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The HIV/AIDS epidemic in South Africa: Convergence with tuberculosis, socioecological vulnerability, and climate change patterns

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Recent assessment reports suggest that climate change patterns are threatening social and ecological vulnerability and resilience, with the strong potential of negatively affecting human health. Persons living with HIV/AIDS (PLWHA) have weakened physiological responses and are immunologically vulnerable to pathogens and stressors in their environment, putting them at a health disadvantage in climate-based rising temperatures, water scarcity, air pollution, potential water- and vector-borne disease outbreaks, and habitat redistributions. These climatic aberrations may lead to increased surface drying and decreased availability of arable land, threatening food/nutrition security and sanitary water practices. Coupled with HIV/AIDS, climate change threatens ecological biodiversity via a larger-scale socioeconomic recourse to natural resources. Corresponding human and environmental activity shape conditions conducive to exacerbating high rates of HIV/AIDS. In South Africa, this epidemic is forming a 'syndemic' with tuberculosis (TB), which has come to include multidrug-resistant TB (MDR-TB) and extremely drug-resistant TB (XDR-TB) strains. Because of high convergence rates, one epidemic cannot be addressed without understanding the other. Concurrent climate change mitigation and adaptation strategies are becoming increasingly important to curb changes that negatively affect the biospheres on which civilisation is ultimately dependent – from an agricultural, a developmental, and especially a health standpoint. Mitigation strategies such as reducing carbon emissions are essential, but may be only partially effective in slowing the rate of surface warming. However, global climate assessments assert that these are not sufficient to halt climate change patterns. The roles of regionally specific climate research, socioecologically sustainable industrialisation paths for developing countries, and adoption of health system strengthening strategies are therefore vital.

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Similar to an organism's physiological state, Earth as a functioning ecological system is comprised of a diversity of biospheres and operates via a synergy of feedback mechanisms that are sensitive to a variety of perturbations. In the past several decades, the inflated ecological demands of an exploding human population have contributed to global climate change. In conjunction with environmental decay, this threatens the integrity and natural services of ecosystems and the basis for supporting human and all other life on Earth. This scenario comes amid a continued complex global HIV pandemic. The southern African sub-region is most heavily burdened by HIV, with South Africa (SA)'s 2012 infection burden at an estimated 6.4 million persons living with HIV/AIDS (PLWHA) out of a population of 60 million.[1] The majority of PLWHA are in the 15 - 40-year age group, with a prevalence of 40% in some regions. It is therefore important to understand this epidemic in the context of changing ecological systems to allow a full understanding of future dilemmas regarding health and sustainability.

Growing impact of global and regional climate change on ecological vulnerability and resilience

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) and the 2014 US National Climate Assessment maintain that carbon dioxide emissions and other greenhouse gases contribute to increased surface temperatures by trapping thermal energy in the atmosphere.[2,3] Current rates of carbon emissions are projected to increase the global temperature by an average of 2.8 - 5.6°C by 2100. Rising temperatures of this magnitude disrupt environmental balance by leading to melting glaciers, rising sea levels, a higher frequency of heat waves, and a combination of flooding and droughts.

Africa is especially vulnerable to climate change in general because of its high burden of disease, scarcity of fundamental resources such as water, historical socioeconomic disparity, and large population numbers living in poverty. In SA, significant patterns of gradual warming and shifts towards more variable and intense precipitation distribution have been observed in the past 50 years.[4,5] Climate modelling for SA points to the eastern parts of the country becoming wetter, with the western and interior parts becoming drier.[6] By 2100, warming is projected to reach around 3 - 4°C along the SA coast, and 6 - 7°C inland.[6]

With rising temperatures, the possibility of considerable loss of soil moisture owing to the processes of evaporation and transpiration is a potential threat to maintaining the balance of Earth's socioecological system. The IPCC's Fifth Assessment notes that southern Africa will probably experience mean surface temperature increases greater than the projected global average, along with decreased precipitation in some regions and increased evapotranspiration rates.[2] Loss of

soil moisture may exacerbate vulnerability of the region by severely affecting agriculture and water security by limiting crop productivity, reducing run-off, and limiting useable water in an already water-scarce setting.

The human population is on a fast track towards saturating the carrying capacity of the biospheres and possibly compromising 'free' ecological services, which is likely to create further major issues around human and ecological vulnerability and resilience. Vulnerability within this context pertains to a human-environmental system and its sensitivity to physical perturbations such as climate change. Resilience is the ability of such a system to respond to and successfully rebound to retain natural balance, and the capacity to transform and adapt on social and ecological levels.[7,8] HIV introduces a major kink in socioecological resilience as it cripples human capacity to rebound from shock (loss of resilience) in severely affected areas such as southern Africa owing to its rapid transmission and life-long chronic nature.

The HIV-TB 'syndemic': Pathophysiology, screening and treatment efficacy, and the rise of drug-resistant TB in SA

The effects of HIV are felt strongly in poverty-stricken regions with high burdens of disease. The southern African sub-region is vulnerable to infectious diseases including tuberculosis (TB), malaria, cholera, and typhoid, both in the form of outbreaks and routine prevalence. The pathophysiology of HIV allows the virus to directly target components of an individual's adaptive immune system, exhausting and eventually eliminating the infected person's capacity to defend the body from the myriad of pathogens and opportunistic agents in the environment. HIV and TB have a tandem relationship, and HIV is fuelling the growing epidemic of infection with TB in all its forms owing to HIV's ability to devastate the immune system, thus increasing vulnerability to acute TB on exposure or activation of latency. Latent TB is characterised by an asymptomatic, immunologically controlled, low or non-replicating TB infection in the body, which only progresses to an active state when intrinsic immunological surveillance and control are compromised, as in HIV infection.[9] SA currently has one of the highest global rates of active TB infection, with an average incidence of 530 000 in 2012, of which 62.2% were HIV-positive.[10]

Among newly diagnosed HIV patients, basic TB screening tools reveal that more than half have active TB.[9] Less than 1% of the global population resides in SA, but >25% of HIV-TB dual infections occur in this country, leading to what has been referred to as the HIV-TB 'syndemic' or a synergistic dual epidemic.[11] TB treatment requires a long, complex regimen that has many unpleasant side-effects. The current syndemic of HIV-TB in SA is fuelling the proliferation of multidrug-resistant TB (MDR-TB) and newer, extreme drug-resistant TB (XDR-TB) strains. The World Health Organization estimates that 3.6% of new TB cases and 20.2% of previously treated cases are classified as MDR.[10] Potential migration patterns towards cities, in light of increased vulnerability of rural areas to volatile and erratic climatic conditions, may worsen the congested living conditions in already overcrowded informal settlements conducive to effective transmission of the *Mycobacterium* through aerosol droplet formation produced during coughing. Recent developments in TB screening strategies, particularly with the use of GeneXpert to identify active MDR strains by drug-resistant gene sequences, show promise in SA. While more expensive than conventional tests, such screening may be economically efficient in the long term by reducing transmission of drug-resistant strains and identifying MDR cases at diagnosis for highly specialised care.[11]

Antiretroviral (ARV) therapy for those infected with HIV is crucial in controlling further transmission of the disease and preventing opportunistic infection with TB. While there is doubt about the real-world effectiveness of ARV therapy in preventing transmission in HIV-dense locations, a recent study yielded results showing that the proportion of PLWHA receiving ARV therapy is inversely related to the likelihood of an uninfected individual becoming infected.[12] This trend is consistent, even without all infected individuals participating in treatment, indicating tremendous benefits from widespread use of the treatment as an effective form of prevention.

Despite the promising results from relatively low levels of ARV coverage in SA, PLWHA *(i)* mostly begin treatment at $CD4^+$ counts below the national policy for treatment initiation; and *(ii)* do not receive treatment in numbers high enough to effectively combat the socioeconomic repercussions of the HIV epidemic. Consequently, this late start of ARV treatment leads to poor regeneration of the immune system, an ongoing risk of major HIV-associated chronic morbidity over time, and eroding of the initial benefits of therapy.[13] Greater attempts to achieve the goals set by the national policy of initiating treatment at or close to a $CD4^+$ count of 350 cells/μl are necessary to address the HIV epidemic.

Climate change impacts on health and living: Projections for air quality, water security, agriculture and nutrition, and outbreaks of infectious diseases

Climate change poses direct threats to human health by creating weather patterns that reduce air quality owing to hydrocarbon and industrial emissions, decreasing water and food security stemming from variable rainfall along with drought and flooding, and potentially fuelling the spread of diseases such as cholera, malaria, and gastroenteritis in extreme weather patterns and redistribution of natural habitats. While these factors affect all members of communities, PLWHA are particularly susceptible to the potential impacts on health owing to weakened immunity, increased nutritional requirements, overall weakened physiology and generally poverty-induced lack of access to amenities.

Decreased air quality due to high levels of ozone, particulate matter, sulphur oxides, and other air pollutants in the troposphere has a direct negative impact on human health, increasing respiratory and cardiovascular morbidity.[14,15] Another factor that could negatively affect health is extended temperature inversion during winter, when air closer to the earth's surface is cooler than that above it. During this process, pollutants in the air we breathe become trapped and concentrated, until the air becomes mixed because of wind or rain.[16] With rising temperatures and continued emissions, rain will become highly variable throughout SA, with periods of drought intensifying this phenomenon. Inhalation of air pollutants absorbed into the bloodstream is associated with oxidative stress and depressed immunity, compromising lung function and increasing physiological vulnerability to lung infections such as TB and other forms of pneumonia, including increasingly prevalent drug-resistant strains convergent with HIV infection.[9] Mitigation strategies, driven by the National Environmental Management Air Quality Act (Act No. 39 of 2004), currently promote the reduction of air pollutants and carbon emissions and construct air quality and emissions management plans.

Projections for decreased water quality and availability because of climate change directly threaten food security, leading to increased levels of hunger and malnutrition in impoverished conditions.

SA is already a water-scarce country, with nearly all surface water resources utilised.[6] Soil drying coupled with irregular rainfall caused by rising temperatures, particularly in the western regions, severely limits arability of land and agricultural production, potentially crippling subsistence farming communities already prone to geopolitical and economic marginalisation. This population is also the most vulnerable to the HIV epidemic from a health and socioeconomic perspective. Protein energy malnutrition, largely due to poverty, compromises the immune system, and is also prevalent among PLWHA owing to increased nutritional needs, poverty and perturbations in the intestinal absorptive capacity caused by HIV. Furthermore, unsanitary water practices because of a limited useable supply can potentially fuel the spread of water-borne diseases such as cholera, dysentery, and typhoid, which are already associated with flooding and environmental catastrophes that serve as markers of climate change.

While adaptation strategies can improve the resilience of a socioecological system, extreme weather events such as flash flooding, heat waves or cold snaps may give little time for response, posing direct and immediate threats to communities and especially PLWHA.[9] Flooding is as harmful to communities as water shortages, impeding plant growth and production, contaminating drainage basins, and facilitating the spread of water-borne diseases that are detrimental to immunocompromised PLWHA. In the case of cholera, variable rainfall and flooding alter temperature, pH, nutrient concentration and salinity levels of a water body, leading to facilitation of bacterial survival and growth.[17] Heat waves pose another direct threat to health, increasing rates of hyperthermia and dehydration, the latter of which is worsened in PLWHA owing to renal toxicity of both HIV and ARV treatment. At the other end of the extreme weather spectrum, cold snaps are projected to become more frequent, which similarly directly affect health owing to vulnerability to hypothermia, crowding and indoor fuel burning for cooking and warmth, creating intense confined air pollution. As a function of a general regional and global increase in surface temperatures, it is also possible that the distribution of vector-borne diseases such as malaria will expand. A recent cross-continental study found that from 1995 to 2004 temperature increases expanded the spatial distribution of malarial incidence to higher elevations.[18] Malaria is believed to increase the susceptibility to HIV transmission in a community, and for PLWHA there is an increased viral load during acute malaria events.

HIV, TB, and the climate change feedback loop: Need for multiscale adaptation strategies

Paradoxically, the HIV-TB syndemic threatens to exacerbate ecological instability amid climate change. In communities with a high prevalence of HIV, there is a cumulative loss of livelihood and an eroded ability to cope with the physical demands of subsistence farming, which contributes to household vulnerability to hunger, loss of assets and entitlements. This leads to increased dependence on easily accessible natural ecosystem services and potentially unstable farming techniques, accelerating the loss of biodiversity and disrupting ecological resiliency.[19-21]

Household vulnerability may also fuel migration towards urban centres, either for individual survival or remittances to support rural families, which would place strain on ecologically fragile, highly populated informal urban settlements.[9,22] This feedback loop, in turn, would be reinforced by projections of unpredictable weather patterns, more extreme temperatures, and soil drying, which threaten the subsistence farming population with regard to rural sustainability and adaptive capacity. In addition to potentially higher rates of migration towards cities, adding to issues such as increased pollution and decreased air quality as a function of population density, the HIV epidemic most critically diverts national funds from potential mitigation and adaptation strategies towards controlling the epidemic.

In addition to mitigating current climate change by emphasising conservationist practices, adaptation is pivotal in reducing long-term vulnerability and enhancing coping strategies. It is important to note, as has been discussed by Professor Mammo Muchie, that African and other developing countries face the unique challenge of forging new socioecologically sustainable development paths distinct to the historical patterns of industrialisation that have contributed to climate change.[23] Adaptation strategies have been orchestrated throughout the African continent to minimise vulnerability at local, national, and regional scales. The Partners Enhancing Resilience of People Exposed to Risks (Universities) and Research Alliance for Disaster and Risk Reduction located in Stellenbosch have been promoting regionally specific climate research, collaborating inter-regional meetings and mainstreaming adaptation strategies across local communities.[2] Such multifaceted approaches are necessary owing to the unique problems faced at different geopolitical scales, ranging from differential regional to sectorial climate impacts. For example, in addition to the Economic Community of West African States (ECOWAS), East African Community (EAC), and United Nations International Strategy for Disaster Reduction (UNISDR) meetings focusing on regional approaches to risk management, bottom-up efforts, such as training local community farmers in Mozambique in the use of drought-resistant crops to preserve food and nutritional security, also reduce vulnerability.[24]

It is crucial to adopt health system and institutional strengthening strategies as prescribed by the World Developmental Report and the Lancet Commissions (Global Health 2035) on Health as critical global policies that outline a framework for creating robust communities and promoting human welfare and economic growth.

Conclusion

While climate adaptation strategies require substantial socioeconomic investments, health systems strengthening and robust policies addressing HIV and TB are essential specific components in a region that has an unprecedented share of the total global burden. A combination of increased environmental stressors, scarcer resources, depleted communal immunity, changing climate, and ecological integrity may also suggest a revision of our impressions of what it means to live with HIV and to be a country with a high HIV prevalence. Consequently, accelerating commitment to a concerted alleviation of the HIV epidemic, climate mitigation and adaptation strategies is becoming increasingly and critically important as we find HIV, TB and inclement weather patterns converging powerfully on human socioecological systems.

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