Tuberculosis and climate change

Analytical framework and knowledge gaps

World Health Organization

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Executive summary

Human health is deeply interconnected with climate change and the health of our planet. Rising temperatures, extreme weather events, air pollution and habitat destruction not only threaten ecosystems but also exacerbate health challenges, particularly in communities that are already facing socioeconomic and health-care inequities. Tuberculosis (TB) is one of the leading causes of death from an infectious agent globally. Every year, at least 10 million people fall ill with TB, and more than a million die from the disease. Between 2000 and 2023, TB treatment and antiretroviral therapy for TB/HIV co-infection saved 79 million lives globally. Progress toward ending TB is, however, increasingly at risk due to the compounded impact of inadequate and inequitable health care, pandemics, conflicts, climate change and disasters.

Approximately 3.6 billion people, predominantly in Africa and South-East Asia, live in areas that are highly vulnerable to climate change and also bear a disproportionately high burden of TB. Climate change is postulated to pose significant barriers to ending TB through many interconnected pathways, which demand an urgent, evidence-based, coordinated response. To strengthen understanding of the impact of climate change on TB, WHO commissioned a literature review and convened a multistakeholder consultation to assess the evidence. They identified pathways linking TB and climate change and also critical knowledge gaps to guide future studies. The present report has three purposes:

- first, to raise awareness of the many ways in which climate change can impact the TB epidemic, with a focus on priority pathways such as food and water insecurity, population displacement and disruptions to health systems;
- secondly, to advance research at the intersection of TB and climate change by identifying questions that enhance understanding of climate-related TB risk factors, including by modelling the impacts on health and economies, and to explore adaptation strategies to strengthen the resilience of communities and TB services; and,
- thirdly, to promote integration of the TB response with work on climate change adaptation, mitigation and resilience in a comprehensive framework combining health solutions with social support systems. This will require securing adequate, sustainable investments, strengthening resilient health-care infrastructure, extending social protection measures and fostering cross-sector collaboration to enhance long-term preparedness.

By identifying TB as a climate-sensitive disease, this report calls for the integration of TB response into national, regional and global climate response strategies, particularly in regions with a high burden of TB. It stresses the importance of prioritizing investment in both ending TB and building resilience to climate change to ensure that health systems are prepared for the evolving challenges of the climate crisis and global health threats. Failure to act will not only stall progress in ending TB but will also exacerbate global health inequities and social disparities.

1. Background

About tuberculosis

Tuberculosis (TB) is a preventable and curable disease; yet, more than 10 million people fall ill from TB annually and more than one million die from the disease. TB is the leading cause of death among people living with HIV, a major driver of antimicrobial resistance and a global health security threat *(1)*. Ending the global TB epidemic by 2030 is the goal adopted by all United Nations Member States in the WHO End TB Strategy *(2)*. Achieving this goal requires universal, sustained access to care, including in humanitarian emergencies, and a multisectoral approach that addresses both health and social determinants of the disease, such as poverty, undernutrition, HIV, smoking, diabetes and mental health. This approach should be delivered in integrated, people-centred care for all people at risk of TB or with TB, including migrants, refugees and other displaced populations.

Climate and health

Climate change impacts health in many ways. Its direct effects include more frequent, more intense extreme weather events, such as heatwaves, storms and floods, which lead to injuries, heat-related illnesses and mental health issues. Indirectly, climate change disrupts ecosystems, reducing food and water security, altering disease vector dynamics and damaging infrastructure. These effects increase the risks of disease and injury, increase morbidity and mortality, strain health systems and worsen resource scarcity, poverty and displacement, escalating threats to livelihoods and human rights. Globally, climate change is anticipated to cause 250 000 deaths annually between 2030 and 2050 due to increased instances of malnutrition, malaria, diarrhoea and heat stress alone *(3)*.

The significance of human health in climate change is increasingly recognized. Article 1 of the United Nations Framework Convention on Climate Change defines the adverse effects of climate change as significant harmful impacts on human health, welfare, socio-economic systems

Mother and child waiting for healthcare in rural area. © WHO / Panos Pictures / Saiyna Bashir

and ecosystems *(4)*. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change provides evidence that climate change is accelerating, primarily due to human-produced greenhouse gas emissions *(5)*. The report further warns of increased risks of injury, disease and death resulting from rising temperatures, more frequent and severe wildfires, food and water insecurity, reduced labour productivity and increased spread of food-, water- and vector-borne diseases.

For the first time, health was at the forefront of discussions at the 28th United Nations Climate Change Conference (COP28), an important milestone. The COP28 Presidency, in collaboration with WHO and partners, hosted the inaugural Health Day, with topics such as the evidence linking climate change and human health, the health co-benefits of climate change mitigation, strengthening the climate resilience of health systems, adaptation measures and the intersection of health with relief, recovery and peace. During this event, global leaders endorsed a declaration on the urgency of action to address the health implications of climate change *(6)*. WHO is therefore assisting countries in improving the climate resilience of their health systems and reducing emissions by providing direct support through projects on climate change and health and guidance for better functioning of health systems.

Objective and scope of the report

Context: Many countries with a high TB burden are also highly vulnerable to the adverse impacts of climate change. Climate change exacerbates food and water insecurity, increases displacement and disrupts access to health care, all of which are known risk factors for TB. While the full impact of climate change on TB is still unclear, growing evidence suggests increased risks of infection and disease, particularly among vulnerable populations *(7)*. It should be noted, however, that no comprehensive, consensus-based framework is available in which such evidence is mapped systematically. As a result, the potential effects of climate change on TB are often overlooked in broader discussions of climate and health, and there is no guidance to help countries mitigate its impacts.

Objective: The report is designed as a resource for policymakers, researchers, health and development partners, financing institutions and civil society for use in work to strengthen the global response to TB in the context of climate change. It promotes research to build evidence for policy, advocates for increased financing and highlights the need to recognize TB as a climate-sensitive disease. By providing an evidence-based framework, the report calls for the development of mitigation, adaptation, and resilience strategies to address the growing impact of climate change on TB.

A group of people gather under the sparse shade of a dry tree in an arid, cracked landscape.
© WHO / Billy Miaron

The document first outlines the broad relation between climate change and health, setting the stage for an analytical framework of pathways that link climate change and TB, supported by country examples. It then briefly discusses how climate change affects health systems and supply chains and how those systems in turn contribute to climate change. A learning agenda follows, highlighting gaps in topical knowledge about TB–climate dynamics. Finally, it provides a discussion of current work, including WHO-led initiatives, to address the links between TB and climate change and outlines the next steps to strengthen the global response.

How the report was developed: In 2024, WHO commissioned an analytical framework based on a literature review to explore how climate change influences the TB epidemic and to identify knowledge gaps. WHO subsequently convened a broader consultation with country representatives, experts and civil society to collect feedback on the framework, supporting evidence and knowledge gaps. The present report synthesizes findings from both the literature review and the consultation process, alongside illustrative country case examples. A detailed account of the methodology has been published elsewhere *(8).* In brief, the development process followed these steps:

- Identification of climate-sensitive pathways: A preliminary expert consultation reviewed the broad social and health determinants of TB and identified those most likely to be influenced by climate factors. Determinants were prioritised based on three criteria: (i) sensitivity to climate change; (ii) established or hypothesised impact on TB incidence, transmission, or outcomes; and (iii) the availability of empirical evidence to support meaningful analysis. Based on this assessment, three priority "climate/health links" were selected for further investigation.
- Literature review and knowledge gaps: A narrative literature review was conducted to validate the initial assumptions and further explore the linkages between climate change and TB. For each of the three selected pathways the review assessed the extent to which existing literature provided: (i) a nuanced understanding of how climate factors affect TB determinants and outcomes; and (ii) evidence of effective interventions for mitigation, adaptation, or strengthening programmatic resilience. Where evidence was limited or absent, knowledge gaps were identified to guide future research.
- Multi-stakeholder consultation: The findings from the literature review were synthesized into an analytical framework, along with a preliminary set of knowledge gaps. These were presented at a WHO-convened consultation. Participants reviewed the framework, assessed the strength and relevance of the supporting evidence, and provided input on the proposed knowledge gaps.
- Country examples: To complement the framework and ground the findings in real-world contexts, WHO commissioned the development of country examples that illustrate how climate factors, aligned with the identified climate/health links are already affecting the TB response in high-burden settings. Countries were selected based on their TB burden, vulnerability to climate factors, and the availability of data from national TB programmes. Each example was contributed by local experts and reviewed by the respective National TB Programmes. An important limitation is the inclusion of only two country examples, which limits representativeness. While the examples presented are context-specific and not universally applicable, they offer valuable insights that may inform climate-related TB responses in comparable settings.

2. Climate change and TB – an analytical framework

Approximately 3.6 billion people, primarily in Africa and South-East Asia, live in regions that are highly vulnerable to climate change *(5)*. The same region also bears a disproportionately high burden of TB, accounting for an estimated 69% of global incident cases in 2023 *(1)*. As environmental conditions shift, climate events can influence TB transmission, progression and outcomes along several pathways. This report acknowledges the interconnected, multifaceted nature of the climate–health dynamic in the context of TB (Fig. 1), giving priority to three main pathways along which climate change can significantly impact the TB epidemic: migration and displacement, food and water insecurity, and disruption of health systems (Table 1). The three pathways were selected because of:

- their sensitivity to climate change, i.e. the extent to which they are influenced by its effects;
- their relevance to TB, particularly in relation to indicators and critical social and health determinants in the WHO End TB Strategy; and
- the availability of data and supporting evidence from the literature review.

The three pathways are discussed in detail in the following sections.

Table 1. The three prioritized climate–health links in the context of TB

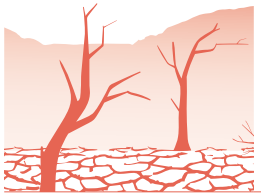
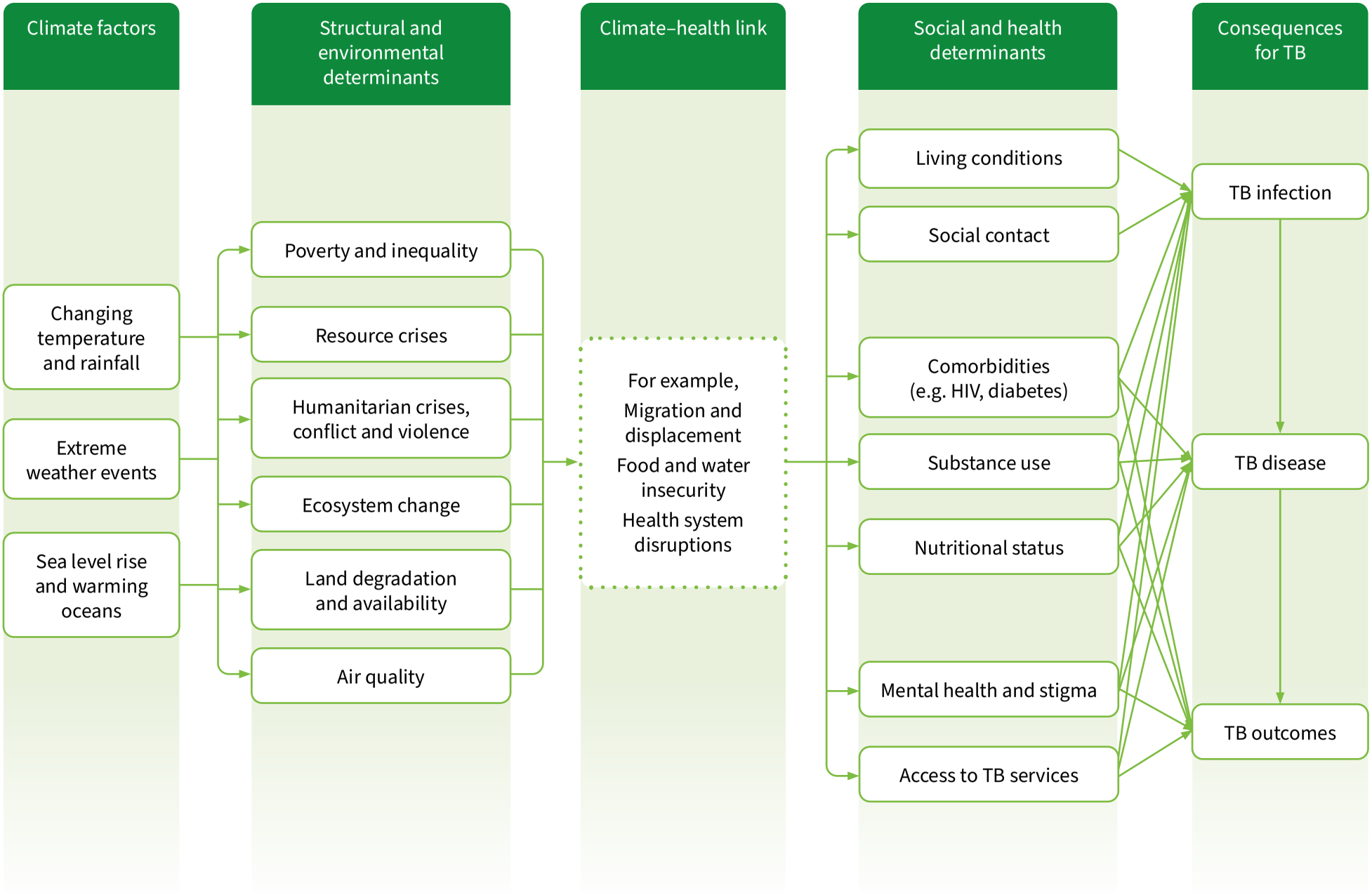
Climate–health link	Postulated primary climate factors	Postulated structural or environmental pathway of influence	Postulated social or health determinant or pathway of influence	Primary postulated consequence for TB
Migration and displacement 	Increasing temperatures, shifting precipitation patterns, extreme weather events, rising sea levels and warming oceans	Poverty and inequality, resource depletion, humanitarian crises, conflict and violence, ecosystem degradation and land loss	Increased human mobility compounded by poor living conditions and disrupted access to health care	Increased TB transmission due to greater exposure and susceptibility
Food and water insecurity 	Increasing temperatures, shifting precipitation patterns, extreme weather events such as drought and rising sea levels	Agricultural instability, reduced food production, economic stress, displacement	Undernutrition	Increased risk of TB disease due to impaired immune function
Health system disruption 	Extreme weather events	Infrastructure damage, service interruptions, supply chain disruptions	Reduced access to TB services	Increased TB transmission and poor health outcomes due to delayed diagnosis and inadequate access to care

Fig. 1. Potential pathways of the impact of climate change on TB



Pathway 1
Migration and displacement

The adverse effects of climate change and environmental degradation are increasingly driving human mobility, particularly in countries with high exposure and low adaptive capacity. The impacts are unequal, most migration and displacement often taking place in low- and middle-income countries. While most displacement associated with disasters is short term and occurs within countries, migration due to slow-onset climate change may be more permanent and possibly on a large scale. In 2023, approximately 20.3 million people were displaced as a result of weather-related hazards *(9)*. By 2050, that number could increase to 216 million people due to slow-onset climate change *(10)*. Women and children are disproportionately affected by displacement and other effects of climate and weather-related disasters *(11)*.

TB and human mobility are closely linked. Refugee and migrant populations often live in conditions that increase the risk of TB transmission and disease, including overcrowding, poorly ventilated housing, poor nutrition and inadequate sanitation. Thus, the rate of TB disease and the prevalence of TB infection are significantly higher among these populations *(12–14)*. Social, cultural and financial barriers, including language differences, legal status and stigma, combined with policy gaps, especially in cross-border protection, increase the vulnerability of these populations. These factors result in delayed, disrupted or inadequate health care, leading to poor health outcomes. Effective public health policies in which TB services and social support are integrated into health services for migrants and displaced people are essential for addressing this challenge. WHO recommends systematic TB screening for migrants and refugees and ensuring that people who test positive are linked to care *(15)*.

A woman and her child sit side by side in a shelter.
© WHO / Panos Pictures / Saiyna Bashir.

Pathway 2
Food and water insecurity

Despite considerable progress made during the past few decades, in 2023 approximately 733 million people faced hunger, equivalent to one in eleven people globally and one in five in Africa *(16)*. If current trends continue, 582 million people will be chronically undernourished by 2030. Exposure to climate risks can affect agricultural production and food availability, with the risk of market disruption, effects on supply and storage systems, as well as increases in agricultural commodity prices, which reduce the accessibility and stability of food supplies. The 2022 Lancet Countdown report *(17)* that extreme heat and droughts associated with climate change led to approximately 98 million more people experiencing moderate to severe food insecurity in 2020 than the 1981–2010 average.

Undernutrition[1] is a key risk factor driving the TB epidemic, as it doubles the risk of developing TB disease. In 2023, undernutrition was linked to nearly one in ten TB cases worldwide, resulting in an estimated 960 000 cases *(1)*. People with undernutrition and TB disease often have more severe illness and an increased risk of mortality. Interventions to address food insecurity, such as distribution of food baskets, reduce the risk of TB *(18)*. In addition, modelling studies suggest that an effective reduction in undernutrition could lead to a significant decrease in the TB burden *(19–21)*. WHO recommends that all individuals diagnosed with TB undergo nutritional assessment and receive appropriate counselling and care throughout their treatment *(15)*.

[1] Defined as a low body mass index in people aged ≥ 5 years.

A lone WHO staff member walks past the carcass of a dead livestock.
© WHO / Billy Miaron

Country example

The impact of drought-induced food insecurity on TB response in Ethiopia

Background

Agriculture is the backbone of Ethiopia's economy, contributing 34% of its gross domestic product (GDP) in 2021 *(22)*. Between 2020 and 2022, East Africa experienced six consecutive failed rainy seasons, leading to severe drought. During this period in Ethiopia, approximately 590 000 people were internally displaced, around 11.9 million people faced crisis, emergency or catastrophic levels of food insecurity, and an estimated 4 million livestock perished *(23)*. This country example describes the impact of the 2020–2022 drought on the TB response in two affected regions: Borena Zone (Oromia region) and Shabelle Zone (Somali region), with different capacities to mitigate the effects of the drought on TB services.

Dry land with visibly sparse and deteriorating vegetation.
© WHO / Andy Craggs

Findings

2020 to early 2023	Borena Zone (Oromia region)	Shabelle Zone (Somali region)
TB service provision	TB services remained operational, supported by outreach campaigns, mobile clinics and screening of internally displaced people. Financial constraints, displacement of health workers and logistical challenges, however, affected service delivery.	TB service provision was impacted as health facilities became overwhelmed, shifting focus to malnutrition and other competing health needs, which led to increase in lost to follow-up in some health facilities.
Mitigation measures	TB services were sustained through community initiatives, mobile TB screening and care in facilities and screening at sites hosting displaced people.	Mobile health teams were pressed to prioritize competing health needs as part of their emergency response efforts.
TB notifications, adherence and outcomes	The number of TB cases reported[2] increased consistently, from 850 in 2020 to 1500 in early 2023. The rate of loss to follow-up quadrupled, before returning to pre-drought levels in 2023. The rates of treatment success decreased slightly but remained relatively stable. Based on perspectives of regional and zonal TB focal persons, the increase in notification was likely related to greater vulnerability, due to undernutrition, displacement and overcrowding in displacement sites, which contributed to increase TB transmission and disease. The continuity of services likely facilitated case reporting, contributing to the recorded increase.	The number of TB cases reported decreased from 870 in 2020 to 470 in early 2023, while the rate of loss to follow-up tripled. The rate of treatment success remained below 50% until 2023. Based on perspectives of regional and zonal TB focal persons, the notification decline, and low treatment success rate were likely related to the aforementioned impact on health service provision and drought induced migration of people with TB and healthcare workers.

Lessons learnt

The country example highlights the potential impact of drought-induced vulnerability on the TB epidemic and response. The comparison between Borena and Shabelle Zones shows how regional adaptation capacity affects the resilience of TB services during climate shocks. In Borena, TB services remained operational, helping to sustain service provision. More cases of TB were identified, despite logistical and financial challenges, and the treatment success rate was relatively stable. In contrast, TB service provision was impacted in Shabelle as health facilities became overwhelmed, shifting focus to malnutrition and other competing health needs.

Way forward

The impact of drought on Ethiopia's TB response highlights the importance of building resilient health-care strategies, particularly in regions facing recurrent climate challenges. Ethiopia's national TB strategic plan includes contingency measures for service delivery during health and humanitarian emergencies. The country example, however, reveals opportunities to further integrate TB services into climate-shock response in all regions. Some of the challenges stem from broader impacts of drought, including disruption of aid delivery and infrastructure. Proactive preparedness can help to strengthen the resilience of TB services in climate shocks, complementing emergency response. This requires well-coordinated governance and a financial framework in which health strategies are integrated with broader climate adaptation, resilience and mitigation initiatives.

[2] Number of people with diagnosed TB who were notified to a public health reporting system

Pathway 3
Health system disruption

The World Meteorological Organization defines extreme weather events as unusual, unpredictably severe or unseasonal weather, such as heavy rainfall and flooding, droughts, heatwaves, tornadoes and tropical cyclones *(24)*. While such events result from natural variations in climate, climate change increases their frequency, intensity, spatial extent, duration and timing. Disasters due to natural hazards are estimated to have affected 93.1 million people in 2023 alone *(25)*. The rising frequency and severity of extreme weather means that hospitals may have to be evacuated, facilities may be damaged or obliged to close, power outages can disrupt medical care, and disrupted transport may limit access to health facilities for both patients and health-care workers. Vulnerable populations who are less capable of withstanding extreme weather events, including children, pregnant women, older adults, individuals with disabilities or pre-existing health conditions and coastal populations, are disproportionately affected.

In the context of TB, extreme climate events can destroy health facilities or disrupt health systems, interrupting screening, diagnosis, treatment, and care. These effects are consequential when the disruptions are prolonged. Without treatment, the death rate from TB disease is high (close to 50%). For example, disruptions to health services during the coronavirus disease 2019 (COVID-19) pandemic and its aftermath are estimated to have led to approximately 700 000 excess TB-related deaths worldwide between 2020 and 2023 (*1*). Effective interventions should include strengthening the resilience of health systems to withstand disruptions, such as improving infrastructure and supply chain management for essential medicines and using innovative service delivery models such as mobile clinics or telemedicine to ensure continuous care.

Country example

Assessing the impact of flooding on TB service delivery in South Africa

A group of people carefully wade through a flooded river, carrying their belongings above the water.

Background

South Africa is a high TB burden country. In recent years, the country has experienced increasingly frequent, more intense flooding, which has further strained its health-care system. This country example from South Africa's Eastern Cape Province summarizes the impact of recent flooding on TB services. On 2 June 2024, severe floods in Nelson Mandela Bay affected over 6000 people, displacing 2500 and damaging critical infrastructure, including health-care facilities. The Letitia Bam Clinic, a 24-h referral facility serving 100 000 people, had to close after a bridge collapsed and cut off access. Other clinics remained operational but with disruptions due to damaged roads and travel barriers.

Findings

Flooding led to sharp decreases in TB service delivery at Letitia Bam Clinic, the frequency of testing decreasing by 97% below expected levels in June and recovering only partly in July (65% below projections). Initiation of TB treatment remained critically low, with a decrease of 79% in June from those in previous years and minimal improvement in July. Other affected clinics also reported lower-than-expected rates of TB testing and treatment initiation. Poisson regression and seasonal autoregressive integrated moving average modelling confirmed that the decreases in TB services were probably due to flooding rather than seasonal fluctuations.

The disruptions in health care were exacerbated by inadequate emergency planning, poor coordination and delayed communication. The closure of the Letitia Bam Clinic led to chaotic staff redistribution, uncoordinated patient referrals and overwhelmed temporary clinics. The temporary facilities faced significant challenges, including inadequate infection control, lack of access to laboratory results and medical records and shortages of medication, particularly for people with TB and HIV. The collapse of electronic record systems disrupted the continuity of care.

Lessons learnt

This study demonstrates the vulnerability of TB health-care services to climate-related disasters and illustrates the importance of climate-resilient health strategies. While the study addressed the short-term implications of extreme climate events on TB services (1 month after the disaster), a prolonged recovery and reconstruction period, often spanning months or years, may have even more profound and lasting consequences.

Way forward

Strengthening climate resilience in health systems requires integration of climate risk assessments into TB service planning, improving emergency preparedness and developing robust strategies for adaptation, resilience and mitigation to ensure continuity of care in high-burden settings. To enhance preparedness, the WHO vulnerability assessment checklist could be used to assess infrastructure, workforce readiness and emergency response capability in the context of South Africa's National Climate Change Response Policy.

Other pathways

The pathways described above are likely the main mechanisms by which climate change influences the TB epidemic, but they are not the only ones. New research adds further plausible pathways that warrant further exploration in additional research. Air pollution, for example, has been linked to increased susceptibility to TB infection and disease progression, as pollutants such as fine particulate matter can impair lung function and weaken immune defences. Meteorological factors, including humidity, temperature fluctuations and seasonal variations, may also influence TB transmission and progression by affecting human susceptibility, pathogen viability and access to health care. Zoonotic TB, caused by *Mycobacterium bovis* and related species, presents another potential pathway, as changes in livestock and wildlife interactions due to environmental changes could lead to increased transmission and human exposure.

- **Air pollution**: Air pollution is an important link between climate and health, with potential implications for respiratory illnesses such as TB *(8)*. Nearly everyone worldwide is exposed to air pollution at levels that exceed recommended health thresholds. Pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}) and sulfur dioxide contribute to major cardiovascular and respiratory diseases. Prolonged exposure can weaken lung defences and alter immune responses, potentially increasing vulnerability to TB infection and progression. There is a well-documented link between household (indoor) air pollution from burning solid fuels and the incidence of TB *(26)*. This disproportionately affects vulnerable populations, particularly those with lower socioeconomic status, increasing their risk of illness and health complications. Climate change may further exacerbate exposure to indoor pollutants as extreme weather and heat drive people indoors, often into poorly ventilated spaces. While some studies suggest a relation between ambient (outdoor) air pollution and increased TB incidence *(27)*, further research should be conducted to identify the specific pathways by which air pollution influences TB risk and outcomes (i.e. whether air pollution increases susceptibility to TB infection, progression to TB disease or both).
- **Meteorological factors**: Some studies on meteorological factors such as temperature, humidity and precipitation suggest that these factors may influence TB incidence; however, the findings are inconsistent *(8)*. For example, some of the studies linked higher temperatures to an increase in the number of TB cases, while others suggest a protective effect. Recent meta-analyses indicate that precipitation and humidity may increase the risk of TB and that wind speed may reduce it. These associations alone do not, however, define causal pathways, and the relations are likely to be context-specific, influenced by, inter alia, regional climate, socioeconomic factors and seasonal patterns.
- **Zoonotic TB**: Although this report addresses mainly TB disease caused by *M. tuberculosis*, other *Mycobacterium* species affect human and animal health. In 2016, zoonotic TB was estimated to have caused 147 000 human cases of illness in humans and 12 500 deaths worldwide *(28)*. Bovine TB, caused by *M. bovis*, affects livestock, wildlife and occasionally humans, resulting in important economic losses and public health challenges. Climate change is postulated to further complicate this dynamic by intensifying factors that promote the spread and severity of bovine TB. Rising temperatures and changing precipitation patterns alter vegetation and water availability, often bringing wildlife and livestock into closer proximity as they compete for scarce resources, thus facilitating the transmission of bovine TB *(29)*. Moreover, extreme weather events such as droughts diminish forage and water supplies, leading to nutritional deficiencies in livestock that weaken their immune systems and heighten their susceptibility to disease *(30)*. Addressing the potential convergence of climate change and bovine TB requires a holistic, multi-sectoral One Health approach, encompassing better livestock nutrition, enhanced disease surveillance systems and policies for managing transboundary animal diseases and human health.

3. Impact of the TB response on climate change

Although not explicitly addressed in the framework, the health system's response to TB may itself contribute to climate change, reinforcing the cycle within broader climate–health dynamics. The health-care sector accounts for approximately 5% of global emissions *(17)*, as many potential sources are embedded in the TB care cascade, including use of energy and materials for diagnostics and treatment, emissions from transport for patient visits and samples, and medical and biological waste *(31)*. For example, Unitaid's 2023 report, From Milligrams to Megatons *(32)*, examines the connection between climate change and health supply chains, describing the environmental impact of 10 health products, including those used for TB (Box 1).

To assist countries in addressing these challenges, WHO has launched an operational framework for building climate-resilient, low-carbon health systems *(33)*. The framework was published before the 28th Conference of the Parties (COP28) of the United Nations Conference on Climate Change. It outlines strategies for countries, particularly low- and middle-income countries, to reduce the risks of climate change, improve their sustainability and strengthen universal health coverage and global health security.

Box 1. In focus: Climate change and health supply chains – Unitaid report

The global health sector saves millions of lives each year by providing essential medicines, diagnostics and prevention tools for diseases such as HIV, TB and malaria. These life-saving interventions, however, also contribute to climate change, as they emit millions of tonnes of carbon annually. While the health consequences of climate change, from air pollution to heat waves, on the spread of infectious diseases are well recognized, the sector's own environmental footprint and vulnerability have not been fully examined. At COP28, the first United Nations climate conference to include a dedicated Health Day, Unitaid issued the results of a study assessing the climate impact and risks of 10 essential health products, which include treatments and diagnostics for HIV, TB and malaria, mosquito nets and oxygen equipment. The study addressed emissions, environmental impacts and climate-related risks throughout each product's lifecycle, from raw material extraction to disposal.

The three main findings were as follows.

First, the 10 health product categories studied, which included the BPaL TB treatment regimen and point-of-care TB assays, generate 3.5 mt of carbon dioxide equivalent (CO_2e) annually, primarily during manufacture, transport and disposal. Greenhouse gas emissions along the value chains of the 10 health products are concentrated mainly upstream, as active pharmaceutical ingredient production and other raw materials account for about 70% of total emissions. Finished product manufacture contributes about 10%, due mainly to electricity consumption, while downstream transport accounts for approximately 1%.

Secondly, beyond carbon emissions, these products have serious environmental consequences. Production of a point-of-care molecular TB test produce 4.3 kg of CO_2e for every kilogram of product produced, plastic consumables being the primary source of emissions. Without sustainable disposal or recycling solutions, most of this waste will end up in unmanaged landfills or be incinerated, further polluting air, soil and water. Improper disposal of active ingredients can also contribute to resistance of bacteria, viruses and parasites to medicines. This is a particular issue for antibiotics, such as the components of the BPaL TB treatment regimen.

Thirdly, climate-related disruptions threaten global health supply chains, putting supply of essential medicines at risk. Important manufacturing sites, for example in India, are increasingly vulnerable to extreme climate events, such as flooding. This underscores the urgent need for low-carbon, climate-resilient strategies to ensure that global health supply chains do not inadvertently exacerbate the climate crisis and vice versa.

A woman healthcare worker sits alone in a hospital waiting area.
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4. Knowledge gaps

Guided by the analytical framework, literature review and expert consultation, the following research topics were identified as priorities for advancing evidence-based strategies and policies on climate change and TB *(8)*. While the list is not exhaustive, addressing these gaps is envisaged to have two main benefits: (i) a more comprehensive, nuanced understanding of the impacts of climate change on TB, and (ii) identification of effective interventions to mitigate the effects, support adaptation and strengthen resilience.

Table 2. Knowledge gaps at the intersection of TB and climate change

	Questions to be addressed
Climate change and TB No evidence exists directly linking climate change to TB. There is an urgent need to generate such evidence, as well as to identify adaptation and mitigation measures for climate-resilient TB services with a minimal environmental footprint.	• Do the effects of climate change on TB differ between high-burden and low-burden settings, including island nations? To what extent could climate change alter the epidemiology and geographical distribution of TB, such as changing low-burden into high-burden countries? • Do the effects of climate change on TB differ by population group (e.g. by gender, age group, socioeconomic status or other vulnerability factors)? • Which other climate–health links (e.g. air pollution, temperature fluctuations) have significant causal effects on TB, beyond those prioritized in this report? • Can climate variables such as air quality and extreme heat be integrated into epidemiological models to predict their impact on TB incidence and transmission? • How does the environmental footprint of TB service provision contribute to climate change, and what sustainable practices can be introduced to minimize the impact? • What adaptation and mitigation measures should be prioritized to build climate-resilient TB services, particularly in resource-constrained settings? • Can models be used to evaluate the effectiveness of climate adaptation and mitigation strategies (e.g. resilient health-care systems) in reducing TB transmission and improving TB outcomes?
Migration and displacement Evidence linking climate change to migration and displacement has focused on population movement in the longer term, particularly due to sea level rise, with less evidence on when climate change is likely to lead to overcrowding, increases in urbanization or poorer living conditions.	• Do current theoretical and operational frameworks adequately capture the complex, multifaceted effects of climate change on migration, including acute displacement and longer population shifts? • How do overcrowding, poor living conditions and increasing urbanization due to climate change affect the risks of TB transmission and health outcomes (including mental health) among displaced populations? • What are the barriers to access to health care for displaced populations affected by climate change, and how do those barriers influence the detection of TB, adherence to treatment and outcomes? • What social and economic determinants related to climate change and displacement (e.g. unemployment, poverty, food insecurity) most significantly influence the TB risk of displaced populations? • How do different migration pathways and experiences (e.g. internally displaced people, asylum seekers, refugees) shape TB transmission dynamics, risk of exposure and health outcomes? • Can the effects of different forms of climate-induced migration and displacement on the risk of TB transmission, particularly in high-burden and climate-vulnerable areas, be quantified? Additional research questions to improve TB prevention and care for migrants, refugees and other displaced populations were published previously *(34)*.

Questions to be addressed	
Food and water insecurity Current evidence on the effect of climate change on food and water insecurity focuses on children and overweight people, due in particular to changing food availability and dietary patterns. Fewer data are available on undernutrition in adults and the effects of extreme weather events and acute nutritional shocks. Evidence for a link between food and water insecurity and TB disease is based on use of body mass index (BMI) as an indicator, with limited data from settings with a high burden of TB, in populations with a particularly high prevalence of severe underweight, for children and adolescents and for other nutritional indicators.	• How do the increasing frequency and severity of extreme weather events and their impacts on food and water insecurity influence susceptibility to TB infection, disease progression and treatment outcomes? What are the most effective forms of nutritional support and anthropometric markers to assess and address TB-related vulnerability in these settings, in both the short and the long term? • How does the association between BMI and TB incidence differ among populations, including children, older adults and individuals with underlying health conditions such as HIV infection, alcohol use disorder or end-stage renal disease? In addition, does the pattern of weight loss (acute versus chronic) or the population-wide distribution of BMI affect TB risk, even in the absence of malnutrition? • Can additional nutritional indicators such as haemoglobin concentration, body composition (by bioelectrical impedance analysis), point-of-care micronutrient testing and measures of dietary diversity and quality provide more precise evidence of vulnerability to TB disease beyond BMI alone? What are the most appropriate nutritional metrics for assessing TB risk in different epidemiological and clinical contexts? • Can models be used to quantify the impact of increased food and water insecurity due to climate change on people vulnerable to TB?
Health system disruption Evidence linking climate change to disruption of health systems has been based on extreme weather events and service delivery and access, with little evidence on more gradual disturbances due to repeated shocks or climate-driven economic slowdown, or the effect on supply chain disruptions, infrastructure, energy and sanitation. Evidence linking health system disruptions to TB outcomes has been based on the COVID-19 pandemic and case notification, with limited evidence from other types of disruption or for a wider range of health and socio-economic outcomes.	• How will climate change impact the essential health service functions (e.g. supply chains, infrastructure, energy availability, health workforce, sanitation) that are critical to an effective TB response? • In addition to extreme weather events, how do factors such as prolonged economic crises or extreme heat contribute to disruption of health systems, and what impact will they have on TB service delivery? • What are the long-term consequences of health system disruptions caused by climate change on TB-related health and social consequences, including the risks of chronic lung damage, acquisition of drug-resistant TB and the financial burden on affected populations? • Can experience from past disruptions of health systems be used to evaluate the impact of acute climate event-induced disruptions (for e.g. service delivery, diagnostics, supply chain and treatment access) on TB outcomes? What policy options can be implemented in high-burden countries to ensure the continuity of TB services during climate-related disasters, and which adaptive measures are effective in minimizing long-term disruptions to service delivery?

5. Addressing TB in the context of climate change

Climate change disproportionately harms the people who are the least responsible for it, such as children, poor communities and future generations, exacerbating inequality and injustice. Nearly half of all TB patients face total costs exceeding 20% of their annual household income because of their illness. If climate change exacerbates the TB epidemic, it will not only worsen health impacts but will also amplify economic burdens, driving vulnerable populations further into poverty. The World Bank estimates that climate shocks could disproportionately affect impoverished populations, potentially pushing an additional 100 million people into extreme poverty by 2030 *(35)*. Addressing this challenge will require a proactive, multisectoral response.

National TB programmes can play an important role by assessing and monitoring the impact of climate change on the TB epidemic and on communities affected by TB and by strengthening resilient response strategies, including in national TB strategic plans. According to the national context, this may entail integrating climate-informed TB surveillance into early warning systems and including TB preparedness planning in broader health and disaster response frameworks. At the same time, national climate response policies in high-burden settings should acknowledge the consequences of climate change on TB to ensure adequate support and protection for those affected by the disease and the health services they rely on. Positioning TB on global climate and health agendas, such as the United Nations Framework Convention on Climate Change, could drive more coordinated multisectoral action.

This will require adequate investment in climate-resilient health systems and mitigation of the health and socioeconomic consequences for vulnerable populations affected by TB. WHO monitors annual financing for TB services from all sources and advocates for greater investment. In 2023, Member States reaffirmed their commitment to mobilizing sufficient, predictable, sustainable funding to ensure universal access to high-quality TB prevention, diagnosis, treatment and care *(36)*. The commitment extends beyond the health sector, as it recognizes the importance of addressing the broader social and economic determinants of the TB epidemic. Actual funding, however, remains alarmingly low, at US$ 5.7 billion in 2023, which is far short of the global targets of at least US$ 22 billion annually by 2027 and US$ 35 billion by 2030 *(1)*. Bridging the gap will require leveraging health and climate finance and other innovative funding mechanisms, with strengthened accountability frameworks to track progress at national and global levels.

Ongoing work of WHO

In the political declaration of the High-level Meeting of the General Assembly on the fight against TB in 2023, Member States requested WHO to continue its global leadership in supporting countries develop a resilient response to TB as a key component of the universal health coverage agenda *(36)*. This includes addressing the drivers and determinants of the epidemic, including in the context of health and humanitarian crises, through multisectoral collaboration, monitoring and reporting. WHO has taken steps to support countries in reducing their vulnerability to TB in the three prioritized pathways.

- **Migration and displacement:** In 2024, WHO issued a report on addressing TB among refugees and migrants *(37)*. The report outlines actions to improve TB care for displaced populations, including mobilizing political leadership to integrate TB work into national health plans, securing adequate resources through sustainable funding and international partnerships, and protecting the legal right of refugees and migrants to equitable, stigma-free care. It also encourages strengthened multisectoral collaboration, enhanced cross-border initiatives, empowering civil society, improving surveillance and data systems,

targeting research to address barriers to access and monitoring progress through global partnerships. WHO previously published an interagency field guide on the provision of TB services for refugees and other populations in humanitarian settings *(38)*.

- **Food and water insecurity**: Since 2013, WHO has been providing guidance on nutritional care for TB patients and those at high-risk of TB, such as household contacts *(15)*. This includes nutritional assessment, counselling, malnutrition management and micronutrient supplementation. In view of emerging evidence on the relation between TB and undernutrition, WHO is updating the guidelines and preparing an operational handbook that includes the latest evidence-based recommendations.
- **Health system disruption:** The milestones and targets for reductions in TB incidence and mortality in the WHO End TB Strategy will be achieved if everyone who develops TB disease can access high-quality treatment, without facing financial hardship. WHO monitors TB treatment coverage as a proxy indicator for access to care, supports countries in implementing national surveys to measure the direct and indirect costs related to TB, and provides guidance to help countries prepare for and respond to health emergencies and disasters *(39)*. Furthermore, WHO advocates for and provides technical guidance for integrating social protection into national TB programmes, in line with the goal of the 2023 United Nations political declaration on TB of ensuring that all individuals with TB have access to a health and social benefits package by 2027 *(36)*.

Achievement of these goals will require strong multisectoral collaboration. Member States have endorsed the WHO TB multisectoral accountability framework *(40,41)*, which advocates for high-level accountability and review mechanisms at national level, with meaningful engagement of people affected by TB. Examples of multisectoral collaboration at the interface of TB and climate change that could be included in such national plans are summarized in Table 3.

Thick smoke billows from a blazing forest as towering flames engulf vegetation.
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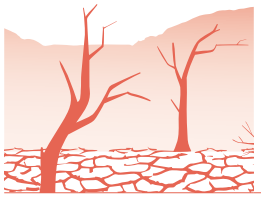
Table 3. Examples of collaboration among sectors in the context of the three climate–health links prioritized for TB

Climate–health pathway	Examples of interventions	Sectors potentially involved in the intervention
Migration and displacement 	• migration-sensitive TB screening programmes • better infection prevention and control in temporary settlements and refugee camps • provision of stable housing and social protection • equitable, stigma-free access to health care, including cross-border TB care	health, migration, human rights, housing or social protection, humanitarian aid, international development
Food and water insecurity 	• climate-resilient agriculture and sustainable water resource management to prevent food and water shortages • strengthening food supply chains to improve accessibility and affordability • integration of nutrition support into TB care • social protection programmes such as food vouchers, cash transfers and community-based nutrition interventions for populations affected by TB	health, agriculture, water and sanitation, social protection, nutrition, humanitarian aid
Health system disruptions 	• strengthening climate-resilient health systems and supply chains • ensuring uninterrupted TB diagnosis, treatment and care through mobile health clinics, telemedicine and digital health solutions • decentralization of TB services to community and primary health care • capacity-building for health-care workers on climate-sensitive disease risks and disaster preparedness	health, environment, emergency response
Cross-cutting planning and coordination in countries most affected by TB: Integration of TB prevention and care into national climate adaptation plans; participation of people affected by TB, particularly those most vulnerable to climate impacts, in policy-making on the response to climate change. Sectors potentially involved: health, climate response, social protection, research and innovation, community engagement, governance		

6. Way forward

As this report shows, climate change is poised to exacerbate the TB epidemic through many pathways, its impact related to the scale of climate hazards, community vulnerability and adaptive capacity. People affected by TB who rely on climate-sensitive livelihoods or who are less capable of withstanding climate shocks, such as migrants, indigenous peoples, food-insecure people, those living with comorbidities such as HIV, children and the elderly, face the greatest risks. Addressing TB in the context of climate change therefore requires a comprehensive, multisectoral approach to tackle its underlying determinants and risk factors while ensuring that mitigation and adaptation prioritize vulnerable populations. Strengthening TB-inclusive universal health coverage and social protection measures must be central to the response. For this to succeed, sustainable, predictable financing is essential, drawing on domestic resources, international funding mechanisms and innovative solutions such as debt-for-health swaps.

Increased investment in research is also critical to advancing understanding of the TB–climate nexus, for testing targeted interventions and strengthening health system resilience. Action should not necessarily be deferred until evidence from research becomes available, particularly when the cost of inaction outweighs the need for certainty due to ethical imperatives, clear risks or the potential for high-impact mitigation. At the same time, the urgency of the climate crisis presents an opportunity to build climate-resilient, environmentally sustainable TB services that can address both health outcomes and broader sustainability goals.

In this context, Member States are encouraged to recognize the links between TB and climate change and ensure that the End TB Strategy is implemented synergistically with other global agreements, including the Future We Want *(42)*, the Paris Agreement *(43)*, the Sendai Framework for Disaster Risk Reduction *(44)*, the 2030 Agenda for Sustainable Development *(45)* and the Global Compacts for Migration and for Refugees *(46,47)*. Recognition of TB as a climate-sensitive disease could be an important first step towards coordinated action and strengthening global commitments to end the epidemic.

A woman stands smiling gently as four young children gather closely around her feet in a rural outdoor setting.
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References

1. Global tuberculosis report 2024. Geneva: World Health Organization; 2024. https://iris.who.int/handle/10665/379339. License: CC BY-NC-SA 3.0 IGO.
2. The End TB strategy. Geneva: World Health Organization; 2015. https://iris.who.int/handle/10665/331326.
3. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva: World Health Organization; 2014. https://iris.who.int/handle/10665/134014.
4. United Nations Framework Convention on Climate Change. New York: United Nations; 1992 (https://unfccc.int/resource/docs/convkp/conveng.pdf).
5. Sixth Assessment Report. Geneva: Intergovernmental Panel on Climate Change; 2021 (https://www.ipcc.ch/assessment-report/ar6/).
6. COP28 UAE Declaration on climate and health. Meeting report. Geneva: World Health Organization; 2023 (https://www.who.int/publications/m/item/cop28-uae-declaration-on-climate-and-health).
7. Maharjan B, Gopali RS, Zhang Y. A scoping review on climate change and tuberculosis. Int J Biometeorol. 2021;65(*10*):1579–95. https:/doi.org/10.1007/s00484-021-02117-w.
8. Saunders MJ, Boccia D, Khan PY, Goscè L, Gasparrini A, Clark RA et al. Climate change and tuberculosis: an analytical framework. medRxiv. 2025. https://doi.org/10.1101/2025.02.18.25322451.
9. 2024 Global Report on Internal Displacement. Geneva: Internal Displacement Monitoring Centre; 2024 (https://www.internal-displacement.org/global-report/grid2024/).
10. Groundswell Part 2: Acting on internal climate migration. Washington DC: World Bank Group; 2021 (https://openknowledge.worldbank.org/entities/publication/2c9150df-52c3-58ed-9075-d78ea56c3267).
11. Gender, displacement and climate change. Geneva: United Nations High Commissioner for Refugees; 2022 (https://www.unhcr.org/sites/default/files/legacy-pdf/5f21565b4.pdf).
12. Kimbrough W, Saliba V, Dahab M, Haskew C, Checchi F. The burden of tuberculosis in crisis-affected populations: a systematic review. Lancet Infect Dis. 2012;12(*12*):950–65. https://doi.org/10.1016/S1473-3099(12)70225-6.
13. Litvinjenko S, Magwood O, Wu S, WeiX. Burden of tuberculosis among vulnerable populations worldwide: an overview of systematic reviews. Lancet Infect Dis. 2023;23(*12*):1395–407. https://doi.org/10.1016/S1473-3099(12)70225-6.
14. Proenca R, Mattos Souza F, Lisboa Bastos M, Caetano R, Ueleres Braga J, Faerstein E et al. Active and latent tuberculosis in refugees and asylum seekers: a systematic review and meta-analysis. BMC Public Health. 2020;20(*1*):838. https://doi.org/10.1186/s12889-020-08907-y.
15. WHO TB Knowledge Sharing Platform (online). Geneva: World Health Organization (https://extranet.who.int/tbknowledge).
16. Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme, World Health Organization. The state of food security and nutrition in the world 2024. Rome: Food and Agriculture Organization of the United Nations; 2024 (https://www.fao.org/publications/fao-flagship-publications/the-state-of-food-security-and-nutrition-in-the-world/en).
17. Romanello M, Di Napoli C, Drummond P, Green C, Kennard H, Lampard P et al. The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. Lancet. 2022;400(*10363*):1619–54. https://doi.org/10.1016/S0140-6736(22)01540-9.

18. Bhargava A, Bhargava M, Meher A, Benedetti A, Velayutham B, Sai Teja G et al. Nutritional supplementation to prevent tuberculosis incidence in household contacts of patients with pulmonary tuberculosis in India (RATIONS): a field-based, open-label, cluster-randomised, controlled trial. Lancet; 2023;402(*10402*):627–40. https://doi.org/10.1016/S0140-6736(23)01231-X.

19. Oxlade O, Huang CC, Murray M. Estimating the impact of reducing under-nutrition on the tuberculosis epidemic in the central eastern states of India: a dynamic modeling study. PLoS One. 2015;10(*6*):e0128187. https://doi.org/10.1371/journal.pone.0128187.

20. McQuaid CF, Clark RA, White RG, Bakker R, Alexander P, Henry R et al. Estimating the epidemiological and economic impact of providing nutritional care for tuberculosis-affected households across India: a modelling study. Lancet Glob Health. 2025;13(*3*):e488–96. https://doi.org/10.1016/S2214-109X(24)00505-9.

21. Mandal S, Bhatia V, Bhargava A, Rijal S, Arinaminpathy N. The potential impact on tuberculosis of interventions to reduce undernutrition in the WHO South-East Asian Region: a modelling analysis. Lancet Reg Health Southeast Asia. 2024;31:100423. https://doi.org/10.1016/j.lansea.2024.100423.

22. Climate risk country profile: Ethiopia. Washington DC: World Bank; 2021 (https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15463A-WB_Ethiopia%20Country%20Profile-WEB.pdf).

23. Horn of Africa drought regional humanitarian overview & call to action (Revised 26 May 2023). New York: United Nations Office for the Coordination of Humanitarian Affairs; 2022 (https://www.unocha.org/publications/report/ethiopia/horn-africa-drought-regional-humanitarian-overview-call-action-revised-26-may-2023).

24. Extreme weather. Geneva: World Meteorological Organization; 2025 (https://wmo.int/topics/extreme-weather).

25. 2023 disasters in numbers: a significant year of disaster impact. Louvain: Centre for Research on the Epidemiology of Disasters; 2024 (https://civil-protection-knowledge-network.europa.eu/media/2023-disasters-numbers-significant-year-disaster-impact#:~:text=Executive%20Summary-,In%202023%2C%20the%20Emergency%20Events%20Database%20(-EM%2DDAT),amounted%20to%20US%24202.7%20billion).

26. Sumpter C, Chandramohan D. Systematic review and meta-analysis of the associations between indoor air pollution and tuberculosis. Trop Med Int Health. 2013;18(*1*):101–8. https://doi.org/10.1111/tmi.12013.

27. Dimala CA, Kadia BM. A systematic review and meta-analysis on the association between ambient air pollution and pulmonary tuberculosis. Sci Rep. 2022;12(*1*):11282. https://doi.org/10.1038/s41598-022-15443-9.

28. Roadmap for zoonotic tuberculosis. Geneva: World Health Organization; 2017. https://iris.who.int/handle/10665/259229.

29. Conteddu K, English HM, Byrne AW, Amin B, Griffin LL, Kaur P et al. A scoping review on bovine tuberculosis highlights the need for novel data streams and analytical approaches to curb zoonotic diseases. Vet Res. 2024;55(*1*):64. https://doi.org/10.1186/s13567-024-01314-w.

30. Nemomsa B, et al. Epidemiology of bovine tuberculosis in Butajira, southern Ethiopia: a cross-sectional abattoir-based study. Afr J Microbiol Res. 2014;8(*33*):3112–7. https://doi.org/10.5897/AJMR2013.6259.

31. Martins MF, Dauphinais MR, Tabackman A, Narasimhan PB, Nielsen MC, Miller NS et al. Clearing the air: microcosting the carbon impact of drug-susceptible pulmonary TB treatment. Int J Tuberc Lung Dis. 2024;28(*10*):488–93. https://doi.org/10.5588/ijtld.24.0157.

32. From milligrams to megatons: a climate and nature assessment of ten key health products. Geneva: Unitaid; 2023 (https://unitaid.org/uploads/Report_From-milligrams-to-megatons_A-climate-and-nature-assessment-of-ten-key-health-products.pdf).

33. Operational framework for building climate resilient and low carbon health systems. Geneva: World Health Organization; 2023. https://iris.who.int/handle/10665/373837. License: CC BY-NC-SA 3.0 IGO.

34. Global research agenda on health, migration and displacement: strengthening research and translating research priorities into policy and practice. Geneva: World Health Organization; 2023. https://iris.who.int/handle/10665/373659. License: CC BY-NC-SA 3.0 IGO.

35. Shock waves: managing the impacts of climate change on poverty. Washington DC: World Bank Group; 2016 (https://openknowledge.worldbank.org/entities/publication/cc42cb9b-3f8e-5bf3-bba3-2cce3b0793ac).

36. Political declaration of the high-level meeting of the General Assembly on the fight against tuberculosis: resolution adopted by the General Assembly. New York: United Nations; 2023 (https://digitallibrary.un.org/record/4025280?ln=en&v=pdf).

37. Innovative solutions for the elimination of tuberculosis among migrants and refugees: report of the 7th edition of the World Innovation Summit for Health. Geneva: World Health Organization; 2024. https://www.who.int/publications/m/item/innovative-solutions-for-the-elimination-of-tuberculosis-among-migrants-and-refugees. Licence: CC BY-NC-SA 3.0 IGO

38. Tuberculosis prevention and care among refugees and other populations in humanitarian settings: an interagency field guide. Geneva: World Health Organization; 2022. https://iris.who.int/handle/10665/352283. License: CC BY-NC-SA 3.0 IGO.

39. Guidance on preparing for national response to health emergencies and disasters. Geneva: World Health Organization; 2021. https://iris.who.int/handle/10665/350838. License: CC BY-NC-SA 3.0 IGO.

40. Multisectoral accountability framework to accelerate progress to end tuberculosis by 2030. Geneva: World Heath Organization; 2019. https://iris.who.int/handle/10665/331934. License: CC BY-NC-SA 3.0 IGO.

41. World Health Assembly, 71. Preparation for a high-level meeting of the General Assembly on ending tuberculosis: report by the Director-General. Geneva: World Health Organization; 2018. https://iris.who.int/handle/10665/276378.

42. The future we want. Outcome document of the United Nations Conference on Sustainable Development (online). New York: United Nations, Sustainable Development Platform (https://sustainabledevelopment.un.org/futurewewant.html).

43. The Paris Agreement. New York: United Nations Framework Convention on Climate Change; 2015 (https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf).

44. Sendai Framework for Disaster Risk Reduction 2015–2030. New York: United Nations Office for Disaster Risk Reduction; 2015 (https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030).

45. Transforming our world: the 2030 Agenda for Sustainable Development. New York: United Nations, Department of Economic and Social Affairs; 2015 (https://sdgs.un.org/2030agenda).

46. Global compact for safe, orderly and regular migration. Geneva: International Organization for Migration; 2018 (https://www.iom.int/global-compact-migration).

47. The global compact on refugees. Geneva: Office of the United Nations High Commissioner for Refugees; 2018 (https://www.unhcr.org/media/global-compact-refugees-booklet).

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