health and nature nexus [The Lancet (2025); Cai et al. (2024)].

The chapters in this report contribute to the growing pool of evidence on environmental factors that have a prominent role in determining mortality and morbidity beyond population income, access to healthcare, and aggregate healthcare spending.

The report recognizes that changes to nature and climate could potentially present the greatest health challenge of the twenty-first century. Climate change and nature degradation has led to increase in mortality related to extreme heat, adverse weather events and spread of infectious diseases. Air quality remains concerning in many regions. These compound the increase in non-communicable diseases and contribute to the overburdening of health systems. Furthermore, chemical hazards in the environment are also posing new hazards to humans and nature. Biodiversity is under significant strain, with societies depending on it for various needs, but yet not fully valuing it in economic terms and health outcomes. Given how essential biodiversity for human life and health, its conservation, optimization and sustainable use must be prioritized amidst competing development goals.

Furthermore, it is crucial to recognize that particular groups are more vulnerable to the impacts of climate change, necessitating an equitable approach that ensures project and policy designs provide inclusive solutions aimed at reducing the health gap and addressing the unique challenges faced by marginalized communities.

Bilateral donors are increasingly investing in climate-relevant projects in the health sector, with the share of climate finance targeting health increasing from 1 percent in 2018 to 9 percent in 2022. This makes health the only sector, alongside education, to experience such an increase. Loans account for 24 percent of bilateral donors' climate and health funding, and more than 90 percent of the Asian Development Bank and Inter-American Development Bank's total funding for climate and health.

There is a substantial potential to improve health through climate action in other sectors as well. In addition to the direct support of USD7.1 billion to the health sector for climate action, funders have committed an average of USD13.5 billion annually between 2018 and 2022 for activities in health-determining sectors. These activities have the potential to bring significant health improvements, particularly through the reduction of air pollution.

Overall, while there has been progress in financing climate action in the health sector, the reliance on loans and the need for further investment in other sectors highlight the ongoing challenges in effectively addressing the health impacts of climate change [The Rockefeller Foundation et al. (2025)].

The report reiterates an opportunity to see health outcomes beyond healthcare, and to stimulate meaningful investments. The report highlights three broad areas of investment and policy actions.

10.1 Accessible, Resilient, Green and Inclusive Healthcare Infrastructure

The first is within the healthcare sector and its infrastructure. The World Health Organization disability-adjusted life years data provides detailed standardized mortality and morbidity statistics across countries. It thus provides a high-level guidance on where healthcare investments should focus on for which country. The report highlights that economic inequality hurts developing countries' mortality (but less so for high-income countries). Policymakers in developing countries need to improve access to health, not just increase aggregate healthcare spending. There is evidence from research that a wider distribution of health facilities is associated with improved health outcomes, though the exact channels remain unclear at this stage. This is an area for productive future research.

However, simply building more health facilities would not be the only answer (especially for fiscal or manpower-constrained economies). Leveraging digital connectivity to distribute health assessments and knowledge, unify medical records, provide remote consultation and telehealth, provide early warnings of adverse weather, etc., can amplify the effectiveness of hard infrastructure.

Healthcare systems will also have to meet the challenge of global warming and more frequent adverse weather conditions. Geospatial information system (GIS) analysis of health facilities and populations is needed to determine which facilities are at risk and which population segments would be vulnerable to being cut off during adverse weather conditions. For example, GIS approaches are used to map out healthcare needs and accessibility for Indonesia during the COVID-19 pandemic [Silalahi et al. (2020)]. There are also emerging efforts to stress-test road networks under disaster scenarios [Schuster et al. (2024)]. This report also highlights the use of GIS to map out at-risk facilities during floods and underscores the need for an expanded and resilient emergency service.

The need to strengthen healthcare infrastructure against emerging challenges is ongoing. For example, the UNDP proposes "Smart Health Facilities," where digital connectivity and improved logistical capacity become key to amplifying healthcare investments. Off-grid solar panels improve the provision of medical and warehousing facilities in remote areas, including bringing cold-chain required treatments (e.g., vaccines) and allowing the pre-positioning of treatments to these communities.

Smart hospitals in the Caribbean, supported by development partners, are designed and built to be hurricane and flood resilient. The combination of solar and battery (as primary or backup sources of electricity) minimizes the risk of critical failures during adverse weather events. Healthcare facilities are also retrofitted to meet emerging threats, such as with antimicrobial floor surfaces. The healthcare sector itself is now responsible for almost 5 percent of global carbon emissions. Healthcare facilities need to be designed or upgraded to be environmentally sustainable, optimizing the use of resources and minimizing the release of waste and chemical hazards into the environment. Efforts to reduce greenhouse gas emissions and waste products from the health sector are also ongoing. These are useful case examples that must be scaled up across developing countries.

The healthcare sector needs to strengthen capacity to effectively conduct surveillance of climate-related diseases. There is a need to collaborate with other sectors like water and sanitation, transportation, energy, agrifood, urban planning, and environment to prepare for the risks posed by climate change and nature degradation. Healthcare facilities need to assess their resilience to climate change threats.

Finally, there are still significant gaps in health coverage. An estimated 4.5 billion people are lacking coverage of essential health services, many of whom are in least developed countries. An estimated 415,000 new health facilities are needed by 2030 to achieve SDG3 in developing countries. Throughout the report, it is also clear that women can be more effected (e.g., by heat stresses during pregnancies, water-borne diseases), and have higher non-communicable disease burdens. Inequalities in access particularly affects women, girls, minorities, indigenous people, rural populations, and other marginalized groups. The systemic barriers and inequalities faced by these groups lead to health inequities, which combined with limited access to other economic opportunities further exacerbate socioeconomic vulnerability and negatively impact health outcomes. Conversely, improving health access for vulnerable groups can help them unlock their economic potential, bolstering social and economic resilience of societies.

10.2 Infrastructure with Health Co-benefits

The second theme recognizes the importance and leverages on broader infrastructure development to enhance health outcomes. Most infrastructure has the potential to affect health and well-being. Well-designed transport systems improve safety and reduce traffic injuries. Improved transportation infrastructure often means improved health accessibility. Investments into cleaner transport improve countries' environmental health.

Furthermore, there are opportunities to improve the built environment with more accessible and active modes of transportation, including bike lanes, pedestrian walks and public transport. These reduce air pollution and increase physical activity at the same time. Modernizing water infrastructure would eliminate lead pipes and protect against severe and often deadly lead poisoning. Investments into digital infrastructure, beyond being important to accessing online health resources and connecting with medical personnel via telehealth, also intersects with everything from employment and educational. Social and digital infrastructure can combine to support active aging.

As highlighted in this report, air pollution is a large killer in developing countries and the health benefits of the net zero transition to cleaner energy sources cannot be overstated. The report shows that investments in renewables need to be accompanied by transmission and policy changes, including electricity trade, to fully realize cleaner air benefits. Cross-border clean electricity trade will be needed to realize regional clean air benefits.

Adaptation is key to avoiding the worst health impacts arising from climate change, and adaptation will be differentiated depending on the nature of climate change stress. Rising temperatures will increase heat-related health stresses. The built infrastructure in urban areas play an important role to mitigate against such heat stresses. In regions with summer heatwaves, infrastructure, public spaces, workplaces and homes will need to be retrofitted to protect populations.

Where warming brings higher storm intensity, improved drainage and water management infrastructure will be needed. In some countries, global warming brings not flooding but aridification and exacerbates water scarcity. Here, the health of populations will depend on improved and resilient water infrastructure that can cope with increasing shortages, including irrigation needs for agriculture and livestock. Many developing countries will continue to host large livestock sectors. There will be a need for robust livestock infrastructure and surveillance to avoid the emergence of zoonotic diseases.

The broader health impact of traditional infrastructure has led some practitioners to coin the phrase "All Infrastructure is Health Infrastructure" to capture the important idea that all infrastructure must ultimately serve the well-being of people [Jain et al. (2022)]. However, there is currently limited evidence on effective actions in the area of health co-benefits, especially in LMICs.

10.3 Nature as Infrastructure and Nature for Health

The third theme is to recognize how nature and biodiversity impact health, and that their restitution and conservation would be greatly needed. China's Sanbei project, highlighted in last year's report, shows how local communities use a mix of plants to slow aridification [AIIB (2023)]. China's experience could hold valuable lessons for other regions in central Asia, Africa, or other regions facing similar threats.

A recent example of nature as infrastructure is how a keystone species like the vulture offers natural "sanitation" services, and its collapse in some parts of India resulted in significant social costs [Frand and Anant (2024)]. Indonesia provides a vivid example of how restoring peatland to its more natural wet habitat is vital in reducing fires and air pollution and how restoring mangroves combats coastal storm surges.[25]

There is also a body of evidence, some through randomized trials, pointing to the benefit of nature and green spaces in assisting patients' recovery. In multiple dimensions, nature as infrastructure is closely linked to nature for health. A holistic approach bringing together healthcare infrastructure, wider infrastructure development, and nature is key to safeguarding human health.

To sum up, well-designed infrastructure projects have large health co-benefits, which should be recognized in economic assessments. Seen in this context, an infrastructure gap is a health gap. This is also where the Asian Infrastructure Investment Bank, as an infrastructure-focused development bank working with other development partners and the private sector, will bolster health outcomes in developing countries.

Box K: Protectionism in Health Goods—What Has Changed Since the Pandemic?

The pandemic prompted a wave of export restrictions on medical goods as countries prioritized their domestic supply.[a] Trade restrictions, including export bans and licensing requirements, limited the availability of products in global markets and disrupted supply chains. Consequently, such barriers exacerbated the rising global healthcare costs, particularly in fast-growing economies [Helbe and Shepard (2017)]. Developing countries were hit the hardest, facing reduced access to medical supplies, undermining their pandemic preparedness and progress.

By 2021, the number of newly imposed export restrictions had decreased, but this trend reversed in 2022 and 2023, with a renewed rise in restrictions. In contrast to the limits in 2020, the newly imposed restrictions in 2022 and 2023 seemed increasingly directed at medical equipment and less at Personal Protective Equipment (PPE), which was the main target during the pandemic. Export restrictions are predominantly being imposed by advanced economies, including the United States (15 percent of restrictions) and European countries like Germany (5.7 percent), Switzerland (5 percent), and Italy (5 percent). As shown in Figure K1 (panel 3) which excludes Russia, a large proportion of export restrictions impacted emerging economies and lower-income countries (LICs). About 70 percent of export restrictions in 2022-2023 impacted these countries, up from around 60 percent in 2020-2021.[b] At the same time, these countries, especially LIDCs, were most dependent on medical imports, given their limited role in producing and exporting such goods.

In the post-pandemic years, global trade has become increasingly shaped by geo-economic fragmentation. To assess its impact on protectionism in health products, countries are categorized into two blocs based on their voting patterns at the UN General Assembly. This serves as a proxy for country alignment, resulting in one bloc (141 economies) and another bloc (52 economies).[c]

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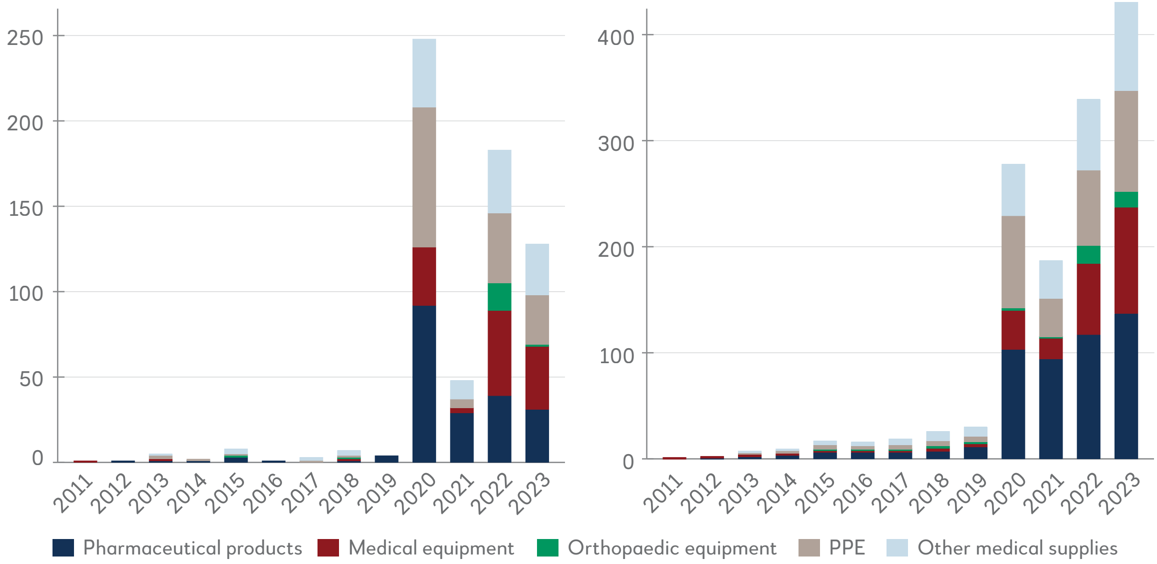
[25] While not covered in this report, it is also increasingly clear that there will be health impacts arising from the condition of our oceans, microplastics and other chemicals in the environment, and also health impacts arising from intensive agricultural.

Box K *continued*

Figure K1: Number of Harmful Export Restrictions

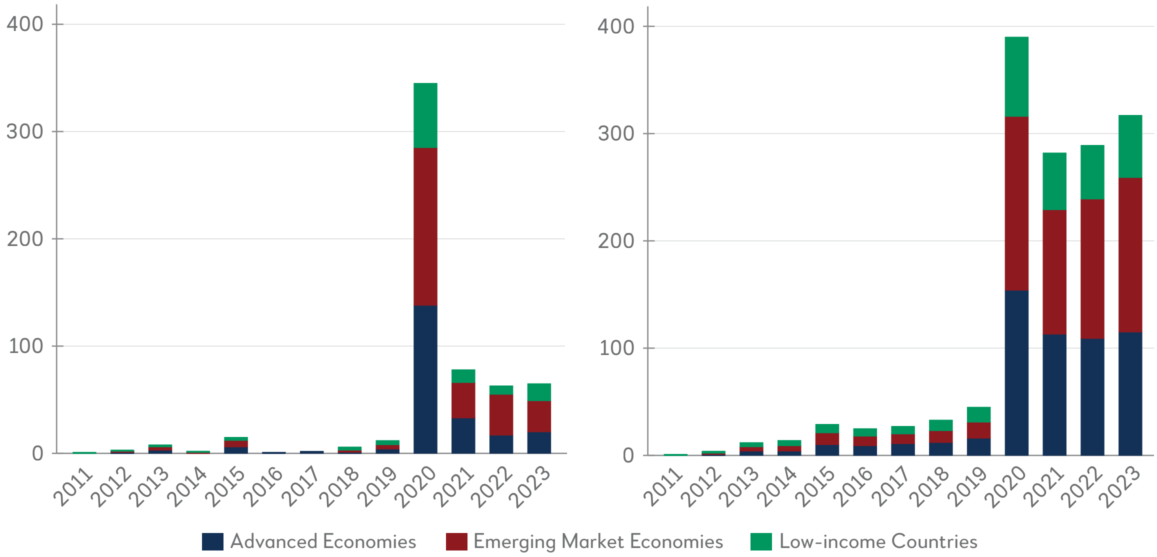
Panel 1: Number of Newly Imposed Export Restrictions

Panel 2: Number of Existing Export Restrictions



Panel 3: Number of Newly Imposed Export Restrictions, by Affected Country Group (excl. Russia)

Panel 4: Number of Existing Export Restrictions, by Affected Coutry Group (excl. Russia)



Source: Global Trade Alert and AIIB staff estimates. Notes: (1) Export restrictions often apply to multiple countries and products, leading to duplicates across different categories in the charts. (2) Cumulative export restrictions are calculated by taking the total number of imposed restrictions and subtracting those that have expired or been removed.

In 2023, pharmaceutical products and medical devices were the most affected by export restrictions, with over 90 percent of these restrictions imposed by one bloc. While in 2020, most restrictions were within the same bloc, by 2022 and 2023, there was a shift towards between-bloc restrictions. In line with this, post-pandemic trade has also shifted. Trade between countries within the same geo-economic bloc rose by 15 percent in 2021 and another 4 percent in 2022, while trade between blocs grew by 5 percent in 2021 but declined by nearly 3 percent in 2022.

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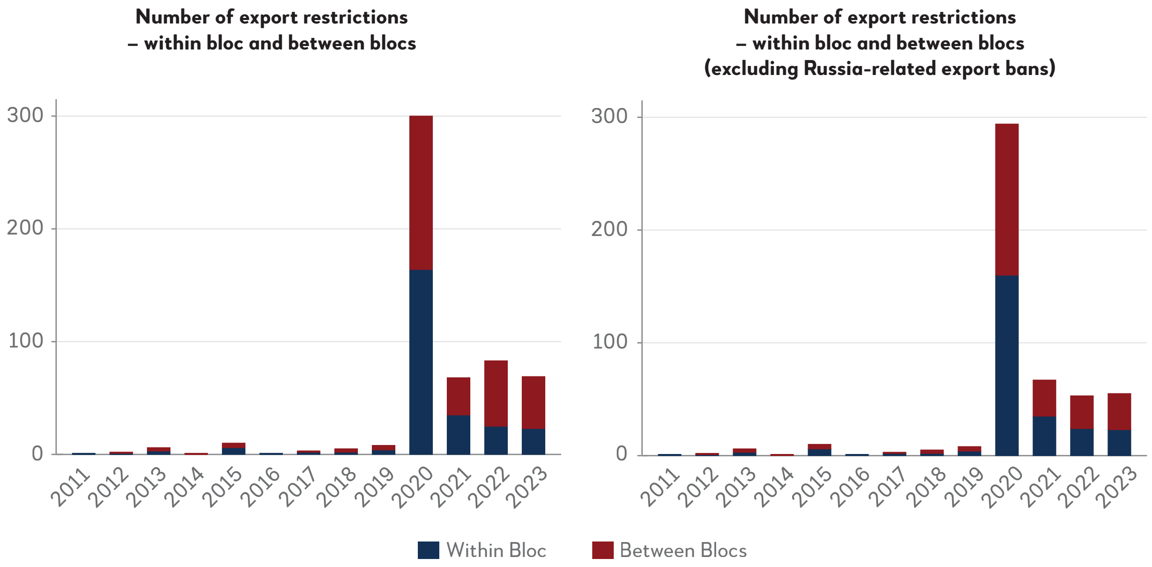
Box K *continued*

Hence, geo-economic fragmentation is impacting trade in health products. Such fragmentation is often associated with rerouting trade through third (aligned) countries, resulting in an inefficient and costly lengthening of supply chains [IMF (2024)]. First, this leads to higher prices, negatively impacting health outcomes in countries with limited capacity to produce these products domestically. Second, such lengthening of supply chains has detrimental environmental impacts, leading to increased waste and pollution.

Figure K2: Number of Export Restrictions by Type (Within Bloc or Between Blocs)



Number of export restrictions – within bloc and between blocs

Number of export restrictions – within bloc and between blocs (excluding Russia-related export bans)

Source: Global Trade Alert and AIIB staff estimates.
Notes: A single restriction can impact multiple countries, potentially counting as both an inter-bloc and intra-bloc restriction.

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[a] The WTO categorizes medical goods into five categories: pharmaceutical products, medical equipment, orthopedic equipment, Personal Protective Equipment (PPE) and other medical supplies (e.g., hospital and laboratory inputs and consumables, such as syringes).

[b] One restriction could impact multiple countries.

[c] See Resolution es-11/1. Those that voted for the resolution are grouped as one bloc, and those that voted against or abstained are grouped as another bloc.

APPENDICES

Appendix 1: Data and Estimations for Chapter 2

Data

Power plants: Data on coal-fired and renewable energy power plants is sourced from the Global Energy Monitor. This dataset provides geographic information and operational status for both retired and active power plants, including details on generator units (e.g., open, retired, canceled or under development), starting year, retired year, capacity and ownership. This research defines a plant as retired if at least one generator unit has been retired, with the retirement year marked by the first unit's retirement. This is then cumulated to derive total retirement. For renewable energy (RE) power plants, the research calculates the count and capacity of RE plants within a 100-kilometer radius of retired coal-fired plants for each type (e.g., wind, hydro, solar or gas) to analyze potential determinants of displacement effects.

Air pollution and climate: The concentration of particulates smaller than 2.5 µg in aerodynamic diameter (PM2.5) is obtained from the Atmospheric Composition Analysis Group. The Group provides global monthly PM2.5 levels at a 0.1-degree grid resolution (approximately 10 kilometers by 10 kilometers). To estimate the impact of coal-fired power plant closures, local air pollution is measured using grid-level sulfur dioxide (SO_2) data from NASA. Daily SO_2 values are recorded at a spatial resolution of approximately 0.25 by 0.25 degrees (27.75 kilometers by 27.75 kilometers). This research replaces any negative SO_2 values with zero and aggregates the data to a monthly level following the literature. The monthly SO_2 data is then matched with power plant locations, and the distance between them is calculated. The climate controls are combined with SO_2 data, such as temperature, precipitation, wind speed, dew point and sea level pressure at month level, from the National Oceanic and Atmospheric Administration (NOAA).

India health: The National Family Health Survey (NFHS) of India, conducted in multiple waves, is used. The NFHS surveys are nationally representative and collect detailed information on a wide array of health and demographic variables across the country. For this study, data from NFHS wave 2 (2015-2016) and wave 3 (2019-2021) are used to assess changes in health outcomes. The analysis focuses on infant weights, examining birth weights and infant mortality for babies born between January 2015 and March 2020 before and after the implementation of GRAP.

Empirical Strategy for Table 2

The following difference-in-differences (DID) empirical specifications are used to measure the closure and displacement effects of coal-fired power plants in China on air quality:

Equation 7

$$ln(SO2_{it}) = \alpha_i + \beta Close_i \times Post_t + X'_{it}\phi + \tau_t + \epsilon_{it}$$

Equation 8

$$ln(SO2_{it}) = \alpha_i + \delta Near_i \times Post_t + X'_{it}\phi + \tau_t + \varepsilon_{it}$$

where, for both Equation 7 and Equation 8, our dependent variable, ln(SO2$_{it}$), is the natural logarithm of SO2 levels measured in a 0.25-degree latitude and longitude grid i (≈ 27 kilometers) in year-month t. For Equation 7, our key variable of interest is Close$_i$ × Post$_t$. Close$_i$ is a binary variable taking the value of 1 if the centroid of grid i is within 35 kilometers from the retired power plant and 0 otherwise.

Post$_t$ is a binary variable taking the value of 1 in year-month t within five years after the power plant retirement and 0 otherwise. β measures the average percentage change in the SO2 levels after the closure of a neighboring coal-fired power plant. If coal-fired power plant closures improve local air quality, β is expected to be <0. Our key variable of interest for Equation 8 is the interaction of Near$_i$ and Post$_t$. Near$_i$ is a binary variable that takes the value of 1 if grid i is (1) within 35 kilometers from the coal-fired power plants that remain open and (2) within 100 kilometers of the coal-fired power plant that is shut down and 0 otherwise. Post$_t$ is a binary variable taking the value of 1 in year-month t after the coal-fired power plant within 100 kilometers is retired and 0 otherwise. Our coefficient of interest, δ, measures the average percentage change in SO2 levels for areas around operational coal-fired power plants. If these plants are intensifying production to meet the shortfall in electricity supply driven by closures, δ is expected to be larger than 0 and air quality to worsen. X'$_{it}$ represents a rich set of observable control variables, including temperature, dew point, air pressure relative to mean sea level, visibility, wind speed, precipitation, and their second polynomials, that could affect air quality. The data sample is limited to no more than five years before and after each plant closure to accurately capture short-run displacement and retirement effects.

As mentioned earlier, older and less efficient coal-fired power plants located in more populous areas are more likely to be retired because these plants generate more pollution externalities to living communities. Therefore, treated and untreated areas are less likely to be comparable and are more likely to have similar trends in air pollution. To ensure that control areas are similar to the treated areas, the analysis is restricted to grids no more than 50 kilometers from the closed coal-fired power plant, defining our control group as grids from 35 to 50 kilometers. To measure displacement, the analysis is constrained to grids at most 50 kilometers from operational coal-fired power plants. Furthermore, as coal-fired power plants across China are retired at different periods, the research exploits this staggered closure timing to estimate the average closure and displacement effects of coal-fired power plants on air quality. Put differently, our analyses only incorporate areas that experience retirements of coal-fired power plants nearby. Areas with no retirements are omitted. Figure 5 shows how the treatment and control areas are defined to measure the closure and displacement effects of coal-fired power plants.

Empirical Strategy for Table 3

This research employs the following DID empirical strategy to estimate the effects of GRAP on air quality, measured by PM2.5:

Equation 9

$$ln(Y_{ict}) = \alpha_i + \delta Delhi_i \times Post_t + \gamma NCR_i \times Post_t + x'_{ct}\beta + \tau_t + \epsilon_{ict}$$

where in Equation 9, ln(Y$_{ict}$) denotes our outcome variable, PM2.5, collected at grid level i in district c at time period t.

The primary variable of interest is the interaction of Delhi$_i$, which is an indicator variable taking the value of 1 for the different districts within Delhi and 0 otherwise, and Post$_t$, which is a binary variable taking the value of 1 after January 2017 and 0 otherwise, denoting periods after GRAP is enforced. δ measures the change in PM2.5 levels in Delhi due to the enforcement of GRAP.

If the enforcement of immediate and stringent response actions by regulators deter industries from "over-polluting" and lead to more sustainable practices, δ is expected to be < 0, indicating improvement in air quality. The effects of GRAP on the National Capital Region (NCR) are further estimated and comprise 24 districts within the states of Haryana, Rajasthan and Uttar Pradesh surrounding Delhi. These percentage changes in PM2.5 are captured by γ, which is the coefficient from the interaction of NCR_i, a binary variable taking the value of 1 for districts within the NCR, and $Post_t$. Effectively, this research compares changes in PM2.5 levels in Delhi and the NCR before and after GRAP is introduced, benchmarking them with changes in PM2.5 levels in areas unaffected by the policy. α_i represents grid fixed effects that control for time-invariant unobservables at the grid level, and τ_t represents year-month fixed effects that control for general trends in PM2.5 across areas. x'_{ct} denotes a vector of time-variant climatic controls (temperature, rainfall, humidity) that could be correlated with the implementation of GRAP. The inclusion of the rich set of controls and fixed effects ensures there are no omitted variables that could bias our estimates.

Empirical Strategy for Table 4

A similar DID empirical strategy is adopted to estimate the effects of GRAP on various health outcomes, which include infant birth weight and mortality rates for children under six months and one years old. The empirical specification takes the following form:

Equation 10

$$O_{hdt} = \alpha_d + \varphi Delhi_h \times Post_t + \theta NCR_h \times Post_t + k'_h \phi \quad + \tau_t + \varepsilon_{hdt}$$

where O_{hdt} represents a vector of health outcomes surrounding household h in district d at time t that could be affected by air quality. Given the delayed effects on birth outcomes following air quality improvements, $Post_t$ is defined as 1 for periods after 2018. Similar to before, the main variables of interest are the interaction of $Delhi_h$ and $Post_t$ and the interaction of NCR_h and $Post_t$. The corresponding estimated effects of φ and θ measures the change in health outcomes in Delhi and the NCR, respectively, after GRAP implementation.

If health outcomes improve after the enforcement of GRAP, both φ and θ are expected to be < 0 if the dependent variable is infant mortality. Put differently, the enforcement of GRAP is expected to reduce premature infant mortality. Conversely, both φ and θ are expected to be greater than 0 when the dependent variable is birth weight, as improved air quality is anticipated to increase birth weight for babies. To mitigate the risk of omitted variables from biasing the estimates, a rich set of household-specific characteristics is controlled, denoted by k'_h, which include mother's age, education, wealth, smoking behavior, occupation, work status, health insurance, religion, place of delivery, prenatal services, doctor assistance, number of antenatal visits during pregnancy, months of breastfeeding and time spent at the place of delivery. αd represents district-fixed effects of the mothers' residences, and τt represents year-month fixed effects of the infants' birth month and year.

Appendix 2: Data and Estimations for Chapter 3

Data. The analysis of flood impact on health in Indonesia benefitted from three main datasets:

1. Indonesia National Health Insurance Sample Dataset. The dataset covers a comprehensive healthcare visit record from 2020, 2021 and 2022. It includes members' basic profiles, such as regency of residence, type of membership, gender and birth dates; and information on visits to health facilities, including date of visits and diagnosis. The diagnosis information was recorded using the ICD-10 categorization (Table 19), where the waterborne diseases are identified, based on Ortiz-Prado et al. (2022).

Table 19: ICD-10 Classification for Waterborne Diseases

ICD-10 classification
A00 Cholera
A01 Typhoid and paratyphoid fevers
A02 Other salmonella infections
A03 Shigellosis
A04 Other bacterial intestinal infections
A05 Other bacterial foodborne intoxications, not elsewhere classified
A06 Amoebiasis
A07 Other protozoal intestinal diseases
A08 Viral and other specified intestinal infections
A09 Other gastroenteritis and colitis of infectious and unspecified origin
A71 Trachoma
B15 Acute hepatitis A
B58 Toxoplasmosis
B68 Taeniasis
B69 Cysticercosis
B75 Trichinosis
B77 Ascariasis
B78 Strongyloidiasis
B79 Trichuriasis
B80 Enterobiasis
B81 Other intestinal helminthiases, not elsewhere classified
B82 Unspecified intestinal parasitism

Source: Ortiz-Prado et al. (2022).

2. National Disaster Database. The database contains data on natural disasters that occurred since 2008. It records the regency where the disaster happened, the dates, and the type of disaster. Included are general flood and tidal flood types for this analysis.
3. Indonesia Database for Policy and Research, World Bank. This database contains economic and social indicators at the province and district level across fiscal, economic, social and demographic indicators, as well as infrastructure. The health infrastructure level across regencies was collected from this database.

Methodology. We classify the sample dataset into four categories based on their health and visitation (Table 20). Group A are those who are healthy and visit healthcare facilities; the purpose of the visits is usually medical check-ups, vaccination, immunization, pregnancy, etc. Group B are those who are healthy and do not visit healthcare clinics. Group C are those who are ill and visit healthcare facilities to treat their illness. Group D, however, are those who are sick but do not visit healthcare facilities.

Table 20: Categories of Observations

	Visit Healthcare	No Visit
Healthy	A Check-up, Vaccination, etc.	B
Sick	C Sick Visit	D No Access
No of individuals	1.2 million	1.1 million

Ideally, Group D should be excluded to estimate the probability of an individual falling sick post-flood, as no information about the Group's illnesses before and after a flood event is available. However, since there is no identification marker to separate Group B from Group D, two sample sets were constructed:

Sample Set 1: A + B + C + D

Sample Set 2: A + C

Sample Set 1 will have a lot of non-visits observation points mainly driven by Groups B and D. Group B can be driven by the individual's overall health status or any other external factors that keep them healthy, so healthcare visits are not necessary. However, for Group D, people may not visit the doctors even though they are sick for many reasons, such as a lack of access and trust in the health system or some general apprehension about visiting a hospital/healthcare facility. Therefore, both Group B and D may be systematically driven by these endogenous factors.

On the other hand, Sample Set 2 only includes observations for those who have visited a healthcare facility at least once in the years of observations. In this set, non-visitation to a healthcare facility only happens when a person does not visit a healthcare facility because they are not sick. All other reasons, such as access, trust, apprehension, etc., may not be a factor for not visiting a hospital because they have visited a hospital at least once in these three years. Therefore, there is less systematic bias for "no visits" in Sample Set 2 compared to Sample Set 1. For this reason, our baseline sample in this analysis uses Sample Set 2.

Further, we used the number of flood events in the years of observations to determine treatment (flood-prone) and control groups. The distribution of total flood events across the years of 2019, 2020 and 2022 is shown in Table 21 below.

Thus, the treatment and control groups for the analysis were constructed as follows:

For simplicity, as the control observations are similar for both groups, we refer to them as 'no-flood group,' and 'flood-prone (X)' and 'flood-prone (Y)' for treatment observations in Group X and Group Y, respectively (Table 22). Table 23 shows the average altitude, precipitation and temperature between the groups to check for any distinct geographical differences between the control and treatment groups that may affect the relationship between flood events and health risk.

Table 21: Distribution of Total Flood Events at the Regency Level in 2019, 2020 and 2022

N	Mean	25%	50%	75%	St. Dev
514	7.9	2	5	11	9.2

Source: AIIB staff estimates based on the Indonesia National Disaster Database.

Table 22: Treatment and Control Groups of the Analysis

	Treatment	Control
Group X	Total flood events in 3 years > 11 N = 132 regencies	No flood events in 3 years. N = 72 regencies
Group Y	At least 1 flood event every year. N = 214 regencies	No flood events in 3 years. N = 72 regencies

Source: AIIB staff estimates.

Table 23: Average Precipitation, Temperature and Altitude of the Regencies

	Rainfall (kg km-2 s-1)	Temperature (C)	Altitude (m)	Urbanization (%)
No flood	88.7	24.1	508	35.15
Flood-prone (X)	82.5	25.7	259	43.86
Flood-prone (Y)	79.6	25.6	282	41.00

Source: AIIB staff estimation from NASA GLDAS dataset.

Table 24: Baseline Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)
Dep Var	**Visit**		**Sick Visit**		**Waterborne**	
Group	**Group X**	**Group Y**	**Group X**	**Group Y**	**Group X**	**Group Y**
Post_treat	0.00125	0.000946	0.00199***	0.00103**	0.000186**	0.000101*
	(0.00115)	(0.000867)	(0.000621)	(0.000464)	(8.50e-05)	(5.97e-05)
Age	0.000625	0.000147	0.000247	0.000147	-7.21e-05	-8.97e-05
	(0.000657)	(0.000517)	(0.000448)	(0.000346)	(8.97e-05)	(7.31e-05)
Constant	0.147***	0.159***	0.0824***	0.0862***	0.00553*	0.00611**
	(0.0231)	(0.0183)	(0.0157)	(0.0122)	(0.00313)	(0.00257)
Observations	20,090,124	26,669,376	20,090,124	26,669,376	20,090,124	26,669,376
R-squared	0.232	0.226	0.225	0.231	0.045	0.045
Prob > F	0.436	0.548	0.00655	0.0813	0.0729	0.145
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
ID FE	Yes	Yes	Yes	Yes	Yes	Yes
Regency FE	Yes	Yes	Yes	Yes	Yes	Yes

The impact of flooding on the probability of contracting waterborne diseases was then estimated using the following equation:

Equation 11

$$y_{i,t,k} = \beta * Post_t * Treat_k + \alpha_i + \delta_t + \gamma_{kt} + \delta_{it} * age + \varepsilon_{it}$$

For each individual i residing in regency k on the month-year t:

$y_{i,t,k}$	Visit	1 if the individual visits healthcare facilities for any reason
	Sick visit	1 if the individual visits healthcare facilities for illness
	Waterborne	1 if there is any waterborne disease diagnosed in the month of visit
	% waterborne	% number of waterborne diseases diagnosed out of the total visits in the month
$post_t$	Flood event	1 if the flood event is recorded for the month and the two months after
$treat_k$	Treatment group	1 if the regency residence is in the treatment group, 0 for control regency
α_i	Individual fixed effect	
δ_t	Time fixed effect	
γ_{kt}	Regency specific time trend	

Results of Regressions

Data. The analysis of impact of flood on health in India benefitted from the following datasets:

1. Demographic and Health Survey Dataset: The dataset provides information on population, health and nutrition for India. Data on prevalence of malaria and diarrhea as well as other characteristics such as sex of the child, age of the child, toilet, drainage, drinking water

and hand hygiene facility, mother's age and education and wealth at the household level is sourced from the database.

2. Central Pollution Control Board Water Quality Data: The surface water quality data was obtained for year 2019. The data includes surface water quality data from rivers (including medium and minor rivers), canals, lakes, ponds, and tanks. Data from around 2500 monitoring stations has been averaged at district level for the analysis.
3. Central Ground Water Board Database: The ground water quality data was derived from Ground Water Quality Report 2019 published by Central Groundwater Board, Ministry of Jal Shakti, Department of Water Resource, River Development and Ganga Rejuvenation. Water Quality data from around 16000 monitoring stations across the country has been averaged at district level for the analysis.
4. Climate Disaster Exposure Database: This is based on Mohanty and Wadhawan (2021), whereby extreme events catalogue for a period of (1970-2019) 50 years was used to identify extreme events district hotspots using globally validated sources. A gridded exposure sheet for climate events has been developed. Exposure is defined as the occurrence of an event within a specific grid characterized by district boundaries. A climate events roster was prepared using EM-DAT criteria, which was then updated with data from multiple sources to create an India-specific roster of extreme events.

The quality of water was rated using the actual and permissible limit values of every parameter. Quality rating is based on the ratio of the actual and permissible limit values of particular parameters. Permissible values for every parameter have been obtained from the Bureau of Indian Standards (BIS) and the World Health Organization (WHO).

$$Quality\ rating\ (Q_i) = \frac{\begin{matrix} Measured\ value \\ of\ the\ parameter\ (C_i) \end{matrix}}{\begin{matrix} Permissable\ value \\ of\ the\ parameter\ (S_i) \end{matrix}} \times 100$$

Further, to standardize every parameter, relative weight has been assigned for every parameter between 1 and 5 based on their impacts on health found in the available literature.

$$Relative\ weight\ (RW) = \frac{Assigned\ weight\ (AW)}{Sum\ of\ AW}$$

Then relative weight has been multiplied with quality rating to get the sub-indices.

$$Sub\ indices\ (SI_i) = RW \times Q_i$$

$$Water\ Quality\ Index\ (WQI) = \sum_{i=1}^{n} SI_i$$

Finally summing up the sub-indices of different parameters produced the water quality index.

Data. The analysis of impact of climate events on food security in Sri Lanka benefitted from the following datasets:

1. Multidimensional Vulnerability Index Dataset: The dataset, relies on data from the National Citizen Survey 2022-23. A total of 25,000 households covering 25 districts were surveyed. The MVO assesses vulnerability in three critical dimensions: Education, Health and Disaster and Living Standards.

Appendix 3: Data and Estimations for Chapter 9

Table 25: List of Variables

Variable	Source	Coverage
YLL	WHO	By country, age, sex, year
YLD	WHO	By country, age, sex, year
Labor force participation rate	ILO	By country, sex, year
Life expectancy at birth	World Bank	By country, sex, year
Years of schooling	PWT	By country, sex, year
Age dependency ratio	World Bank	By country, sex, year
GDP	World Bank	By country, year

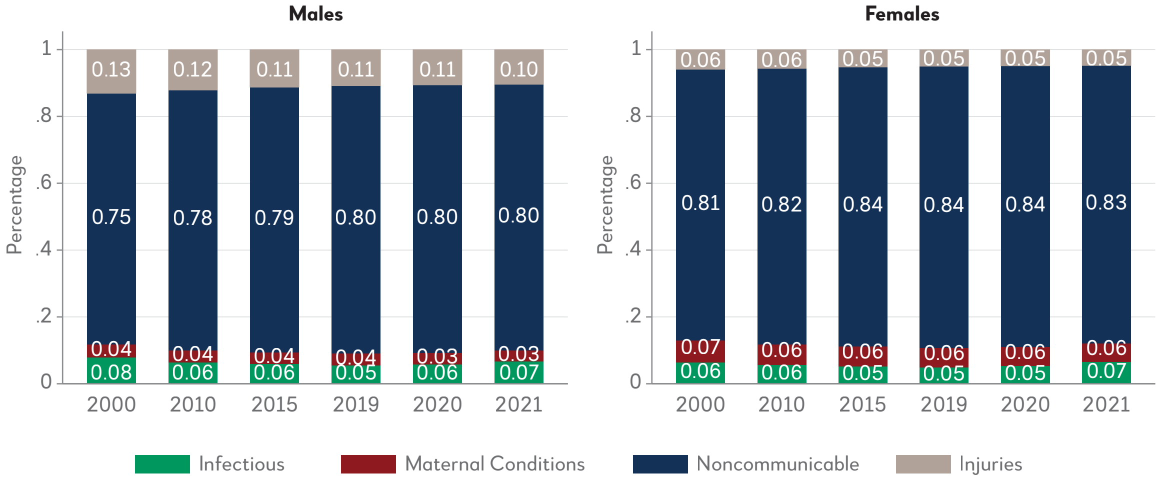
Detailed Analysis of Disease Burdens

Mortality and morbidity from infectious diseases have fallen in the past two decades due to the roll-out of vaccines and the advancement of treatment options. DALY has also declined in the two decades prior to COVID. There is some reversal due to COVID, but whether the upticks are temporary or more persistent remains to be seen. Noncommunicable diseases remain the major causes of YLD, with the share of total YLD increasing since 2000 (Figure 56).

Breaking down by country income group, the share of YLD from infectious diseases and maternal conditions decreases markedly as income levels rise, with the lowest incidences observed in HICs. Conversely, as income increases, noncommunicable diseases emerge as the predominant type of disease, encompassing various chronic conditions (Table 26).

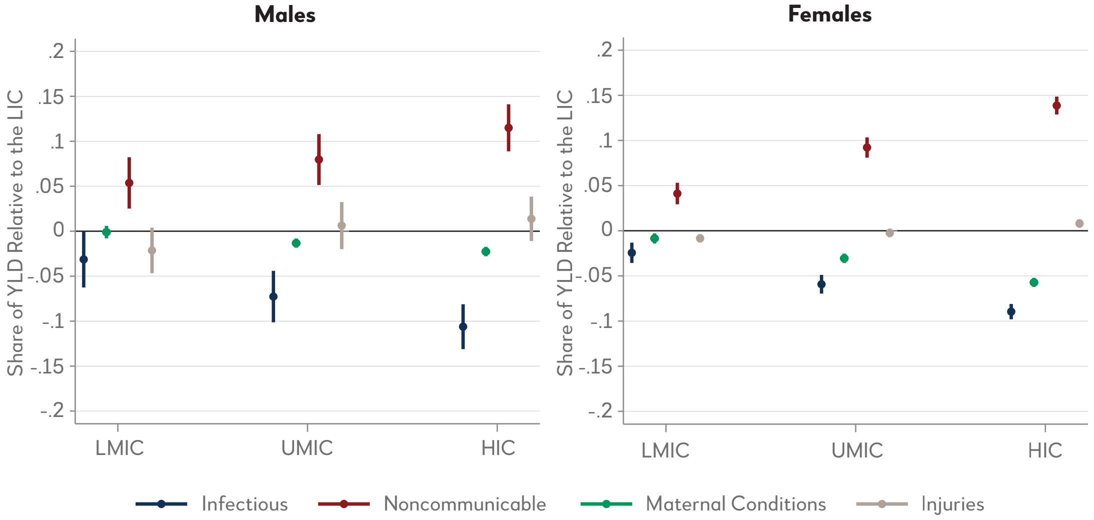
The reduction in infectious diseases should not be taken for granted in the context of global warming. In warmer temperatures, vectors become infectious more quickly. Recent studies such as Mordecai et al. (2017) show that maximal transmission of Zika and dengue—both potentially fatal—occur in the temperature range of 26 to 29 degrees Celsius. Studies suggest that 218 out of 375 infectious diseases can be aggravated by climate [Mora et al. (2022)].

Figure 56: Share of Causes of YLD, Men and Women



Source: WHO DALY and AIIB staff estimates.

Figure 57: Share of YLD by Causes and Income Levels



Source: WHO DALY and AIIB staff estimates.

Notes: YLD = years lived with disability; LMIC = low- or middle-income country; UMIC = upper-middle-income country; HIC = high-income country

Table 26: Relationship Between Income and Disease Types (measured by shares of YLD)

	Males			
	Infectious	**Maternal**	**Noncommunicable**	**Injuries**
GDP Per Capita (log)	-0.008**	-0.002**	0.013***	-0.003
	(0.003)	(0.001)	(0.003)	(0.003)

	Females			
	Infectious	**Maternal**	**Noncommunicable**	**Injuries**
GDP Per Capita (log)	-0.003	-0.004***	0.009***	-0.002*
	(0.002)	(0.001)	(0.002)	(0.001)

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

In recent years, populations, on average, experienced 86 days of high temperatures a year [Lancet (2023)]. Besides impacting infectious diseases, heat can also exacerbate underlying illnesses, worsening heart disease and kidney injury. Older populations are particularly vulnerable. A 1.5-degree Celsius rise in temperature due to global warming is associated with a 0.5 percent increase in heat-related deaths [Chen et al. (2024)]. Heat-related illness becomes a more serious concern with aging.

It is estimated that by 2050, more than 23 percent of the population over 69 will live in a climate with heat exposure of 37.5 degrees Celsius or more [CMCC (2024)].

The chapter investigates the impact of temperature on specific infectious diseases. A regression analysis of infectious YLD rate against average temperature using pooled cross-country data is conducted while controlling for GDP per capita to account for the influence of country income. The regression results are displayed in Table 27. The coefficient for GDP per capita (in log) is negative and statistically significant. Moreover, this effect is particularly pronounced in developing countries, highlighting the large impact incomes have on infectious disease reduction. Higher temperature is associated with a rise in infectious diseases, and this effect is especially significant for developing economies.

Table 27: Effects of Temperature on YLD Rate due to Infectious Diseases

	All		HIC		Developing	
	Males	Females	Males	Females	Males	Females
	(1)	(2)	(3)	(4)	(5)	(6)
GDP Per Capita (log)	-0.180***	-0.191***	-0.019	-0.014	-0.225***	-0.199*
	(0.031)	(0.035)	(0.019)	(0.013)	(0.080)	(0.106)
Temperature	0.008***	0.008***	0.002*	0.002***	0.014***	0.014***
	(0.002)	(0.003)	(0.001)	(0.001)	(0.004)	(0.005)
Year Fixed Effect	Y	Y	Y	Y	Y	Y
Observations	388	388	159	159	229	229
R-squared	0.308	0.235	0.184	0.362	0.207	0.116

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

First Stage Regressions of YLDs and Instruments

The regressions of YLD against instruments are provided in Table 28. Essentially, these are the first-stage regressions for males and females, respectively. Both instruments are positive and significant, highlighting their explanatory power.

Regressions of LFPRs with Extreme Temperatures

Table 29 shows the POLS regressions (mirroring Table 18), using the PYLD and NYLD as instruments but with recorded P99 temperature as an additional variable. In general, high temperatures negatively impact labor force participation in developing economies, especially for females.

Table 28: Regressions of YLD and Instruments

	Males	Females
	(1)	(2)
PYLD	0.642***	0.579***
	(0.130)	(0.128)
NYLD	0.375***	0.422***
	(0.100)	(0.113)
Year Fixed Effect	Y	Y
Income Group Fixed Effect	Y	Y
Observations	900	900
R-squared	0.645	0.658

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 29: Instrumental Variable Regressions (POLS) by Country Groups with P99 Temperatures

	(1)	(2)	(3)	(4)	(5)	(6)
	LFPR, Males			LFPR, Females		
	All	HIC	Developing	All	HIC	Developing
YLD (rate)	-3.978***	-4.650**	-2.159	-5.651***	-1.072	-8.408***
	(0.996)	(1.931)	(1.374)	(1.375)	(1.200)	(1.770)
Education Level	-0.613	0.288	-0.931	2.418***	2.071**	2.303***
	(0.544)	(0.631)	(0.667)	(0.569)	(0.890)	(0.700)
Dependency Ratio	-0.243***	-0.337***	-0.090	-0.094	-0.225**	-0.144
	(0.082)	(0.088)	(0.113)	(0.141)	(0.111)	(0.215)
Life Expectancy	-1.972	2.131	1.071	-9.222***	-9.036	-5.263**
	(1.361)	(6.000)	(1.627)	(2.362)	(21.258)	(2.549)
Life Expectancy^2	0.015	-0.013	-0.007	0.060***	0.059	0.028
	(0.010)	(0.040)	(0.013)	(0.016)	(0.129)	(0.019)
Temperature (P99)	-0.060	0.061	-0.179*	-0.368***	-0.339**	-0.462***
	(0.079)	(0.099)	(0.099)	(0.110)	(0.132)	(0.141)
Instruments	Y	Y	Y	Y	Y	Y
Year Fixed Effect	Y	Y	Y	Y	Y	Y
Observations	478	196	282	478	196	282
R-squared	0.241	0.603	0.143	0.276	0.398	0.280

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

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ASIAN INFRASTRUCTURE FINANCE 2025

INFRASTRUCTURE FOR PLANETARY HEALTH

The Asian Infrastructure Finance 2025 report presents evidence of the multifaceted health challenges faced by developing countries due to climate change, nature degradation, and biodiversity loss. It emphasizes that safeguarding human health requires achieving planetary health, demanding a fundamental shift in infrastructure development. By adopting a holistic approach, stakeholders can work collectively to ensure a sustainable and healthy future for all. Well-designed infrastructure development thus brings health co-benefits, increases healthcare resilience; reduces carbon emissions, biodiversity loss and nature degradation, supports workforces, and spurs greater economic returns.

Asian Infrastructure Investment Bank (AIIB)
AIIB Headquarters, Tower A, Asia Financial Center
No. 1 Tianchen East Road, Chaoyang District, Beijing 100101 China

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