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Air Pollution in the Global South: An Overview of Its Sources and Impacts

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Abstract

While air pollution is a significant global threat, its impact is especially pronounced in emerging nations. This review explores the recent economic literature on the diverse effects of air pollution in the Global South, emphasizing causal evidence. We begin by examining regional challenges, such as indoor air pollution (IAP) and biomass burning, which are prevalent in Global South countries. Next, we synthesize the broad spectrum of health and non-health impacts associated with exposure to fine particulate matter and other pollutants. Our assessment reveals an increase in research to document these impacts in Global South contexts. Nonetheless, some challenges, such as an incomplete understanding of underlying mechanisms and regional data disparities, remain.

Keywords: Air Pollution, $PM_{2.5}$, Development, Global South, Health, Human Capital

JEL Codes: Q53, Q56, Q52, O13

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Introduction

Air pollution is increasingly acknowledged as a global health emergency that disproportionately affects low- and middle-income countries in the Global South.[1] For over a decade, cities in these regions have consistently ranked among the highest for levels of fine particulate matter ($PM_{2.5}$) pollution (WHO, 2023). In these countries, households often face extreme levels of air pollution due to the use of traditional household fuels (Shupler et al., 2018) and exposure to biomass burning from agricultural practices and forest fires (Pullabhotla et al., 2023). According to recent data, of the 7.3 billion people affected by unsafe levels of particulate matter, a staggering 80% live in low- and middle-income countries (Rentschler and Leonova, 2023).

This uneven exposure to air pollution highlights a significant disparity in academic research, which has predominantly focused on developed nations. One obvious explanation for the limited research on the Global South is the scarcity of high-quality data, especially regarding air pollution. To accurately assess the impacts of harmful emissions, researchers need high-frequency, granular pollution and meteorological data to distinguish these effects from other environmental factors. Despite the severe air quality issues in these regions, only a few areas have adequate infrastructure and effective air quality monitoring systems, and their data availability is often uncertain.[2] This issue is also relevant for assessing the wide-ranging impacts of pollution beyond its health implications. For instance, studies that assess the effects of pollution on productivity require firm-level administrative records in addition to high-frequency pollution data (Zivin and Neidell, 2012; He et al., 2019; Soppelsa et al., 2021).

Moreover, the lack of robust health infrastructure and resources in developing countries further complicates research efforts. The effective tracking of health outcomes necessitates substantial government capacity, transparency, and a well-established healthcare system, which are often lacking in these regions. Additionally, it has been argued that the immediate economic priorities in developing nations frequently overshadow environmental concerns; when there are trade-offs between environmental improvement and economic development, attention might be diverted towards the latter (Jack et al., 2017), although in this regard, important nuances exist (Aguilar-Gomez, 2024).

[1] We employ this term to refer to countries and regions that are less economically developed and often have a history of colonialism. Therefore, this definition includes countries in Africa, Latin America, South, Southeast, and East Asia, and the Pacific Islands. Specifically, we use the classification in UNESCO (2024).

[2] For a review on the current global landscape of air pollution data, emphasizing advancements and global variations in coverage and accessibility, see Aguilar-Gomez (2024).

Research on the health and welfare impacts of pollution encompasses studies from an increasingly diverse range of developing countries, partly due to advances in data and methodology that facilitate the tracking of air pollution concentrations. For example, satellite-based high-frequency pollution measurements, such as the $PM_{2.5}$ estimations by Van Donkelaar et al. (2016), have enabled research in areas where ground-based monitors are scarce. Additionally, increased funding and improved communication technologies have fostered greater collaboration among researchers from different regions worldwide. The increasing recognition of the harmful impacts of air pollution has led to growing support for understanding and addressing these issues in regions where they pose significant risks.

In this review, we examine recent evidence on the diverse outcomes influenced by air pollution in the Global South. Our focus on Global South regions, rather than on developed nations, is motivated not only by their higher levels of pollution but also by additional factors that may intensify its effects. For instance, developing countries often have less stringent environmental regulations and standards. While the World Health Organization (WHO) recommends that annual average concentrations of $PM_{2.5}$ should not exceed 5 $\mu g/m^3$, local standards in these countries vary significantly: Bangladesh, China, and India set limits of 15 $\mu g/m^3$, 35 $\mu g/m^3$, and 40 $\mu g/m^3$, respectively. Whether these variations stem from institutional weaknesses that impede effective environmental regulation and management or from differing priorities regarding environmental quality, as suggested by Greenstone and Jack (2015), falls beyond the scope of this review. Importantly, however, these variations may lead to more severe impacts in the Global South than in developed nations.

Additionally, disparities in access to personal protective technologies against pollution can contribute to higher exposure levels in developing countries, even when ambient pollution levels are similar. These technologies may be less affordable or less accessible relative to income in the Global South, but several studies reveal that populations make significant efforts to engage in avoidance behaviors to prevent exposure (Zhang et al., 2017; Agarwal et al., 2020; Rivera, 2020). Other factors influencing our focus on these regions include potential non-linear effects, the population age profile, the mix of pollutants, inadequate infrastructure, and significant socioeconomic disparities.

Our assessment specifically targets studies in economics that emphasize causality and concentrate on $PM_{2.5}$. These fine particulate matter particles are small enough to penetrate deep into the lungs and even enter the bloodstream, leading to a range of serious health and non-health issues (Kim et al., 2015; Aguilar-Gomez et al., 2022). While we acknowledge that many studies reviewed also address other pollutants, $PM_{2.5}$ is our primary focus due to its wide-ranging implications.

However, we highlight instances where other pollutants are discussed.

Estimating the causal effects of air pollution on specific outcomes involves several well-known challenges. At the aggregate level, one primary issue is that air pollution emissions often correlate with economic activity, which in turn can influence the very outcomes being studied. Other confounding variables can obscure these relationships, for example, the winter peak in pollution and respiratory diseases that can be observed in many countries, including Chile, Mexico, and Mongolia.

At the individual level, people with varying characteristics might choose to live in areas with differing air quality. For example, higher-income individuals may not only have better access to healthcare but also reside in less polluted areas. Additionally, accurately measuring exposure to air pollution is complex, as such measurement depends on emissions, geographical factors, meteorological conditions, and individual behaviors. These complexities contribute to measurement errors, which can lead to attenuation bias in estimating pollution impacts. This bias results in an underestimation of the benefits of investing in cleaner air.

Given these challenges, this review primarily focuses on studies that employ rigorous identification strategies to better isolate causal effects. While we mainly emphasize such studies, we also include a few that use fixed effects estimations or other methods with potentially weaker causal interpretations. Their inclusion is crucial for addressing understudied areas where strictly causal research is limited. In these cases, we explicitly use the terms "association" or "correlation" to describe the findings of these studies.

The remainder of this review is organized as follows. In Section 1, we examine two major categories of pollution sources that are particularly pertinent to the Global South: indoor air pollution (IAP) and biomass burning. The following sections synthesize the extensive evidence on the impact of air pollution exposure. Section 2 focuses on clinical outcomes, including a comparison of health impacts across various settings, while Section 3 reviews the expanding evidence on non-health impacts. We conclude with final remarks in Section 4.

1 Sources

Much of the literature on the detrimental effects of air pollution focuses on urban environments in developed countries, where industrial activities and mobile emissions are significant contributors. For example, in their widely cited study on pollution, health, and human capital, Graff Zivin and Neidell (2013) note that "*a considerable amount of pollution can be traced to industrial processes, electricity generation, and the transportation sector*" (Graff Zivin and Neidell (2013), p.

692).

However, environmental degradation extends beyond industrialization and urbanization. Some forms of pollution predate modern industry. For instance, Africa is a major source of desert dust emissions, with strong winds lifting vast amounts of dust from arid soils into the atmosphere (Dai et al., 2022). The continent also contributes approximately one-third of the world's biomass burning aerosol particles, primarily due to agricultural practices (Bauer et al., 2019). Controlled burns have historically played a crucial role in agriculture (Rangel and Vogl, 2019) and remain prevalent, particularly in various parts of the developing world.

Additionally, the use of solid fuels and kerosene for cooking and heating is more common in developing countries, especially in rural areas. These fuels are often the most affordable option compared to cleaner alternatives. The resultant household air pollution is substantial, and according to the WHO, it accounted for the loss of an estimated 86 million healthy life years in 2019, with women in low- and middle-income countries bearing the largest burden.

In this section, we explore key sources of air pollution that are particularly relevant to the Global South, focusing on IAP and biomass burning. While urbanization and its impact on outdoor air pollution in developing cities are significant, we do not delve deeply into this topic in this section. For a comprehensive examination of urban pollution in the developing world, see Kahn et al. (2021).

1.1 Indoor Sources

Given that people worldwide spend a substantial amount of time indoors, especially at home, the use of polluting fuels can significantly elevate overall exposure to air pollution. IAP is associated with approximately 1.6 million deaths globally each year (Junaid et al., 2018). The primary sources of global IAP are the combustion of solid fuels for cooking and heating and environmental tobacco smoke (Smith and Mehta, 2003).[3]

In developing countries, household air pollution is often the predominant form of air pollution. However, as households transition to cleaner fuels for cooking and heating, such as natural gas or electricity, the burden of IAP typically decreases. Simultaneously, the impact of ambient air pollution increases and eventually surpasses that of IAP (Cohen et al., 2017; Fisher et al., 2021). Consequently, policies and interventions aimed at reducing IAP are more commonly examined in the

[3] It is important to differentiate between indoor pollution sources and indoor exposure, which can also result from outdoor pollutants infiltrating indoor environments. This section focuses specifically on indoor sources.

Global South context and receive less attention in developed regions such as the U.S. and Europe (Jack et al., 2017).

Despite the ongoing shifts in the burden of disease, IAP remains a critical challenge in regions where solid fuels are prevalent, such as Sub-Saharan Africa (SSA and Latin America. For example, Masekela and Vanker (2020) document the severe effects of IAP on children's lung health in SSA, where reliance on biomass for cooking exposes young children to acute and chronic respiratory conditions. Over 80% of children in the region live in households that use unclean energy sources. This exposure increases not only the incidence of respiratory infections but also the risk of carrying pathogenic bacteria, highlighting the compounded vulnerability of children in these settings. Similarly, Gajate-Garrido (2013) finds that IAP significantly impairs the respiratory health of young boys in Peru, indicating that the health impacts of pollution are closely tied to local environmental and socioeconomic conditions. A randomized controlled trial by Barron and Torero (2017) in El Salvador shows that electrification reduces IAP and improves self-reported health. Specifically, two years after enrolling in a government-led electrification program, $PM_{2.5}$ levels were, on average, 66% lower in treated households.

The disproportionate burden of IAP on women and children underscores the intersection of this pollution source with gender and health inequality. In Mexico, Stabridis and van Gameren (2018) show that women, who typically handle cooking duties, suffer disproportionately from respiratory issues related to firewood use. Such issues not only affect their health but also diminish their labor force participation, linking household energy practices to broader economic outcomes. Building on these findings, Li and Zhou (2023) explore the non-health impacts of IAP by analyzing how the use of polluting cooking fuels affects labor supply in rural China. Their findings reveal a 14.8% decrease in the working hours of rural employees due to reliance on polluting fuels, highlighting the broader economic consequences of fuel choices.

1.2 Biomass Burning

Biomass burning includes the intentional burning of vegetation for purposes such as land clearing and land-use changes, as well as natural fires caused by lightning. Most biomass burning emissions originate in the tropics, notably in the tropical forests of South America and Southeast Asia, as well as the savannas of Africa and South America. In these regions, most biomass burning is human-initiated, primarily for agricultural management or land-use changes (Levine, 2003). The global health impacts of these practices are significant: Pullabhotla et al. (2023) find that each additional square kilometer of burning is associated with a nearly 2% increase in infant mortality in downwind areas. Their analysis, which covers district-level data accounting for 98% of global infant deaths between 2004 and 2018, estimates that exposure to outdoor biomass burning is linked to approximately 130,000 additional infant deaths annually worldwide.

In Africa, despite a recent decline in biomass burning, its health impacts are particularly concerning. Africa is responsible for nearly 75% of global infant deaths attributed to this source (Pullabhotla and Souza, 2022). Bauer et al. (2019) perform an interesting non-economic exercise, simulating atmospheric chemical compositions to estimate mortality rates (MRs) across Africa by different emission sources. Their findings indicate that natural emissions are the largest contributor to pollution, accounting for 67% of these concentrations, followed by industrial emissions (25%) and biomass burning (8%). Notably, biomass burning, particularly in agricultural activities in Central and West Africa, is directly linked to 43,000 premature deaths in Africa.

Separating the effects of agricultural fires from forest fires can be challenging, as these phenomena often occur together, especially at Africa's rainforest frontier or in its grasslands (Rangel and Vogl, 2019). Below, we review studies that differentiate between these events.

1.2.1 Cropland Fires

Cropland fires are a prevalent agricultural practice used for post-harvest fertilization, land management, and pest control (Andreae, 1991). These fires significantly contribute to global carbon emissions, accounting for over 6% of the total, and they severely degrade regional air quality (Xu and You, 2023). Regarding volume, burning crop residues accounts for nearly half of the biomass burned compared to forest fires (Rangel and Vogl, 2019). During peak agricultural fire seasons, these fires can contribute more than half of the particulate pollution in urban areas, such as in India (Pullabhotla and Souza, 2022).

Farmers across the developing world use fires to burn vegetation and clear land for planting (Pullabhotla and Souza, 2022; He et al., 2020). These controlled burns are an integral part of traditional harvesting practices. He et al. (2020) note that effective regulations on straw burning are rare, and the lack of scientific evidence on its health impacts often makes governments hesitant to enforce strict regulations. Enforcement challenges persist; in China, despite legal bans, approximately 31% of maize, wheat, and rice stalks are burned in situ in major agricultural regions (Zivin et al., 2020).

The persistence of these practices is also driven by their importance for agricultural productivity, complicating regulatory efforts. For example, in Brazil's sugar cane industry, burning increases labor productivity (cane cutters), with minimal loss in glucose content (Rangel and Vogl, 2019). Rangel and Vogl (2019) find that fires not associated with significant smoke exposure, where wind direction prevents plumes from reaching populated areas, correlate with improved health outcomes, highlighting the need to differentiate pollution from its economic benefits. However, the economic importance of agricultural fires must be balanced against their costs. For instance, Pullabhotla and Souza (2022) estimate that the increased mortality from hypertension related to agricultural fires in India incurs annual costs of $9 billion. The non-health impacts, such as those on educational outcomes, should also be considered in cost-benefit analyses. Zivin et al. (2020) find that exposure to pollution from these fires substantially reduces test scores and decreases students' chances of being admitted to top-tier universities in China.

1.2.2 Wildfires

Wildfires can occur naturally and benefit ecosystems by renewing nutrients, providing access to sunlight, and controlling pests. Some plant species even rely on fire heat to release their seeds, making wildfires an integral part of specific ecological processes. However, wildfires also pose significant risks to human health and productivity and can lead to deforestation.

The world's "lungs" are in the Global South, encompassing 54% of global forest area.[4] In Africa and South America, 30% of forests are in protected areas, compared to 11% in North and Central America and 6% in Europe (FAO, 2020b). Despite growing global concerns about forest fires, Africa faces the most exposure, accounting for approximately 50% of global exposed person-days from 2000 to 2019, followed by Asia (>25%). Low- and middle-income countries represent over 96% of global exposed person-days and 86% of exposed people, with wildfire $PM_{2.5}$ and ozone concentrations being approximately four times higher than those in high-income countries (Xu et al., 2023).

Climate change is extending fire seasons and increasing dry years, making conditions more favorable for wildfires, especially in already hot tropical regions (Pausas and Keeley, 2021; Barlow et al., 2018). Consequently, forest fires have become more widespread, burning nearly twice as much tree cover as 20 years ago (MacCarthy et al., 2023). From 2004 to 2020, Central and Southern Africa and parts of South America experienced an increase of up to 60 additional days of wildfire exposure annually. These areas are also highly vulnerable and often lack the resources to manage and mitigate these risks (Romanello et al., 2021). Forest fires thus emerge as a major health concern in the studies reviewed in this paper.

[4] The other 20% lies within Russian territory and the remaining 26% in the rest of the world. Own calculation with data from (FAO, 2020a).

Although temperate forest coverage has increased since 1990, tropical deforestation rates have consistently exceeded five million hectares per year (Barlow et al., 2018). In the Brazilian Amazon, the world's largest rainforest, most deforested areas are burned to clear land for cattle ranching, crop cultivation, and mining (Rocha and Sant'Anna, 2022). Small-scale farmers in many low- and middle-income countries traditionally use controlled burning as a cost-effective land-clearing method compared to more expensive alternatives involving heavy machinery. However, this practice has significant health and environmental impacts. Approximately 42% of Brazil's greenhouse gas emissions come from land cover changes, with recent increases in deforestation-related fires and biomass smoke (Silvério et al., 2019). These emissions contribute to rising global temperatures, creating drier, more fire-prone conditions that fuel a cycle of increasing fire frequency and intensity.

Similarly, between 1990 and 2015, Indonesia lost nearly 25% of its forests, primarily due to intentional burning for palm oil and timber plantations. Despite a 1995 ban on land-clearing fires, the practice persists, and the scale of these fires has grown (Rosales-Rueda and Triyana, 2019). Studies highlight the substantial short- and long-term health costs of Indonesian wildfires (Rosales-Rueda and Triyana, 2019; Jayachandran, 2009; Sheldon and Sankaran, 2017). Tan-Soo and Pattanayak (2019) conducted a social cost-benefit analysis of oil palm plantations under various land-clearing methods. They found that mechanical clearing methods offer greater social net benefits than burning, underscoring the need for more effective fire bans, improved fire suppression strategies, and moratoriums on oil palm concessions in Indonesia.

2 Health Impacts

2.1 Classical Outcomes: Mortality and Hospitalizations

Recent estimates indicate that outdoor air pollution is the most significant environmental risk factor for mortality worldwide (Cohen et al., 2017). Beyond the immediate and profound consequences of lost lives, mortality is a commonly studied outcome because it is easier to measure than other health and non-health outcomes. However, mortality data are available for 6 out of 10 countries globally, and this availability varies significantly by region. For example, while 98% of deaths are registered in the WHO European region, only 10% are in the African region (WHO, 2021).

In the environmental health literature, global estimates of the pollution burden of disease and life years lost rely on exposure-response relationships primarily derived from studies in high-income, mid-latitude nations. These estimates are then extrapolated to other regions using spatial demographic data. However, these approximations remain unverified across extensive regions of the world, particularly in Africa (Heft-Neal et al., 2018). In this section, we review the growing body of literature in economics examining the causal link between pollution and both morbidity and mortality.

2.1.1 Short-Term Impacts

Air pollution can acutely translate into significant health harms. According to a joint statement by the European Respiratory Society and American Thoracic Society, these harms include cardiovascular and respiratory mortality and morbidity and events such as pneumonia, high blood pressure, decreased lung function, and premature mortality. Pollution exposure has also been associated with premature birth and low birth weight, which can have short-run effects on infant morbidity and mortality and long-run effects on adult outcomes (Kim et al., 2015; Thurston et al., 2017).

Globally, most outdoor air pollution is generated by the combustion of fossil fuels for electricity production, heating, transportation, and industry, causing millions of premature deaths. For instance, using China's coal-fired winter heating systems, Fan et al. (2020) find that turning on a heating system increases the weekly air quality index (AQI) by 36% and causes a 14% increase in the MR. The authors employ a regression discontinuity design based on the exact starting dates of winter heating across different cities. Focusing on straw burning in agriculture, He et al. (2020) utilize satellite data to measure fire intensity and combine this measurement with land use and pollution data to estimate the extent of this practice. They estimate that a 10-$\mu g/m^3$ increase in $PM_{2.5}$ results in a 3.25% increase in mortality.

Also focusing on coal-based pollution, Fan et al. (2023) exploit the implementations of the "Two Control Zones" (TCZs) policy in China, a national program aimed at reducing sulfur dioxide (SO_2) emissions by imposing stringent regulations, mostly on coal-fired power plants and heavy industries. They find that a 1-μg/m^3 reduction in SO_2 concentrations leads to a 0.9% decrease in cardiovascular deaths among people over 60 years and a 1.5% decrease among children under 5. Agnostic to the pollutant driving the results, Tanaka (2015) finds that the infant mortality rate (IMR) fell by 20% in TCZs.

Many studies specifically examine infant mortality due to the increased vulnerability of this age group. For example, Beach and Hanlon (2018) explore the historical impact of coal use on infant mortality in 19th-century Great Britain.

Despite their lack of direct pollution data, they estimate coal use from local industrial activity and use wind patterns for identification. Their findings reveal that a one-standard-deviation (SD) increase in coal use corresponds to a 6.7%-8% increase in infant mortality.

Exploring the same outcome in a contemporary context, Gutierrez (2015) explores the consequences of pollution deterioration induced by the installation of small-scale power plants throughout Mexico. Using monthly data at the municipality level, the author finds that a 1% increase in aerosol optical depth (AOD, a proxy for particulate pollution) causes a 0.58%-0.84% increase in infant deaths due to respiratory diseases. In a related study, Heft-Neal et al. (2018) combine household survey-based information on the location and timing of nearly 1 million births across SSA with satellite-based estimates of exposure to $PM_{2.5}$ to estimate the impact of air quality on IMRs. The authors find that a 10 $\mu g/m^3$ increase in $PM_{2.5}$ concentrations is associated with a 9% increase in infant mortality.

Infant mortality represents only the most visible part of the adverse effects of pollution on this group. Jayachandran (2009) proposes that there are "missing children" due to extreme pollution exposure during infancy and in utero, specifically referring to forest fires in Indonesia. Using satellite aerosol monitoring data, the author demonstrates that particulate matter from fires led to a 1.2% reduction in the size of the exposed birth cohort, an effect primarily driven by prenatal exposure. Although data on infant respiratory morbidity are limited, health at birth is well documented through vital statistics. Rangel and Vogl (2019) utilize data from satellite-based fire detection systems, air monitors, and vital records in Brazil to investigate the impact of in-utero exposure to smoke from sugarcane harvest fires on birth outcomes. By leveraging daily variations in fire location and wind direction, they identify that late-pregnancy exposure to a 1-SD surge in upwind fires per week raises the prevalence of very low birth weight and very preterm births by approximately 0.6 SDs.

Air pollution can increase vulnerability to other diseases, leading to substantial overall increases in mortality when additional threats emerge. This effect was particularly evident during the COVID-19 pandemic. Focusing on four countries in Latin America highly affected by the pandemic (Brazil, Chile, Colombia, and Mexico), Bonilla et al. (2023) find that an increase in long-term exposure to 1 $\mu g/m^3$ of fine particles is associated with a 2.7% increase in the COVID-19 MR.

In addition to mortality, hospitalizations, especially those related to respiratory diseases, constitute an important outcome in this literature. Regarding fossil fuel combustion, a field study conducted by Brooks et al. (2023) in Bangladesh quantifies the contribution of coal-powered brick kilns to $PM_{2.5}$ exposure. As major sources of air pollution, these kilns have proliferated with the country's industrialization. The study finds a positive relationship between brick kiln emissions and various health outcomes, such as child asthma, chronic obstructive pulmonary disease, and general respiratory symptoms.

Focusing on fossil fuel combustion, Rivera et al. (2024) investigate the impact of solar energy on local air quality by examining its effect on coal-fired power generation in northern Chile. They find that a 1-GWh increase in solar-induced coal displacement led to a 2.25% decrease in daily average hospital admissions. This reduction was even more pronounced (16.6%) in the immediate vicinity and downwind of displaced coal-fired plants.

In another study from Chile, Dardati et al. (2024) examine the short-term effects of $PM_{2.5}$ on respiratory emergency room (ER) visits. The authors use wind speed at different altitudes to instrument for $PM_{2.5}$ based on two mechanisms: wind speed at higher altitudes can transport pollutants from distant regions, and a lower vertical velocity variance can lead to pollutant accumulation within the planetary boundary layer. The authors find that a 1-μg$/m^3$ increase in daily $PM_{2.5}$ exposure increases ER visits for respiratory illness by 0.36%. This estimate is remarkably similar to that in Kim (2021), who exploits seasonal variation in pollution and controls for avoidance behavior during environmental alerts in South Korea. Respiratory hospitalizations increase 4% for every 10 μg$/m^3$ of heavy particulate matter (PM_{10}). The findings in these two studies are remarkably larger than those in Rocha and Sant'Anna (2022), who employ an instrumental variable (IV) strategy that exploits wind direction to uncover the effects of fire-related $PM_{2.5}$ pollution on population health in the Brazilian Amazon. They find that a 10-μg$/m^3$ increase in $PM_{2.5}$ entails a 0.9% increase in the monthly hospitalization rate for respiratory conditions, with some non-linearities.

Some studies covered in this section have also explored the geographical and sociodemographic distribution of pollution damages. Fan et al. (2020) find that people in poor and rural regions are especially affected by the rapid deterioration in air quality driven by coal-fueled heating, while Gutierrez (2015) highlights that the effect of pollution is significantly lower in municipalities with a high presence of primary healthcare facilities and is more pronounced in areas where a significant portion of households has low educational attainment.

Magnitude of the effects. Heft-Neal et al. (2018) suggest that updating disease-burden estimates for African countries based on their findings would lead to a doubling of the current global estimates for infant deaths attributable to air pollution. Table 1 underscores this argument by highlighting regional heterogeneities in the impacts covered in this review. The table summarizes the findings from studies measuring the impacts of particulate pollution on classical health outcomes, mortality and hospitalizations, considering both $PM_{2.5}$ and PM_{10}. Notably, while PM_{10} includes $PM_{2.5}$, it also includes larger particles. However, we include it in Table 1 given the scarcity of $PM_{2.5}$-based studies that present comparable results. We include one study from each region of the Global South whenever available.

In Panel a) on infant mortality, Heft-Neal et al. (2018) find a substantial 9.2% increase in the IMR per 10-μg/m^3 increase in $PM_{2.5}$ for SSA. In China, Wang et al. (2023) observe a smaller but significant 1.63% increase in the IMR per 10-μg/m^3 increase in $PM_{2.5}$. For Mexico, Arceo et al. (2016) report a 6.8% increase in the IMR per 10-μg/m^3 increase in PM_{10}. A vast literature has uncovered the significant cultural shift in China around pollution, with China's information system enabling the population to make significant investments in avoidance behavior. Given the more recent nature of these estimates, avoidance could be a relevant driver of the substantial difference between Wang et al. (2023) and the other two studies.

Regarding overall mortality in Panel b), Sankar et al. (2020) show a 3.3% increase in the MR per 10-μg/m^3 increase in $PM_{2.5}$ in India, a point estimate that is remarkably similar to that found by He et al. (2020) for China. In contrast, He et al. (2016) observe an 8.3%–9.6% increase in the MR per 10 μg/m^3 of PM_{10} in China, a higher impact likely due to their focus on urban air pollution in Beijing, where air quality improvements were implemented in densely populated areas, potentially leading to larger estimates. In Panel c) on respiratory morbidity, Dardati et al. (2024) find a 3.6% surge in respiratory ER visits per 10 μg/m^3 $PM_{2.5}$ in Chile. Kim (2021) reports a 4% increase in respiratory hospitalizations per 10-μg/m^3 increase in PM_{10} in South Korea. The lower impact observed by Rocha and Sant'Anna (2022) in Brazil (0.9% increase in respiratory hospitalizations per 10 μg/m^3 $PM_{2.5}$) is attributable to the study's focus on the Amazon region, where the population has less access to health facilities, potentially affecting the observed magnitude of healthcare demand impacts.

Study	Region	Pollutant	Baseline levels	Impact
Panel a) Infant mortality rate (IMR)				
Heft-Neal et al. (2018)	SSA	$PM_{2.5}$	25.2 $\mu g/m^3$	9.2 % ↑ in IMR per 10 $\mu g/m^3$
Wang et al. (2023)	China	$PM_{2.5}$	36.48 $\mu g/m^3$	1.63 % ↑ in IMR per 10 $\mu g/m^3$
Arceo et al. (2016)	Mexico	PM_{10}	66.94 $\mu g/m^3$	6.8 % ↑ in IMR per 10 $\mu g/m^3$
Panel b) Overall mortality rate (MR)				
Sankar et al. (2020)	India	$PM_{2.5}$	60 $\mu g/m^3$	3.3 % ↑ in MR per 10 $\mu g/m^3$
He et al. (2020)	China	$PM_{2.5}$	49.2 $\mu g/m^3$	3.25 % ↑ in MR per 10 $\mu g/m^3$
He et al. (2016)	China	PM_{10}	97.99 $\mu g/m^3$	8.3-9.6 % ↑ in MR per 10 $\mu g/m^3$
Panel c) Respiratory morbidity				
Dardati et al. (2024)	Chile	$PM_{2.5}$	26.32 $\mu g/m^3$	3.6 % ↑ in resp. ER visits per 10 $\mu g/m^3$
Kim (2021)	South Korea	PM_{10}	49.23 $\mu g/m^3$	4 % ↑ in resp. hospitalizations per 10 $\mu g/m^3$
Rocha and Sant'Anna (2022)	Brazil	$PM_{2.5}$	16.1 $\mu g/m^3$	0.9 % ↑ in resp. hospitalizations per 10 $\mu g/m^3$

Table 1: Health impacts of air pollution

2.1.2 Long-Term Impacts

In the public health literature, repeated exposure to particle pollution has been associated with chronic inflammation, an increased risk of cardiovascular and respiratory morbidity and mortality, and an increased likelihood of other chronic diseases such as cancer, neuro-degenerative diseases, and thrombosis (Kim et al., 2015; Thurston et al., 2017). Despite this evidence, most pollution-health causal research has concentrated on acute impacts.

The potential sorting of poorer households into places with poor air quality represents an important identification challenge for long-run dose-response function estimations. Economic circumstances that are correlated with pollution and have effects on health also hinder rigorous long-run studies. However, studying such effects is crucial for uncovering the cumulative and sometimes irreversible damage caused by prolonged exposure and for identifying pollution-driven poverty traps, which have serious implications for environmental justice (Cain et al., 2023). Such studies also require long panels of granular data on health outcomes and pollution levels, which are often limited in the Global South (Aguilar-Gómez et al., 2024).

One exception to the current paucity of research in these countries is the study by Gong et al. (2023), who find a significant impact of long-term (three-year average) exposure to $PM_{2.5}$ on mortality in China. To address endogeneity, they leverage the global economic recession in the late 2000s, which produced a demand-driven decrease in pollution by manufacturing firms. They find that a 10-μg/m^3 increase in long-term $PM_{2.5}$ exposure led to a 20% increase in all-cause mortality.

Chen et al. (2013) and Ebenstein et al. (2017) study China's Huai River policy, which provided free coal-based winter heating to cities north of the Huai River but not in the south. This policy greatly increased total suspended particulates (TSP) air pollution. Chen et al. (2013) find that long-term exposure to an additional 10-μg/m^3 increase in TSP is associated with a reduction in life expectancy at birth of approximately 0.3 years. These estimates translate into residents of northern China losing more than 2.5 billion life years of life expectancy, mostly driven by an increased incidence of cardiorespiratory mortality. Ebenstein et al. (2017) find that a 10-μg/m^3 increase in PM_{10} reduces life expectancy by 0.64 years, twice the previous estimate. The authors attribute this difference in magnitude to their focus on smaller, more harmful particles (PM_{10} vs. TSP) and their use of more accurate measures of mortality from a more recent time period (2004–2012).

Finally, Rosales-Rueda and Triyana (2019) take the geographical variation of Indonesia's forest fires during the El Niño phenomenon in 1997 as a natural experiment. They exploit the timing of birth relative to the shock and compare affected cohorts (children who were in utero or under two years old during the fires) with comparable groups. They find that affected cohorts have worse health outcomes but do not suffer significant effects in cognitive function relative to children not exposed to the shock.

2.2 New Outcomes in the Pollution-Health Literature

The scope of adverse health effects from pollution has broadened over time. Initially focusing on respiratory system impacts, the scientific consensus now includes morbidity and mortality driven by cardiovascular effects as well (Brook et al., 2010). A leading cause of cardiovascular disease is hypertension, which has also been recently linked to pollution. Pullabhotla and Souza (2022) match blood pressure readings from nearly 784,000 individuals across India with satellite data on 1.2 million agricultural fires, wind direction realizations, and local ambient air pollution. They find that the incidence of hypertension increases by 1.8% for every 1-SD increase in the number of upwind fires observed one day before the blood pressure readings. This broadened understanding is extremely relevant: high blood pressure is the leading risk factor for noncommunicable disease mortality in developed and developing countries.

In recent decades, accumulating evidence has shown that pollution also affects the central nervous system, reproduction and development, cancer, certain mental health indicators, and certain metabolic outcomes including diabetes (Thurston et al., 2017). In alignment with this expansion, economic studies have identified adverse health impacts of pollution on previously unexpected outcomes such as obesity, stunting, and even mental health issues, including insomnia.

Deschenes et al. (2020) use the China Health and Nutrition Survey to document significant positive effects of air pollution, instrumented by thermal inversions, on body weight. Specifically, a 1-μg/m^3 (1.54%) increase in average $PM_{2.5}$ concentrations in the past 12 months increases people's body mass index by 0.27%. The authors find suggestive evidence not only for the anticipated behavioral mechanisms (avoidance leading to less physical activity) but also for less sleep and more fat intake. The sleep mechanism finds empirical support in other papers exploring the effects of pollution on new outcomes. Heyes and Zhu (2019) link daily air pollution exposure with sleep loss in a panel of Chinese cities. To measure sleeplessness, the authors track social media posts mentioning insomnia and exploit plausibly exogenous variations in pollution in upwind cities. Their results indicate that a 1-SD increase in $PM_{2.5}$ causes a 12.8% increase in sleeplessness. As discussed by the authors, their results offer a candidate mechanism supporting recent research that links daily air quality to other diminished non-health outcomes including workplace productivity, cognitive performance, school absenteeism, and traffic accidents.

A similar discussion is offered by Balakrishnan and Tsaneva (2023). They find that higher annual average air pollution increases the likelihood of reporting feeling sad, experiencing cognitive difficulties, and feeling unable to control and cope with important things in life. Potential mechanisms include worse health and sleeping difficulties. However, the public health literature currently lacks a thorough understanding of the biological mechanisms linking air pollution to mental health issues (Thurston et al., 2017).

In India, Balietti et al. (2022) exploit wind direction to show that a 1-SD increase in $PM_{2.5}$ accounts for 5 and 2.4 percentage points of stunting and severe stunting rates, respectively. Stunting has critical long-term health and economic consequences; through its impact on stunting, pollution exacerbates the height premium in earnings, with girls being more adversely affected than boys. In a study less causally focused but encompassing 32 African countries, deSouza et al. (2022) find a clear association between prenatal and early-life exposure to $PM_{2.5}$ and stunting. They link nationally representative anthropometric data from 58 demographic and health surveys to build a sample of 264,207 children under 5 with the average in-utero $PM_{2.5}$ concentrations derived from satellite imagery. The magnitude of their point estimate, i.e., a 1.6% increase in stunting per 10-$\mu g/m^3$ increase in $PM_{2.5}$, is not too far from that of Balietti et al. (2022) despite the different regions studied and approaches used.

Datt et al. (2023) examine the impact of $PM_{2.5}$ driven by the increase in coal–fired power units on the anaemic status of children and women in India. They draw on the public health literature to elucidate the mechanisms underlying this relationship. In children, such pollution impairs red blood cell production by inhibiting key enzymes, damaging cell membranes, and disrupting cell metabolism, ultimately reducing cell survival. In adults, evidence suggests that $PM_{2.5}$ lowers hemoglobin levels and promotes inflammation, which hampers iron absorption by the body (Honda et al., 2017).

3 Non-Health Impacts

Exposure to air pollution can have a wide range of impacts on various outcomes beyond health, including economic productivity, cognitive and educational performance, and overall life satisfaction and well-being.[5] In this section, we review the literature exploring these non-health impairments due to pollution exposure. While many of these impacts may arise through health-related channels, we address them separately from the health section, as they do not necessarily manifest

[5]For a theoretical representation and scientific background of such non-health consequences, see Aguilar-Gomez et al. (2022).

as symptoms or biomarkers and, instead, correspond to consequences for economic outcomes.

3.1 Educational Outcomes

Since the foundational framework of Currie and Neidell (2005), numerous studies have explored the broader effects of air pollution on human capital and educational outcomes. One significant area of focus relates to the cognitive efforts associated with educational achievements, including cognitive performance on high-stakes tests. The mechanisms include inflammation and oxidative stress in the brain. Psychologically, air pollution can lead to fatigue, discomfort, and disrupted sleep patterns, which are all cognitive abilities essential for test-taking.

Ebenstein et al. (2016) represent a pioneering effort to provide causal estimates of air pollution's impact on students' cognitive performance in the Global South. This study examines the short-term exposure to $PM_{2.5}$ during a series of national college qualifying exams. The authors leverage variations across multiple exams taken by the same student and find that a 1-SD increase in the $PM_{2.5}$-based AQI led to a 3.9%-SD decline in student performance. Similarly, Yao et al. (2023) document a 3.86%-SD reduction in Chinese college students' performance on their College English Test per 1-SD increase in $PM_{2.5}$ exposure during the three-hour exam, while Zivin et al. (2020) show that a 1-SD difference between upwind and downwind agricultural fires in China during the country's nationwide college entrance examination leads to a 1.4%-SD decrease in scores, also affecting the likelihood of getting into top-tier universities.

The aforementioned studies are in contexts with $PM_{2.5}$ concentrations ranging from 20-60 $\mu g/m^3$. Evidence of the immediate impact of $PM_{2.5}$ on student performance is observed globally, even at lower concentration levels. In Brazil, Bedi et al. (2021) focus on a range of domain-specific and sensitive cognitive tests at university, revealing that performance on exams requiring higher mental processes was 17 percentage points lower on days with poor air quality ($PM_{2.5} > 35\ \mu g/m^3$) than on days with acceptable air quality ($PM_{2.5} < 12\ \mu g/m^3$). Similar conclusions were drawn by Carneiro et al. (2021), who examined the performance of college aspirants in Brazil's nationwide university entrance examination. Although their study focused on exposure to PM_{10}, they found that a 10-$\mu g/m^3$ increase in PM_{10} on exam day led to an 8%-SD reduction in student test scores.

These impairments extend beyond immediate effects. For example, the short-term effects of pollution documented by Ebenstein et al. (2016) extend to a reduction in the number of years of college education and a decrease in future monthly salary. Similarly, Zhang et al. (2018) use data from a nationally representative survey of Chinese households to show that a 1-SD increase in China's AQI (based on PM_{10}, nitrogen dioxide (NO_2), and SO_2) over three years prior to the survey led to a 0.108-SD decline in the verbal score of the survey's cognitive module. While the authors control for contemporaneous exposure in their analysis, the cumulative effects were more significant.

While these findings are concerning, the potential long-term consequences of early-life pollution and the associated poverty traps related to human capital costs may be even more significant. For example, Fisher et al. (2021) estimate that $PM_{2.5}$ exposure during early childhood resulted in a loss of 1.96 billion intelligence quotient (IQ) points among African children in 2019. A study by Bharadwaj et al. (2017) on Chile further illustrates these concerns. The authors find that a 1-SD increase in carbon monoxide (CO) exposure during the third trimester of pregnancy is associated with a 0.036-SD decrease in fourth-grade math scores and a 0.042-SD decrease in fourth-grade language scores. These effects remain significant even after controlling for factors such as sorting, time-invariant family characteristics, and avoidance behavior.

Molina (2021) investigates the long-term consequences of fetal exposure to air pollution in Mexico City. Using thermal inversions as a proxy for air pollution levels, the study examines how early-life exposure affects young adults' performance on the Raven's Progressive Matrices test, which measures fluid intelligence. The findings reveal that exposure to poor air quality during thermal inversions is associated with lower Raven's test Z-scores. The study further explores how this cognitive impairment influences educational and labor market outcomes later in life, focusing on gender differences. The results are striking: for women, exposure to pollution during the second trimester of pregnancy is linked to significantly lower high school completion rates and reduced income levels. In contrast, no statistically significant impacts are found for men.

Air pollution can also lead to increased school absenteeism, which further affects test performance by reducing instructional time and creating knowledge gaps. For instance, Balakrishnan and Tsaneva (2021) document declines in reading and math outcomes among children in rural India due to annual exposure to $PM_{2.5}$, as measured by AOD. Their study finds that a 0.01-unit increase in annual AOD was linked to a 6.3% reduction in attendance for grades 1-5 and a 7.2% reduction for grades 6-8. Similarly, Chen et al. (2018) observe that a 10-unit increase in China's AQI led to a 2.31% increase in the daily absence rate, primarily due to respiratory illnesses among children. Furthermore, Liu and Salvo (2018) find that severe $PM_{2.5}$ pollution increased the likelihood of next-day school absences by 0.9 percentage points in China's international schools, translating to a 14% increase relative to the sample average. This effect grows to 18% when high pollution levels persisted for two weeks.

3.2 Labor Supply

Evidence suggests that even moderate levels of air pollution can significantly impact the labor market, operating through mechanisms similar to those affecting school absenteeism. Just as children may miss school due to air pollution-related health problems, workers may also miss work because of illnesses caused by exposure to polluted air.

A compelling example of causal evidence on this effect is provided by Hanna and Oliva (2015), who investigate the closure of a major oil refinery in Mexico City to evaluate the short-term effects of improved air quality on labor supply. Following the refinery's closure and the consequent reduction in SO_2 concentrations, there was a 3.5% increase in weekly work hours within 5 km of the refinery compared to areas farther away. By exploiting wind direction and altitude, the authors pinpoint the impact of reduced air pollution on labor market activities specifically through the health channel, rather than through economic disruptions caused by the refinery's shutdown.

Aragon et al. (2017) report similar findings in Peru: a 10-μg/m^3 increase in $PM_{2.5}$ leads to a reduction of 2 hours worked per week. The impact of moderate pollution levels on hours worked primarily affects households with vulnerable dependents, such as young children and elderly adults. Conversely, when $PM_{2.5}$ concentrations exceed 75 μg/m^3, the impact also affects the broader population.

IAP has been causally linked to reduced labor supply, particularly affecting women and exacerbating their economic challenges. Stabridis and van Gameren (2018) find that IAP, driven by firewood used for cooking, significantly increases the prevalence of cough among women, with no comparable effects observed in men. Similarly, Li and Zhou (2023) examine the impact of cooking fuels on indoor pollution and labor availability in rural China. Their analysis reveals that using firewood or coal reduces weekly working hours for rural employees by 14.8%, with the effect being more pronounced among women, blue-collar workers, and younger individuals. The study also suggests that shifting to cleaner fuels, such as natural gas or electricity, could boost rural labor supply by 3%-5%. These findings indicate that transitioning to cleaner energy sources could substantially improve labor outcomes and reduce economic disparities.

3.3 Productivity

The effects of poor air quality on the labor market extend beyond merely reducing working hours. Similar to its impact on education, air pollution can diminish workers' productivity through cognitive impairment. This impact suggests that the detrimental effects of pollution can also affect productivity on the intensive margin, even when labor supply remains unchanged (Zivin and Neidell, 2012).

A pioneering study exploring the link between pollution exposure and productivity in the developing world is Aragón and Rud (2016). They examine the impact of proximity to large-scale gold mining pollution in Ghana on agricultural workers' productivity. Using satellite imagery, they find that NO_2 concentrations are higher near active mines and decrease with distance. They also show that a 1-SD increase in gold production, used as a proxy for pollution emissions at each mine, is associated with a 10% reduction in productivity in areas within a 20-km radius.

In the manufacturing sector, He et al. (2019) analyze high-frequency output records per worker to investigate how daily fluctuations are influenced by $PM_{2.5}$ and SO_2. While they find no immediate impact of short-term variations in $PM_{2.5}$, they find that a 10-μg/m^3 increase in $PM_{2.5}$ levels over a 25-day period results in a 0.5%-2% reduction in average daily output. These findings are consistent with Fu et al. (2021), who also study the impact of particulate matter concentrations on manufacturing productivity in China but use monthly variations in $PM_{2.5}$. They estimate a productivity elasticity with respect to $PM_{2.5}$ of -0.44. Similar findings regarding the impact of $PM_{2.5}$ are reported by Chang et al. (2019) for the productivity of Chinese workers in the service sector, by Li et al. (2020) for the timing and accuracy of forecast analyses in China, and by Soppelsa et al. (2021) for firm productivity in Africa.

Cognitive impairments can impact creative thinking, memory, and concentration, which are all crucial for fostering innovation. Additionally, factors such as anxiety and depression, which are linked to air pollution exposure, may further inhibit innovative thinking. Cui et al. (2023) use over 12 million records of patent applications in China to document the causal effect of $PM_{2.5}$ on innovation. Their findings reveal that a 1-μg/m^3 increase in the annual average $PM_{2.5}$ concentration results in a 1.3% decrease in the number of patent applications. Their analysis suggests that this effect primarily operates through the intensive margin by reducing the productivity of R&D workers.

Could the detrimental effects of air pollution drive talented and skilled workers to relocate away from heavily polluted areas? Xue et al. (2021) examine the impact of air pollution on the accumulation of corporate human capital and overall firm performance. Using the search volume index of Baidu, China's leading search engine, as a proxy for people's job search intentions, they obtain results showing that individuals tend to increase their job searches in areas with lower pollution and reduce their searches in more polluted regions when faced with a deterioration of air quality. Additional analyses show that this pollution-driven brain drain negatively impacts the development of management and employee human capital, ultimately influencing corporate performance.

The findings of Xue et al. (2021) align with the location sorting model, which suggests that individuals choose to live in areas that best match their preferences. When faced with poor air quality, people may first employ defensive strategies to reduce exposure or lessen its negative effects, rather than completely avoiding the risk. However, if these short-term measures are insufficient or become too costly over time, individuals might choose to fully avoid the risk by relocating to areas with better air quality. Below, we examine the literature on the various ways individuals respond to the risks associated with air pollution.

3.4 Avoidance Behavior

Individuals often respond to air pollution by adopting defensive measures to reduce their exposure without necessarily changing their environment. For example, Zhang and Mu (2018) investigate how daily fluctuations in the AQI impact the purchase of particulate-filtering face masks in China. Their study reveals that a 100-point increase in the AQI leads to a 54.5% increase in the purchase of all types of masks and a 70.6% increase in the use of anti-$PM_{2.5}$ masks.

When outdoor activities can be avoided, people may choose to stay indoors to limit their exposure to pollution. For example, Agarwal et al. (2020) examine how air pollution from fires in Indonesia affects household utility consumption in Singapore. They discover that a 100% increase in the pollutant standards index (PSI) leads to a 14.3% increase in water consumption and a 7.9% increase in electricity use, reflecting efforts to manage risk during severe pollution events. Similarly, Fan (2024) notes a decrease in outdoor exercise in China due to poor air quality, with a 10-μg/m^3 increase in $PM_{2.5}$ linked to a 1.43% drop in outdoor exercise likelihood. Days with an AQI above 200 see a 28% reduction in outdoor activity. Additionally, Yi et al. (2020) find that electricity use in China increases significantly on high-pollution days, highlighting a self-reinforcing cycle: higher electricity consumption, aimed at avoiding pollution, leads to increased emissions and worsened air quality due to the energy grid's reliance on polluting sources.

An additional short-term strategy for avoiding poor air quality is taking trips to cleaner areas. This behavior is suggested by Chen et al. (2020), who explore the relationship between air pollution and travel patterns in China. Using records of all flights from Beijing International Airport, they find that a 1-unit difference in the air pollution index (API) between two cities results in a 0.36% increase in the number of passengers traveling to the cleaner city. First-class passengers are more likely to undertake such trips, indicating a preference for avoiding polluted environments among higher-income travelers. Chen et al. (2021) further support the notion that individuals actively seek cleaner environments, even if only temporarily. Using extensive mobile phone data to track subscribers' locations, they find that a 1-unit difference in the AQI between two cities in China increases the short-term population flow towards the less polluted city by approximately 0.15%.

If avoiding outdoor activities due to air pollution becomes increasingly costly over time, individuals may take more permanent measures, such as relocating to neighborhoods or cities with better air quality. Although evidence of this sorting behavior in the Global South remains limited, advances in data availability are fostering a growing body of research in Global South regions.

One effective way to study sorting behavior is by analyzing local housing markets. As individuals seek out areas with better air quality, the demand for housing in these cleaner locations typically increases, leading to higher property prices. Evidence supporting this sorting hypothesis, although indirectly, comes from Rivera (2020), who examines households' willingness to pay (WTP) to avoid living near mining sites in Chile. The author finds that people's WTP increased by 20% for every 1-SD increase in $PM_{2.5}$ and by 8% for every 1-SD increase in SO_2. Additionally, Gonzalez et al. (2013) find an elasticity of housing prices with respect to PM_{10} that ranges between -0.07 and -0.05 for major cities in Mexico, and Tan Soo (2018) report that households in Indonesia are willing to pay approximately \$10.60 for a 1-$\mu g/m^3$ reduction in $PM_{2.5}$. These studies collectively provide strong evidence that individuals in the Global South also engage in sorting based on air quality preferences.

Researchers have investigated how air pollution influences household relocation across larger geographical areas. For example, Chen et al. (2022) show that in China, a 10% increase in county-level air pollution, equivalent to approximately 5.31 $\mu g/m^3$ of $PM_{2.5}$ over a 5-year period, results in a 2.8% decrease in the county's population. These migration patterns are primarily driven by well-educated individuals beginning their professional careers, suggesting a brain drain phenomenon.

While Chen et al. (2022) were among the first to rigorously link air pollution to migration patterns, the connection had been previously suggested by Qin and Zhu (2018). This earlier study explored the immediate impact of air pollution on migration interest in China by analyzing an emigration sentiment index derived from daily Baidu searches related to moving abroad. They found that a 100-point increase in the AQI from the previous day led to an approximately 2.5% increase in the current search index, with a more pronounced effect during days of severe pollution, underscoring the presence of non-linear dynamics.

Building on this research, Liu and Yu (2020) provide further insight by examining how air pollution influences migrants' decisions to settle in new cities within China. Their research reveals that a 100-point increase in the AQI decreases the likelihood of migrants choosing to remain in their destination city by 15.1%. This study adds a valuable dimension to the discussion of the relationship between air pollution and long-term settlement decisions.

3.5 New Outcomes in the Pollution-Non-Health Literature

The growing body of evidence on air pollution's harmful effects on human behavior and performance has expanded significantly in recent years. In this section, we examine recent research that explores new dimensions of this impact, moving beyond more conventional effects to reveal broader, more diverse consequences.

3.5.1 Well-Being and Social Capital

The impacts of air pollution on human well-being and family life can be significant and far-reaching. For example, an increased frequency of illnesses in children or declines in academic performance can elevate stress levels and diminish overall family quality of life. Additionally, rising healthcare costs due to exposure to poor air quality further exacerbate this stress. Xia et al. (2022) highlight significant increases in healthcare visits and medical expenses associated with even minor increases in $PM_{2.5}$ in Beijing, and similar challenges are likely to be experienced in other cities in the Global South. These financial and emotional pressures can severely strain family dynamics and overall well-being.

A compelling example is provided by Sanduijav et al. (2021), who explore the link between particulate matter concentrations and self-reported life satisfaction in Ulaanbaatar, Mongolia. Their findings show that a 10-μg/m^3 increase in PM_{10} correlates with a 0.017-point decrease in life satisfaction, equivalent to a 0.24% reduction in the average satisfaction score. During the study period, the average $PM_{2.5}$ concentrations in Ulaanbaatar reached 126 μg/m^3 and 276 μg/m^3 during the winter. This seasonal spike is largely due to residents burning coal in traditional iron stoves for heating and cooking, which significantly impacts their quality of life.

Air pollution affects not only life satisfaction but also mood and behavior through neurotransmitter dysregulation caused by inflammation in the central nervous system (Felger and Lotrich, 2013). Agarwal et al. (2021) show that transboundary air pollution from Indonesian forest fires leads to a 5.2% drop in consumer satisfaction in Singapore, as reflected in online reviews, largely due to mood changes rather than service quality. Similarly, Dong et al. (2021) find that air pollution during investment analysts' site visits in China negatively affects earnings forecasts, linking this effect to mood and pessimism driven by poor air quality.

Since high trust levels are closely linked to individuals' well-being (Diener and Seligman, 2004), people with high life satisfaction often also have greater trust in others and institutions (Lount Jr, 2010). For example, Yao et al. (2022) find that a 1-$\mu g/m^3$ increase in $PM_{2.5}$ results in a 4.1% reduction in trust in local governments in China, equivalent to a 1-SD change. They suggest that this drop in trust is mainly due to reduced life satisfaction from prolonged exposure to fine particulate matter. Other aspects of social capital may also be eroded. Analyzing daily variations in air pollution in China and using thermal inversions as an instrument, Li and Meng (2023) demonstrate that short-term fluctuations in air quality are associated with an increased likelihood of social conflicts in the workplace.

In response to impacts on mood, stress, and overall well-being, organizations might adjust their compensation strategies to retain and motivate employees. Supporting evidence is provided by Wang et al. (2021), who show that air pollution in China leads to enhanced employment benefits. Their results indicate that in response to poor air quality, companies offer improved monetary compensation, better employee safety measures, and enhanced career training opportunities. The authors suggest that concerns over potential brain drain, particularly among highly skilled workers, and heightened public awareness may drive these adjustments.

In light of the challenges posed by worsening air pollution, could there be a growing sense of hope or positive change, akin to what sometimes follows economic downturns or natural disasters? Chew et al. (2021) offer an affirmative answer. Their findings reveal that significant increments in $PM_{2.5}$ concentrations lead to a 2.9%-5.1% increase in lottery sales in China. This result suggests that individuals may seek out uplifting activities, such as buying lottery tickets, in response to the adversity created by poor air quality.

3.5.2 Risky Behavior and Crime

Recent economic research is increasingly examining how air pollution impacts cognitive functions that extend beyond academic or task performance and that relate to an increased propensity for risky behavior. Neuroscience research identifies two primary pathways through which air pollution might induce these effects (Block and Calderón-Garcidueñas, 2009). First, ultra-fine particulate matter may penetrate the brain, disrupting neural functions. Second, as mentioned above, air pollution can trigger neuroinflammatory responses, affecting the central nervous system and influencing mood and behavior by activating stress pathways (Miller et al., 2009). This evidence suggests that air pollution could contribute to higher-risk behaviors, including criminal activity, as shown by studies from the U.S. (Jones, 2022; Herrnstadt et al., 2021; Burkhardt et al., 2019) and London Bondy et al. (2020).

In the Global South, the relationship between air pollution and crime presents a more nuanced picture. Batkeyev and DeRemer (2023) find a positive short-term correlation between air pollution and property crime in Almaty, Kazakhstan's largest city, but not between air pollution and violent crime. Conversely, Han et al. (2023) report a positive relationship between air pollution and daily crime rates in China, particularly for violent crimes, with a highly non-linear response indicating a stronger reaction to higher pollution levels.

Although these two studies highlight different types of crime, they both suggest that air pollution can induce aggressive behavior. However, Singh and Visaria (2021) present a contrasting finding in Bihar, India, where marginal increases in daily $PM_{2.5}$ actually reduce the number of complaints received by police stations. Similarly, Zarate-Barrera (2021) finds that while crime rates in Mexico City, particularly violent crimes, are positively correlated with air pollution up to an AQI of 120, further increases in air pollution decrease crime rates. This result suggests an inverted U-shaped relationship between air pollution and aggressive behavior.

What explains the radically different findings regarding the impact of air pollution on crime in Kazakhstan, China, India, and Mexico? Bracketing institutional, cultural, and methodological differences that might contribute to these divergent results, we note that the studies vary significantly in their average daily $PM_{2.5}$ levels. Specifically, Singh and Visaria (2021) examine an unusually high average daily $PM_{2.5}$ level of 150.355 $\mu g/m^3$, while Batkeyev and DeRemer (2023) and Han et al. (2023) analyze daily averages of 89.71 $\mu g/m^3$ and 55.43 $\mu g/m^3$, respectively.

Additionally, the mechanisms through which air pollution affects crime may differ, reflecting variations in pollution salience and regulatory policies across countries. Batkeyev and DeRemer (2023) propose that increased property crime linked to air pollution may arise from heightened impatience and a tendency to discount future consequences. In contrast, Han et al. (2023) attribute the effects to the increased salience of pollution, which can influence mood and negative emotions. This view is further supported by Zarate-Barrera (2021), who finds a positive correlation between air pollution and negative sentiment but note that avoidance behavior becomes more pronounced at higher pollution levels, leading to the inverted U-shaped relationship. In India, Singh and Visaria (2021) suggest that the negative relationship between air pollution and crime may be due to people staying indoors to avoid poor air quality, thus reducing opportunities for criminal activity.

3.5.3 Cognitive Bias and Decision-Making

One reason people might engage in risky behaviors is errors in judgment and decision-making, often resulting from systematic deviations from rational thinking known as cognitive biases. Could air pollution also influence how individuals make judgments and decisions? The following studies unanimously suggest that air pollution does indeed affect cognitive biases.

Chang et al. (2018) find that daily variations in air pollution significantly influence the purchase and cancellation of health insurance in China. Although one would expect that daily changes in air pollution should not affect rational choices regarding health insurance (since the value of an insurance policy is based on infrequent and uniform premiums across cities, as well as future illness probabilities), the study reveals otherwise. Specifically, a 1-SD increase in daily $PM_{2.5}$, as measured by the AQI, leads to a 7.2% increase in the number of insurance contracts sold on the same day. Conversely, a similar increase in air pollution during the cooling-off period results in a 4% increase in the rate of insurance contract cancellations. The authors suggest that these findings are likely due to intertemporal behavioral biases, where short-term air quality changes affect decision-making beyond rational expectations.

Similar conclusions are offered by Huang et al. (2020) and Li et al. (2021), who explore the relationship between air pollution and investors' stock-trading behavior and performance in China. Both studies suggest that air pollution causally influences cognitive biases in financial markets, particularly through the disposition effect, i.e., the tendency to sell winning assets while retaining losing assets, thus realizing gains instead of losses.

4 Final Remarks

The diverse range of studies reviewed demonstrates that researchers worldwide have successfully produced high-quality, credible evidence on the impacts of air pollution, even in contexts with limited resources, few pollution monitoring stations, and challenges in data accessibility. While there is some imbalance in the volume of research across different developing nations, which must be addressed, this review shows that substantial and reliable evidence has been collected across all regions of the Global South.

Nevertheless, several research challenges remain. The studies reviewed indicate that the mechanisms underlying some key findings are still poorly understood and require further investigation. For instance, it remains unclear whether the documented negative effects of air pollution on non-health outcomes are a direct consequence of its health impact or whether they represent distinct dimensions of its influence. Additionally, few studies have explored the dose-response relationship and potential non-linear effects of pollution. In contexts with exceptionally high pollution levels, addressing these possibilities becomes crucial.

Despite the myriad outcomes affected by air pollution and documented in this review, several important areas for future research remain. First, many of these impacts are likely to be exacerbated by climate change. For instance, colder days or disruptions in electricity services due to severe weather may increase reliance on solid fuels, thereby increasing IAP. Additionally, the frequency of forest fires might rise, further degrading the air quality in the regions where these fires occur. Similarly, reliance on dirty energy grids could lead to increased emissions, particularly if people stay indoors during extreme weather events, which can worsen air pollution if electricity sources are not clean.

A detailed examination of which populations are most affected by air pollution is another important area for future research. Many studies covered in this review examine differential impacts by gender and age. However, environmental justice research in the Global South remains scare. Understanding the specific vulnerabilities of different groups can help tailor more effective policies.

In conclusion, the growing body of evidence on the effects of air pollution in the Global South, as detailed in this review, underscores that air pollution has emerged as one of the most pressing environmental threats in Global South regions. This evidence reveals not only severe health impacts but also extensive non-health consequences that affect daily life and societal well-being, with potentially profound implications for economic development.

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