The tuberculogenic environment

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Tuberculosis persists as the world's deadliest infectious disease, despite improved diagnostics and effective treatment. The tuberculogenic environment describes the sum of influences, vulnerabilities, policies, life conditions, and health factors that sustain the tuberculosis pandemic in vulnerable communities. The persistence of these environments is attributable to challenges upstream of the health system, involving sectors such as trade, taxation, finance, agriculture, employment, social services, and education. The availability, affordability, access, and acceptability of safe infrastructure (including housing), nutritious foods, protection against harmful consumption (tobacco, alcohol, sugar, etc), and adequately resourced health services are all linked to tuberculosis risk. Yet people affected by tuberculosis and national tuberculosis control programmes continue to bear almost the sole responsibility for a problem that is largely beyond their control. Reframing tuberculosis through the lens of complex systems science highlights the array of decision makers who, by action or inaction, have a shared responsibility to end tuberculosis as a global pandemic.

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Introducing the tuberculogenic environment

Infection with *Mycobacterium tuberculosis* is a necessary but not sufficient cause of tuberculosis disease. Most people infected with *M tuberculosis* will never develop active disease.[1] The risk of progression to tuberculosis disease varies considerably among individuals and communities, with host and environmental factors partly explaining this heterogeneity. The environment—broadly encompassing the physical, socioeconomic, commercial, political, and health-care milieu—has a particularly important role, as it influences both an individual's risk of *M tuberculosis* exposure and infection, and their vulnerability to subsequent disease progression and onward transmission.[2–4] People with tuberculosis often face vulnerabilities such as inadequate housing or food insecurity, which are beyond their own control, or that of their national tuberculosis programme.[5,6] This lack of control is recognised by WHO and the END TB strategy,[7,8] both of which highlight the need for multi-sectoral engagement to achieve global tuberculosis control.

Key decision makers in government departments such as finance, trade, agriculture, social services, and education, in addition to health, hold important levers of power to drive the structural interventions needed to improve country-level resilience to tuberculosis. Framing tuberculosis as a product of the tuberculogenic environment, using a complex systems approach,[9] extends the social determinants of health framework to identify relevant non-health actors who influence and shape environments that foster tuberculosis. Defining these high-level actors is essential for recognising shared responsibility and delineating the interventions within their sphere of influence. The summative effect of the tuberculogenic environment (figure 1) is that individuals often live, work, and age in environments where they lack the means, knowledge, or agency to protect themselves and their families from tuberculosis.

National tuberculosis programmes have potent biomedical tools to diagnose and treat tuberculosis disease, and drug-susceptible—and, more recently, drug-resistant—*M tuberculosis* infection.[10] However, these tools are inequitably distributed across and within countries[11] and do not directly modify the conditions that sustain *M tuberculosis* transmission and disease vulnerability, such as HIV co-infection, or poor living conditions.[12,13] Tuberculosis recurrence (relapse or reinfection) is common after successful treatment, exceeding 10% in many high-tuberculosis incidence settings.[14,15] Underlying environmental risk factors contribute to this recurrence, as individuals with a history of tuberculosis continue to live within settings that magnify their vulnerability. Some of the most celebrated and durable tuberculosis control campaigns have implemented improvements in community nutrition and living conditions in concert with biomedical interventions.[16] When upstream changes to tuberculogenic environments reduce systemic vulnerabilities and barriers to care, even people who are unreached by tuberculosis services benefit from the trickle-down effects that reduce *M tuberculosis* transmission and vulnerability at the community level. Although the current model of person-centred care is essential for saving lives, reductionist approaches that downplay the complexity of tuberculogenic environments have contributed to missed targets in the effort to end the tuberculosis pandemic.[17] In 20th century Europe, improved nutrition and living conditions preceded major declines in tuberculosis incidence and mortality, in the absence of a protective vaccine or effective antituberculosis medication.[18,19] This outcome focused renewed attention on interventions that benefit vulnerable communities as a whole, such as nutritional supplementation[20] and social protection.[21]

As the value of interventions that target the social determinants of tuberculosis is increasingly appreciated, there is a risk that national tuberculosis programmes will be expected to execute these without the requisite political power or adequate support to implement them effectively. Instituting new recommendations without assigning responsible actors risks over-committing national

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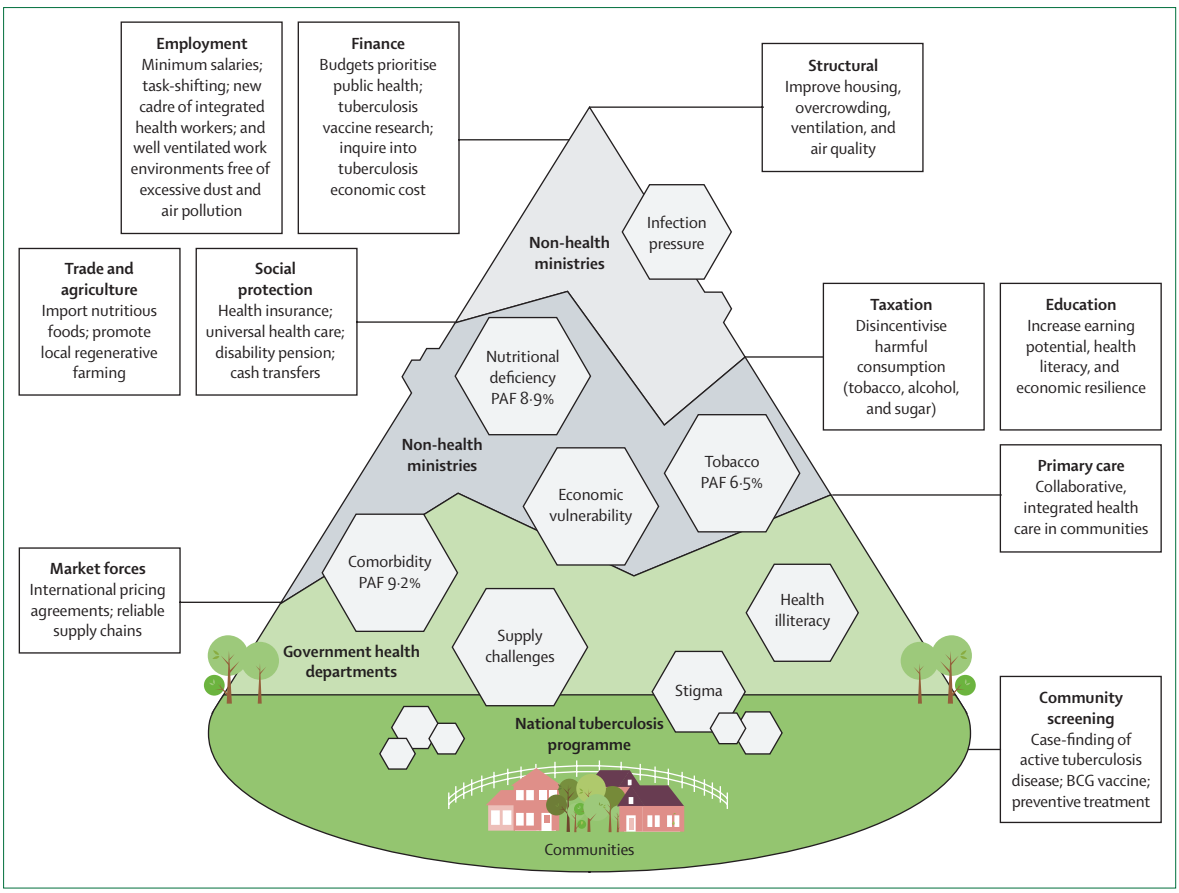

Figure 1: **Factors that create and sustain community vulnerability to tuberculosis**
The factors outlined are not fully comprehensive but show the principle. Uphill (upstream) risk factors are signified by grey rocks falling down the mountain. White flags indicate the actors and actions best placed to mitigate these risk factors. The mountain levels signify the proximity of factors and actors to the community and the ultimate disease outcome. Government health departments, for example, have insufficient power to prevent the accumulation of risk factors uphill of their level of influence. National programmes, signified by the picket fence shielding communities, have a mandate to treat individual tuberculosis patients and to protect communities at the most proximate level. However, the avalanche of uphill risk factors can overwhelm them, to the point where even activities that should, in theory, be within the power of national tuberculosis programmes to execute (such as contact screening and TPT provision) become unmanageable. PAF is calculated from the 2025 World TB report[10] and represents the fraction of all incident tuberculosis in the global population that is attributed to each specific risk factor. PAF=population attributable factor.[10] TPT=tuberculosis preventive treatment.

tuberculosis programmes and detracting from their primary focus on tuberculosis diagnosis and patient care.[22] In other words, we cannot expect national programmes to change tuberculogenic environments without other sectors taking relevant responsibility. Accelerating progress towards tuberculosis elimination requires radical changes to the established network of actors and institutions whose collective actions are essential for reducing tuberculosis incidence. This need for diversified responsibility has been recognised by WHO[8] and their Health in All Policies approach,[23] but is not a trivial task, as tuberculosis is essentially a marker of global inequality, an age-old reality that exposes deep philosophical and political divisions. The challenge lies in developing a coherent framework that brings influential stakeholders to the table and outlines a clear path for action. In this Health Policy, we consider tuberculosis through a complex systems lens:[9] a framework that highlights how structural, social, health, and economic system factors interact to shape tuberculogenic environments, foregrounding questions of responsibility, power relations, and agency to identify the various actions and actors required to help make a positive difference.

M tuberculosis exposure

Individuals in high-incidence settings can experience multiple *M tuberculosis* infections during their lifetime due to sustained high transmission pressure.[24–26] Modelling studies hypothesise that tuberculosis disease might result from multiple *M tuberculosis* infection episodes, each associated with disease progression risk that accumulates over a lifetime (figure 2).[27,28] Poorly ventilated and overcrowded living conditions amplify *M tuberculosis* transmission, yet individuals and government health departments have neither the finances nor the political mandate to improve these

conditions.[5] Importantly, with up to 70% of *M tuberculosis* transmission occurring in the community,[29–32] community members cannot feasibly protect themselves using personal protective measures. The COVID-19 pandemic showed that complex personal protection measures, such as wearing N95 masks and social distancing, are not practical long-term solutions to limit airborne transmission at the community level.[33,34] There is a need to assist infrastructure and planning departments in understanding the value of transmission-proofing at the community level; however, this admittedly poses major challenges in resource-constrained environments.

The frequency with which *M tuberculosis* infection occurs in high-burden settings is difficult to quantify, as there is no accurate measure of reinfection. However, in environments conducive to transmission, such as prisons, mines, or informal drinking places where people with bacteriologically unconfirmed tuberculosis are likely to congregate in poorly ventilated settings, *M tuberculosis* infection could occur multiple times per year.[35,36] Generally, each infection event is associated with a relatively low risk of disease progression, but multiple infections amplify that risk and also increase the likelihood of an infection event coinciding with a period of immune vulnerability.[24,37] The ability of

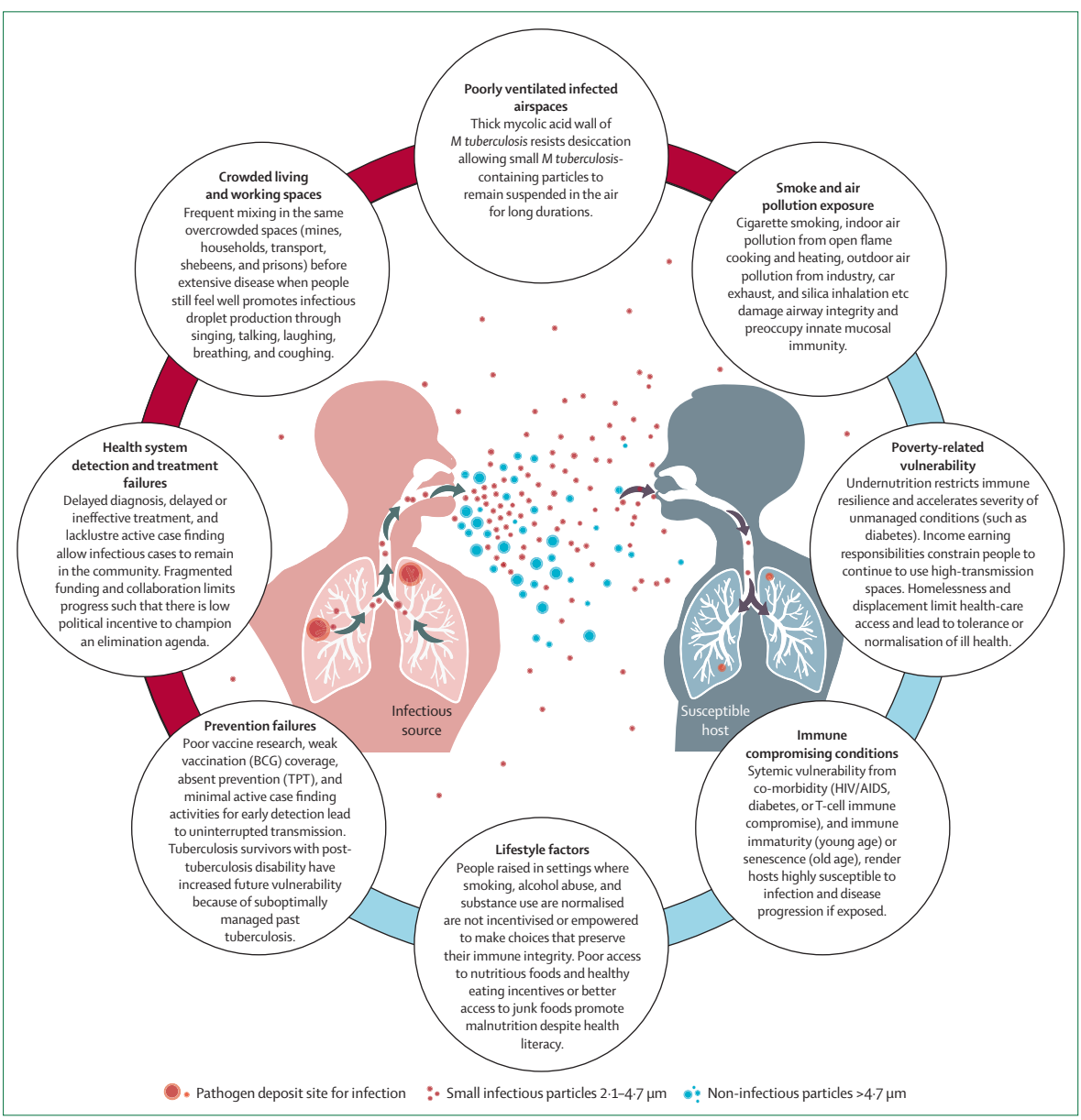

***Figure 2*: The revolving cycle of *Mycobacterium tuberculosis* infection and vulnerability that sustains the global tuberculosis pandemic**
TPT=tuberculosis preventive treatment.

M tuberculosis to remain viable in poorly ventilated airspaces without natural sunlight for long periods of time also increases exposure risk in crowded homes, public transport, churches, clinic waiting rooms, x-ray facilities, etc.[38–42] Meaningful structural interventions[30,43,44] are required to reduce the infection pressure placed on communities by improving the physical environment; however, such actions are beyond the control of affected individuals, national tuberculosis programmes, or even Ministries of Health.

Tuberculosis vulnerability

Most tuberculosis-affected people live in communities with inadequate economic opportunities, restricting their ability to reduce overcrowding, avoid high-risk public transport, or otherwise improve the conditions of poverty in which they live.[45] These individuals are not only more likely to be exposed to *M tuberculosis* but are also vulnerable to comorbidities such as malnutrition, HIV infection, and chronic lung disease.[46] Persistently underfunded health-care systems are ill-equipped to manage this burden of comorbidity and chronic disease, which further exacerbates tuberculosis vulnerability and disease severity.[47,46] Upstream interventions to reduce conditions of poverty would benefit all poverty-associated conditions but require coordinated action among government departments of finance, labour, agriculture, and social services. Such approaches would increase community resilience against tuberculosis and strengthen tuberculosis-specific interventions, such as preventive treatment, active screening, accurate diagnosis, and effective treatment.

Undernutrition and diabetes

Undernutrition is a well recognised and important risk factor for tuberculosis. In India, the provision of food baskets to tuberculosis-affected households provided 39% protection against tuberculosis incidence,[20] informing updated WHO guidelines.[48] However, access to adequate nutrition is constrained by inequitable resource distribution, which is influenced by global trade agreements, national economic, agricultural, and land use policies, and climate change-induced environmental instability,[49–51] which is outside the agency of affected families and even Ministries of Health. Although nutrition literacy is important, the prohibitive costs of fresh foods or unsafe water supply might prevent people from applying this knowledge, fostering feelings of powerlessness and shame in families who cannot provide for the food and health needs of their household.[52,53]

At the same time, large-scale commercial food producers and marketers normalise the consumption of processed calorie-dense micronutrient-poor foods over traditional balanced diets.[54,55] National tuberculosis programmes are not in a position to combat these influential commercial interests and global trade dynamics that contribute to the growing diabetes–tuberculosis syndemic.[55] Although undernutrition remains the leading risk factor for tuberculosis,[10] and high BMI is inversely correlated with tuberculosis risk,[56] increasing rates of diabetes globally could reduce the protective effect of a high BMI,[57,58] requiring nuanced approaches to food interventions that prioritise healthy foods.[57] Effective nutritional support programmes have been instituted for people living with HIV, and there is increasing evidence of their benefit for people with tuberculosis.[59]

Cigarette smoking, silica dust exposure, and air pollution

Although ostensibly within the control of individuals, the prevalence of smoking and air pollution (both indoor and ambient pollution) is often shaped by wider cultural norms, government policy, and industry priorities. The influence of the tobacco industry is particularly destructive in low-income tuberculosis endemic settings, which represent the majority of the global market.[60] Adolescents and young working-age adults are already at high risk of tuberculosis according to global WHO tuberculosis age pyramids.[10] These age groups are highly mobile and highly social, increasing their risk of *M tuberculosis* exposure due to extended time spent in overcrowded transport and congregate settings where other risk factors such as poor ventilation, smoking, and alcohol use overlap.[61] Many also bear income-generation responsibilities and do not have the time to be sick, leading to longer infectious periods in communities before seeking health care, amplifying transmission risk among these age groups.[61] Unfortunately, adolescents in particular are especially vulnerable to lifelong tobacco addictions, amplyfying risk.[62] The detrimental effects of tobacco use account for up to 17% of incident tuberculosis in high-burden settings,[63] with passive smoke exposure particularly harmful to children, increasing their risk of *M tuberculosis* infection and disease.[63] Although tuberculosis programmes have the opportunity to offer smoking cessation support to people with tuberculosis, the most effective strategies to reduce tobacco use require action from non-health ministries. Tobacco taxes are highly effective in driving down tobacco use and have substantial public health benefits;[64] however, this strategy would need to counter strong commercial interests and tobacco lobby groups.

Similarly, occupational exposure to silica dust,[65,66] and exposure to outdoor (including wildfires and agricultural burning practices),[67] and indoor (household solid fuels[68]) air pollution, promotes chronic lung inflammation that increases tuberculosis susceptibility. Reducing these tuberculosis risk factors require action from government departments of industry and the environment to protect air quality.

Alcohol and substance abuse

Excessive alcohol use is associated with increased *M tuberculosis* exposure in poorly ventilated drinking venues, and increased risk of disease progression

mediated through malnutrition and other immune-modulating effects.[69] Similar risks are associated with other substance use disorders, with smoked substances bringing additional lung-health challenges.[70] Mental health syndromes such as depression are recognised tuberculosis comorbidities, and can create environments where the triad of substance use, poor mental health, and tuberculosis are mutually exacerbating.[71] These factors are all heavily influenced by government policy and education, but are fraught with complexity in striking the right balance between regulation feasibility, respect for personal autonomy, improving health literacy, and providing appropriate mental health support.

Financial insecurity

The costs of diagnosis, treatment, and care incurred by tuberculosis-affected households can hamstring the financial solvency of families long beyond disease recovery.[72] This economic precarity is particularly common in low-income settings in Africa and south and southeast Asia where working-age men—often the primary income-earners for a household and working informally in occupations that amplify their vulnerability (such as mining and construction)—are the population who most often fall ill with tuberculosis.[10] Reduced employment opportunity and security after tuberculosis could further exacerbate economic disadvantage.[73] Although global consumption of resources and goods, such as precious metals, gem stones, clothes, and cheap plastics, might create job opportunities, the health consequences are often borne by low-income economies; the demands of high-income countries can drive unsafe working conditions that aggravate tuberculosis disease risk.[74–76] A 2021 estimate predicts a global economic loss of US$17·5 trillion if Sustainable Development Goal tuberculosis targets are not met by 2030.[77] The deleterious economic impact of tuberculosis upon individuals and their families, communities, and countries requires greater awareness and should spur intervention beyond Ministries of Health.

Health system factors

Diagnosis and drug supply challenges

At a minimum, national tuberculosis programmes are expected to ensure access to accurate molecular testing and effective short-course treatments for drug-susceptible and drug-resistant tuberculosis to reduce tuberculosis-related morbidity and mortality. However, these treatments are yet to become universally available in many high-tuberculosis-incidence countries.[10] Aggressive find-and-treat strategies that involve active community-wide case finding have documented epidemiological and transmission effects,[78,79] but such ambitious programmes require major population mobilisation and funding commitment that national tuberculosis programmes might be unable to broker.[80,81] National tuberculosis programmes are also expected to provide tuberculosis preventive treatment (TPT).[80] These important activities reduce secondary cases and help to break the transmission cycle that sustains the pandemic, but are infrequently implemented due to perceived unaffordability, futility in high *M tuberculosis* transmission settings, and reduced priority compared with patient care.[10]

Recent innovations in tuberculosis diagnostics and therapeutics are both timely and welcome; however, some national tuberculosis programmes feel unable to keep pace with the latest advances and rapidly changing guidelines, which can diminish their sense of agency and capacity to make a difference.[82] Prevention activities have also been affected by global BCG vaccine shortages, rifamycin impurities, and corporate pricing disputes.[83–85] Inconsistent global supply of TPT and tuberculin, along with the high costs of WHO-preferred diagnostic tools (such as digital chest x-rays and molecular diagnostics), are destabilising to national tuberculosis programme planning and budgeting.[86,87] The tremendous progress that has been made in this space should be acknowledged, particularly through mechanisms such as the Global Drug Facility and regional drug stockpiles.[88] However, countries and regions with smaller or more remote populations continue to face prohibitive shipping costs and can be deprioritised by suppliers. Concerningly, the global funding apparatus that has enabled past progress is now at risk, due to divestment by the USA—historically the main sponsor of these activities—and overall reduced commitments to global health.[89]

The tuberculogenic environment

The summative effect of the tuberculogenic environment (figure 1) is that individuals must live, work, and age in settings where they have insufficient means, knowledge, and agency to protect themselves and their families against tuberculosis. More than half the global population (3·7 billion people) live in these environments, considering the 63 countries classified by WHO as high tuberculosis-incidence nations (>100 cases per 100 000 people).[90] Even in countries with lower tuberculosis incidence, tuberculogenic environments persist among many Indigenous people,[91] refugees and recent immigrants,[92] people experiencing homelessness,[5] and those in prisons,[93,94] where poor living conditions continue to foster vulnerability to tuberculosis—far beyond that experienced by the wider community. The stigma and feelings of shame associated with tuberculosis, together with catastrophic health-care costs, often have devastating mental health consequences, compounding a sense of powerlessness and social exclusion.[71] Tuberculogenic environments are characterised by high *M tuberculosis* infection pressure, increased disease vulnerability, and socioeconomic precarity, in a context where the most affected parties (communities and national tuberculosis control programmes) do not have meaningful power to effect change.

The tuberculogenic environment as a complex system

As with climate change,[95] the obesogenic environment,[96] and public health in general,[97] tuberculosis can be viewed as a complex system, characterised by features such as feedback, emergence, and adaptation.[97] Applying complex systems thinking might help us identify the full array of actors who (by action or inaction) contribute to the global tuberculosis pandemic. Systems thinking enlarges the sphere of responsibility and identifies key actors of influence, both within and outside health-care systems.[8] As an example, a simplified systems map helps to identify the core domains that contribute to the tuberculogenic environment (appendix).

See Online for appendix

Feedback

There are numerous feedback loops related to *M tuberculosis* transmission and disease vulnerability. For example, biological factors that predispose men to tuberculosis disease[98,99] interact with other vulnerabilities linked to high *M tuberculosis* transmission environments, be they occupational (mining, prisons)[93,100] or social (cigarette smoking and drinking alcohol) factors.[69,101,102] This heavily affects young working-age men who mix in these high-risk spaces and whose financial responsibilities could pressure them to continue working while ill, accelerating disease severity and increasing the likelihood of onward transmission within the community.[72]

Emergence

Emergence is a characteristic of complex systems in which the combination of interactions and influences within the system leads to properties that are far greater than the sum of their individual effects. The effect that tuberculosis disease and disability have on a primary income earner and their family provides an example. These families must simultaneously cope with the incapacity of a household member, dedicate time to caregiving, manage catastrophic costs imposed on the household, face the fear of secondary cases arising among close contacts, take TPT (if offered and available), and cope with the psychosocial burden of community and self-stigma.[103] The multiplication of negative effects, which compromise the wellbeing and financial security of affected families, represents an emergent property that is replicated among hundreds of thousands of poverty-stricken households every year.[104]

Adaptation

Complex systems adapt in ways that can enhance or undermine progress. For example, increased international tuberculosis funding can lead to reduced domestic investment, undermining local ownership of the problem and increasing dependence on external donor support, potentially jeopardising national programme sustainability. In low-income countries with multiple development priorities and poor governance systems, donor aid—meant to complement local tuberculosis funding and to increase local agency—can achieve the exact opposite and shift national budgets to other areas of perceived need or priority, potentially weakening long-term tuberculosis control and reducing optimal integration with other health programmes.

Benefits of applying a complex systems lens to tuberculosis

Reframing tuberculosis as a complex systems issue[3,4] highlights the multiple pathways leading to tuberculosis exposure and vulnerability, which could empower key decision makers to implement policies that address the complex social, political, and commercial determinants sustaining the epidemic in high-incidence settings in a more systematic way. This approach also enables the tuberculosis community to advocate more effectively for upstream, non-biomedical interventions. The adapted Frieden's impact pyramid[105] (figure 3) provides examples of interventions to reduce tuberculosis-related disease and mortality at various levels, viewed through a complex systems lens. Understanding tuberculosis as a disease driven by tuberculogenic environments widens the focus from individualistic biomedical interventions to broader structural changes, recognising that many solutions extend beyond health systems alone.

Broadening responsibility

Given the restricted influence and capacity of national tuberculosis programmes and even ministries of health to change tuberculogenic environments, it is essential to broaden the responsibility for tuberculosis elimination to all relevant political actors. For example, tax departments could raise and allocate tobacco and sugar tax revenues to fund efforts that improve lung health and nutrition.[60] Trade and agriculture departments could prioritise the availability of nutritious food for local populations, and infrastructure and transport departments could enforce building and transport ventilation standards and implement interventions to improve air quality in key public spaces.

National tuberculosis programmes should not be responsible for the provision of all social protection where other actors have responsibility and have failed to supply this. However, evidence-driven food basket provision,[20] cash transfers,[21,106,107] or pulmonary rehabilitation[108] as part of tuberculosis treatment to reduce post-tuberculosis disability is something national programmes can incorporate into care (directly or through partnership), and these interventions can empower vulnerable families to increase their resilience.

Building alliances and empowering communities

Underfunded tuberculosis programmes could form alliances with other health sectors, such as maternal and child health or non-communicable diseases, fostering joint advocacy and shared resources. This integrated

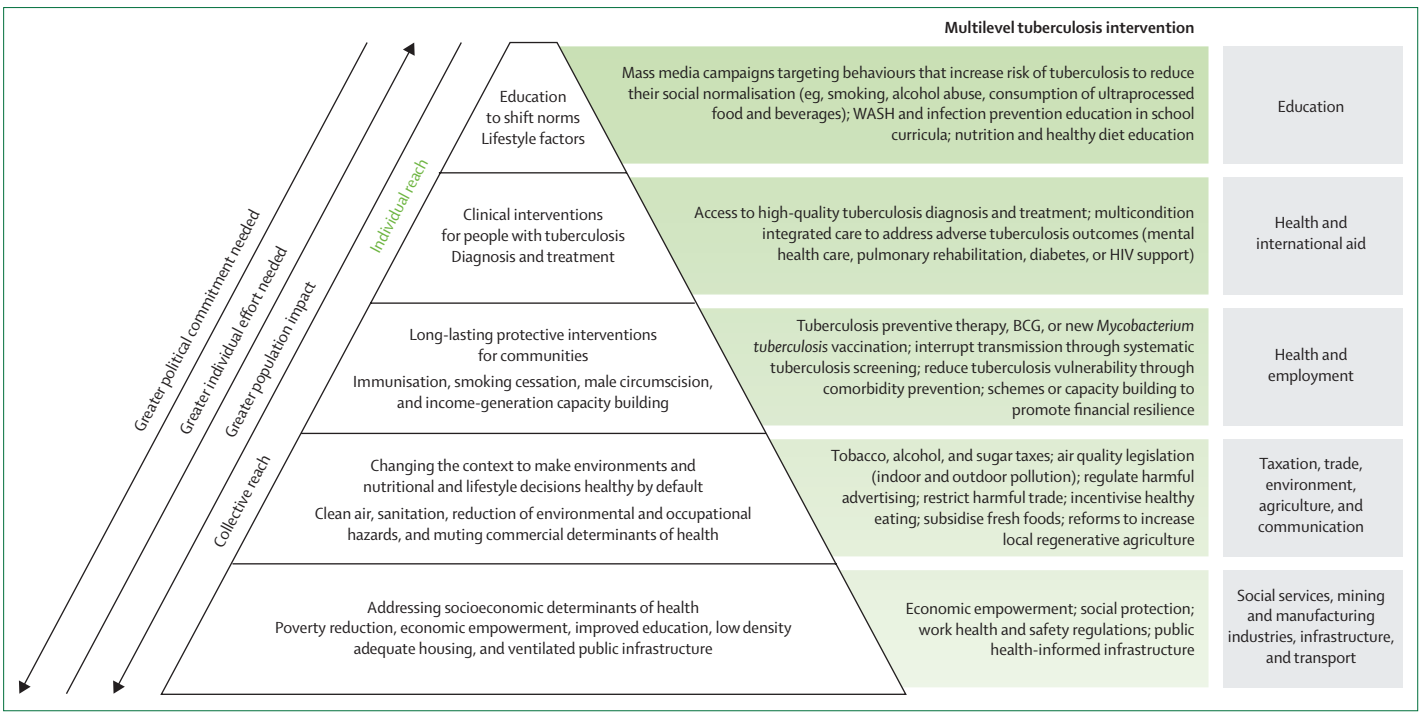

Figure 3: **Applying a systems thinking lens to tuberculosis control**
The adapted Frieden's pyramid[105] shows the hierarchy of tuberculosis public health interventions from interventions with lowest population impact (at the top of the pyramid) to greatest population impact (at the foundations of the pyramid), including examples of interventions (green boxes) and the actors that might be best placed to implement these (grey boxes). WASH=water sanitation and hygiene.

approach could improve efficiency,[109] reduce tuberculosis comorbidity, and galvanise action to tackle multiple overlapping health risks. Multi-disease screening strategies could increase efficiency and population health benefits, while also reducing tuberculosis-related stigma and increasing community engagement. Additionally, reframing the problem of tuberculosis might help diminish stigma by promoting understanding that individuals have minimal real power to mitigate their own risk when they live in tuberculogenic environments.

Illustrative case studies

The prospect of altering the tuberculogenic environment, with all its associated health benefits, is appealing, yet it can seem impossible to implement in practice. Complex systems thinking provides a framework for designing more comprehensive interventions that address the upstream drivers of tuberculogenic environments. We provide several illustrative case studies as examples of such interventions, with shown measurable effects.

Case study 1: historical insights from the Papworth studies in England

Although a systems approach to tuberculosis control might seem new, the concept that social interventions are required to reduce incident tuberculosis in vulnerable communities is not. From 1918 to 1943, a social experiment in England referred people from tuberculosis sanatoria to live in the Papworth Village Settlement, a community where people with tuberculosis had assured employment, health-care access, housing, and adequate nutrition. This was before effective tuberculosis treatment or TPT became available. In families with children under 5 years, tuberculosis incidence before their relocation to Papworth was 1217 per 100 000 person-years. Among children born or moving to Papworth after birth, disease incidence was zero despite child *M tuberculosis* infection estimated at 80%. Later re-analysis indicated that adolescents in households that had been affected by tuberculosis were 15 times less likely to develop disease during their stay in Papworth than in the preceding period.[110]

Case study 2: Brazil's Interministerial Committee for the Elimination of Tuberculosis

In 2023, incumbent leadership in Brazil convened an Interministerial Committee for the Elimination of Tuberculosis and other Socially Determined Diseases.[111] Meeting regularly and funding multiple health initiatives, including conditional cash transfers and improved primary health care, tuberculosis incidence and mortality were substantially reduced in programme recipients.[21,112] The interministerial committee brought together nine ministries under the remit that health is a community right and a state's duty, requiring united public policies across multiple sectors. The positive effects of this collaboration continue to emerge, and this

approach represents a powerful example of how health-minded political leadership can synchronise action to reshape tuberculogenic environments and health equality for communities.

Case study 3: nutrition support to prevent tuberculosis in India

An intervention comprising food baskets and micronutrient supplementation delivered to household contacts of people with tuberculosis reduced their risk of developing disease by 39–48% over a 2-year follow-up period.[20] Although this was a population with a high prevalence of undernutrition (almost one in three tuberculosis household contacts were underweight), only modest weight gain was needed to dramatically improve the resilience of contacts against tuberculosis. In this setting the number needed to treat was 30, requiring basic nutrition support of 30 average households to prevent one new incident case of tuberculosis. Such nutrition support should complement other prevention strategies such as TPT, but this has not been quantified.

Case study 4: Marshall Islands tuberculosis elimination and multimorbidity reduction efforts

In the Marshall Islands, a decade of community-wide tuberculosis active case finding, integrated with care for other community needs, resulted in a substantial and sustained decrease in tuberculosis incidence. Tuberculosis screening was offered as a package of services (incorporating tuberculosis screening and prevention, leprosy screening and prevention, diabetes screening, hypertension screening, and dental care) leading to increased uptake and destigmatisation. Revenue from the country's tobacco tax now supports the continuation of activities and provides a sustainable domestic financial commitment. The success and acceptability of the programme has led to a feeling of national pride and success, resulting in high staff satisfaction and retention, and additional domestic and donor funding.

Case study 5: hyper-tuberculogenic environments within prisons

Prisons in high tuberculosis incidence settings exemplify tuberculogenic environments, with tuberculosis disease rates among incarcerated individuals far exceeding that of the general population.[93] However, structural interventions in prisons can reduce *M tuberculosis* transmission and disease rates, and deserve to be emulated more broadly.[113] Studies in Brazil estimate that improved ventilation in prison cells could reduce *M tuberculosis* transmission by two-thirds.[44,114] Unfortunately, most prisons are constantly overcrowded, and rates of tuberculosis among inmates and spillover effects into communities are increasing, as prisons act as epidemic amplifiers within the community,[115] especially when large numbers of people cycle in and out of prison. As all tuberculogenic environments are, to varying degrees, characterised by diminished agency and liberty to make choices that improve health, the prison example is a fitting reminder of the need to restore some measure of health agency to vulnerable communities.

Conclusion

Infection with *M tuberculosis* is a necessary, but not sufficient, cause of tuberculosis disease; both host and environmental factors contribute to the risk of progression to disease. Reductionist approaches that focus solely on biomedical interventions have had minimal success in decreasing global disease incidence. Acknowledging the full array of interacting factors that fuel the tuberculosis pandemic might appear overwhelming, and has been criticised as impractical or even nihilistic. However, we ignore global inequality and community vulnerability at our peril. Biomedical interventions, such as mass screening, prevention, and vaccination, are key components of the solution; however, they must be partnered with upstream improvements that reduce community vulnerability and promote overall health. Using the tuberculogenic environment and complex systems framework, which recognise the shared responsibility of a broad coalition of stakeholders, is important to guide policies and define concrete actions to strengthen community resilience against this preventable and curable disease.

Contributors

MC and CJC conceptualised and developed the original manuscript with core input during initial drafting by BJM, SB, KK, LM, and SM. MC, CJC, SM, LM, and BJM developed the figures. MB, AB, FU, and LM provided illustrative exemplars and writing support. CJC, SM, TK, CT, KV, ELM, MP, PYK, AB, MB, LM, KK, SB, and BJM provided critical review, editing, and specific input into areas of special expertise.

Declaration of interests

We declare no competing interests.

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