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Pathways Linking Climate Change to Advanced HIV Disease: A Narrative Review

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ABSTRACT

Climate change has emerged as a major global health challenge that may worsen HIV-related outcomes through biological, psychosocial, socioeconomic, and healthcare-related mechanisms. This narrative review aimed to synthesize current evidence on the pathways linking climate change to advanced HIV disease (AHD) and to develop a conceptual framework explaining these interactions. A literature search was conducted in the Scopus database for articles published between 2010 and 2025. Studies addressing the relationship between climate change and HIV-related outcomes, including disease progression, ART adherence, food insecurity, migration, psychosocial stress, and healthcare access, were included and synthesized narratively. Relevant studies were screened and synthesized thematically into major pathways, including biological effects, healthcare disruption, food insecurity, psychosocial stress, migration, and social determinants of health. The findings indicate that climate change contributes to HIV progression through direct biological mechanisms, including oxidative stress, NF-κB activation, immune dysregulation, and HPA axis dysfunction. In addition, indirect socioecological pathways, including disrupted ART access, malnutrition, poverty, migration, and psychosocial stress, further accelerate immune suppression and increase morbidity and mortality among people living with HIV. Climate-adaptive HIV care, resilient healthcare systems, nutrition-sensitive interventions, and interdisciplinary public health strategies are urgently needed to reduce climate-related HIV vulnerabilities.

Keywords: Advanced HIV disease; ART adherence; climate change; food insecurity; HIV progression

INTRODUCTION

Climate change has emerged as one of the most significant global health challenges of the twenty-first century, with profound effects on environmental conditions, food systems, healthcare infrastructure, and population health [1,2]. Simultaneously, HIV/AIDS remains a major public health burden, particularly in low- and middle-income countries that are highly vulnerable to climate-related disruptions [3]. Increasing evidence suggests that climate change may exacerbate HIV disease

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progression and contribute to the development of advanced HIV disease (AHD) through interconnected biological, psychosocial, and socioeconomic pathways [3,4,5]. Advanced HIV disease (AHD) is a severe stage of HIV infection characterized by profound immune suppression, usually indicated by a CD4 count below 200 cells/mm³ or the presence of AIDS-defining illnesses, which increases vulnerability to opportunistic infections, malignancies, and other life-threatening complications [6,7].

Current studies indicate that climate-related stressors, including heat exposure and extreme weather events, can directly influence HIV pathophysiology [5]. Evidence also demonstrates that elevated temperatures may alter viral replication, latency mechanisms, and immune cell regulation by activating heat shock proteins (HSPs), oxidative stress pathways, and nuclear factor kappa B (NF-κB) signaling [8]. These mechanisms are associated with immune dysregulation, increased inflammatory responses, and enhanced viral persistence, potentially accelerating CD4 decline and increasing viral load among people living with HIV (PLWH).

Beyond biological mechanisms, the indirect impacts of climate change on HIV outcomes appear to be more substantial. Climate-related disasters such as floods, droughts, storms, and extreme heat disrupt healthcare systems by damaging facilities, interrupting antiretroviral therapy (ART) supply chains, and reducing access to routine HIV care [2,9]. Previous studies report that drought and extreme temperatures are associated with lower ART adherence, increased clinic absenteeism, unsuppressed viral loads, and higher mortality among PLWH [9]. These findings suggest that climate change acts as a major disruptor of continuity of HIV care and treatment outcomes.

Food insecurity represents another critical pathway linking climate change and HIV progression. Climate variability contributes to crop failure, declining agricultural productivity, and nutritional instability, particularly in resource-limited settings [10]. Malnutrition among PLWH is strongly associated with impaired immune function, micronutrient deficiencies, elevated inflammatory cytokines, and increased morbidity and mortality [11,12]. Consequently, climate-induced food insecurity may intensify the vicious cycle between HIV infection and malnutrition, thereby accelerating progression toward advanced HIV disease.

Psychosocial stressors associated with climate change also play an important role in HIV progression. Economic instability, displacement, migration, and disaster-related trauma may contribute to chronic stress, depression, and anxiety among vulnerable populations [13]. Evidence suggests that chronic psychosocial stress dysregulates the hypothalamic–pituitary–adrenal (HPA) axis and cortisol responses, which are associated with immune suppression, faster CD4 decline, and increased viral replication in PLWH [14].

Conceptually, climate change may influence HIV outcomes through both direct biological and indirect socioecological pathways. Climate-related exposures, such as rising temperatures, extreme weather events, and environmental degradation, can trigger immune dysregulation and inflammatory responses while simultaneously disrupting healthcare access, ART adherence, food security, and social

stability [15]. These interconnected mechanisms may accelerate HIV progression and increase the risk of advanced HIV disease among vulnerable populations.

Despite growing interest in climate-related HIV research, important gaps remain. Existing evidence is heavily concentrated in Sub-Saharan Africa, while other climate-vulnerable regions, including Southeast Asia, remain underrepresented. Moreover, most studies examine isolated pathways rather than integrating biological, social, environmental, and healthcare dimensions into a comprehensive framework. Therefore, this narrative review aims to synthesize current evidence on the pathways linking climate change to advanced HIV disease and to propose a conceptual framework integrating biological, psychosocial, socioeconomic, and healthcare mechanisms. Such understanding is essential for developing climate-adaptive HIV care strategies, resilient healthcare systems, and evidence-based nursing and public health interventions.

METHODS

This study employed a narrative review design to synthesize and critically analyze the existing evidence regarding the relationship between climate change and advanced HIV disease (AHD). A narrative review was considered appropriate because the topic involves complex and multidimensional interactions among biological, psychosocial, environmental, and healthcare-related factors. This approach enabled the integration of findings from diverse disciplines, including environmental health, immunology, epidemiology, public health, and HIV care. The question in this is "how does climate change contribute to the progression of advanced HIV disease through biological, psychosocial, socioeconomic, and healthcare-related pathways?"

The literature search was conducted exclusively using the Scopus database due to its broad multidisciplinary coverage and comprehensive indexing of peer-reviewed international journals. The search aimed to identify relevant articles published between January 2010 and December 2025. The search process used combinations of keywords and Boolean operators, including “climate change” AND “advanced HIV disease”, “climate change” AND “HIV progression”, “food insecurity” AND “HIV”, “psychosocial stress” AND “HIV”, “ART adherence” AND “climate change”, “migration” AND “HIV transmission”, and “climate-related disasters” AND “HIV care”. The search was limited to article titles, abstracts, and keywords to improve the relevance of retrieved studies.

The inclusion criteria were peer-reviewed articles indexed in Scopus, articles published in English, studies published between 2010 and 2025, empirical studies, review articles, and conceptual papers, studies discussing the relationship between climate change and HIV/AIDS outcomes, including biological mechanisms, healthcare disruption, food insecurity, psychosocial stress, migration, or antiretroviral therapy (ART) adherence, and studies involving people living with HIV (PLWH) or populations vulnerable to HIV-related outcomes.

Relevant articles were screened through title and abstract review, followed by full-text assessment based on the predefined eligibility criteria. Information extracted from each study included authors, publication year, country or region, study design, study population, climate-related exposure, HIV-related outcomes, and key findings. The data were synthesized using a thematic synthesis approach.

RESULT

This study identified findings that were grouped into major themes, including: 1) direct biological pathways, 2) healthcare disruption and ART adherence, 3) food insecurity and nutritional vulnerability, 4) psychosocial stress and mental health, 5) migration and HIV vulnerability, and 6) social determinants of health. Current evidence suggests that climate change can advance HIV disease progression both directly via effects on immune cell function and viral replication, and indirectly through exacerbation of social determinants such as food insecurity, disrupted healthcare systems, and psychosocial stress (Table 1). The synthesized findings were subsequently used to develop a conceptual framework illustrating the multidimensional pathways linking climate change and advanced HIV disease (Figure 1).

Table 1. Main Findings on the Pathways Linking Climate Change and Advanced HIV Disease

Main Findings Themes	Evidence Summary	Impact on Advanced HIV Disease	Supporting Studies
Direct Biological Effects	Elevated temperatures influence HIV viral replication, latency mechanisms, and immune cell function through heat-related cellular responses.	Climate-related heat exposure may either accelerate or inhibit HIV progression depending on temperature intensity, cellular conditions, and host factors.	[15,16,17]
Indirect Socioeconomic Pathways	Climate change contributes to food insecurity, migration, healthcare disruption, poverty, and psychosocial stress among vulnerable populations.	These disruptions impair ART adherence, reduce continuity of care, and increase the risk of HIV progression and adverse clinical outcomes.	[18,19,20]
Psychosocial Stress and HPA Axis Dysregulation	Climate-induced psychosocial stress alters neuroendocrine regulation and disrupts hypothalamic–pituitary–adrenal (HPA) axis functioning.	Chronic stress is associated with faster CD4 decline, higher viral load, and worsening immune suppression among people living with HIV.	[14,21]
Food Systems and Wild Edible Plants	Local food systems and wild edible plants may serve as nutritional buffers during climate-related food insecurity.	Improved nutritional resilience may support immune function and reduce vulnerability to HIV-related complications.	[11,12,22]
Migration and HIV Transmission Risk	Climate-driven migration disrupts social networks and increases behavioral vulnerability, including risky sexual practices.	Population displacement and migration may contribute to higher HIV transmission risk and reduced continuity of HIV care.	[3,18,23,24,25]
Oxidative Stress and NF-κB Activation	Heat exposure and oxidative stress activate NF-κB signaling pathways and modulate HIV-related viral gene expression.	Increased oxidative stress contributes to enhanced viral replication, persistent	[8,26,27,28]

Main Findings Themes	Evidence Summary	Impact on Advanced HIV Disease	Supporting Studies
		inflammation, and immune dysfunction.	

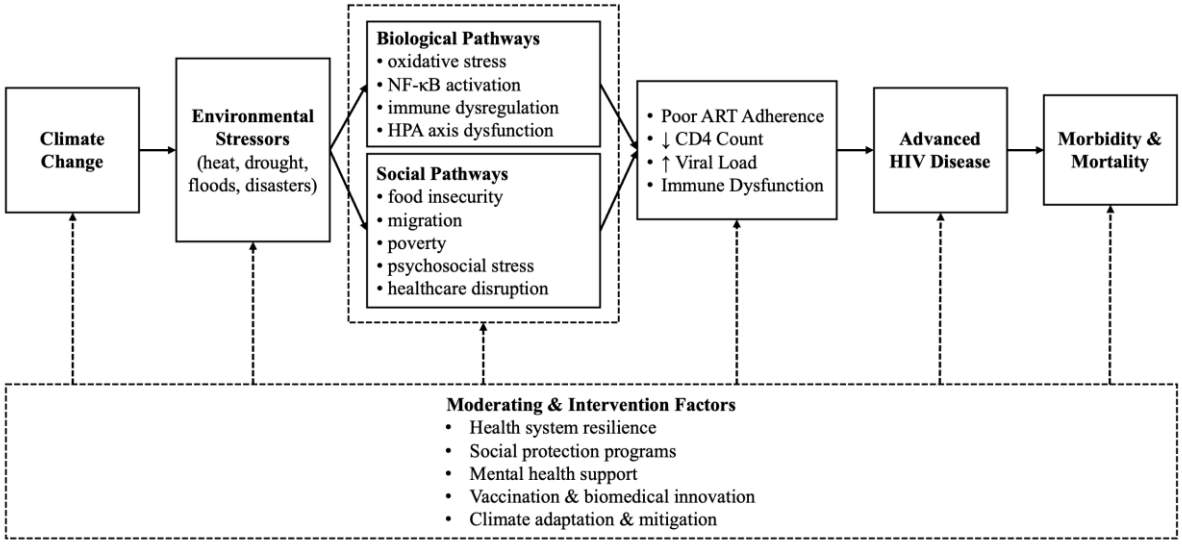

Figure 1. Pathways Linking Climate Change to Advanced HIV Disease

Figure 1 explains that climate-related environmental stressors (e.g., heat, drought, floods, and disasters) influence HIV outcomes through biological pathways (oxidative stress, NF-κB activation, immune dysregulation, and HPA axis dysfunction) and social pathways (food insecurity, migration, poverty, psychosocial stress, and healthcare disruption). These mechanisms contribute to poor ART adherence, CD4 decline, increased viral load, and immune dysfunction, ultimately leading to AHD and increased morbidity and mortality. Moderating factors may mitigate these adverse effects.

The findings demonstrate that climate change influences advanced HIV disease through interconnected biological, psychosocial, socioeconomic, and healthcare-related pathways. Direct biological effects primarily involve heat-induced modulation of viral replication, oxidative stress, immune dysregulation, and activation of inflammatory pathways such as NF-κB, all of which may accelerate HIV disease progression. However, some studies also suggest that specific hyperthermic conditions may temporarily inhibit viral replication, suggesting complex, context-dependent biological responses.

Indirect pathways appear to exert broader and more consistent impacts on HIV outcomes. Climate-related disruptions such as droughts, floods, food insecurity, healthcare interruptions, and forced migration negatively affect antiretroviral therapy (ART) adherence, continuity of care, and overall immune resilience among people living with HIV. These conditions contribute to increased viral load, accelerated CD4 decline, and higher morbidity and mortality risks.

Psychosocial stress emerged as another important mechanism linking climate change and HIV progression. Climate-induced stressors may dysregulate the hypothalamic–pituitary–adrenal (HPA)

axis, leading to neuroendocrine imbalance and immune suppression. In addition, migration and displacement caused by environmental instability may increase HIV transmission risk through disruption of social support systems and increased engagement in high-risk behaviors.

Conversely, local food systems and wild edible plants may confer protective benefits by enhancing nutritional resilience in climate-vulnerable communities. This finding highlights the potential importance of community-based and sustainable interventions in mitigating climate-related HIV vulnerabilities. Overall, the evidence suggests that climate change acts as a multidimensional driver of advanced HIV disease, emphasizing the urgent need for climate-adaptive HIV care, resilient healthcare systems, and interdisciplinary public health interventions.

DISCUSSION

Climate change contributes to the progression of advanced HIV disease through interconnected biological, psychosocial, environmental, and healthcare-related pathways. Evidence suggests that elevated temperatures and climate-related stressors influence HIV replication, immune regulation, and inflammatory responses [15,16,17,26]. Heat stress increases reactive oxygen species (ROS) production and activates inflammatory pathways such as nuclear factor kappa B (NF-κB), which may enhance viral transcription and persistence. Persistent oxidative stress also contributes to chronic inflammation, immune exhaustion, and accelerated CD4 decline among people living with HIV (PLWH). Heat shock proteins (HSPs) further demonstrate complex roles in HIV pathogenesis, as some facilitate viral replication while others provide cytoprotective effects [8,28]. These contradictory findings indicate that the biological effects of hyperthermia on HIV progression remain context-dependent and require further mechanistic investigation.

Indirect pathways appear to exert broader impacts on HIV outcomes. Climate-related disasters such as floods, droughts, and extreme heat frequently disrupt healthcare infrastructure, transportation systems, and antiretroviral therapy (ART) supply chains [9]. These disruptions reduce clinic attendance, interrupt treatment continuity, and increase the risk of treatment failure, viral rebound, and antiretroviral drug resistance. Such findings highlight the importance of climate-resilient HIV care systems capable of maintaining treatment continuity during environmental crises [4,18,19]. Climate-adaptive HIV nursing should therefore incorporate disaster preparedness, decentralized ART delivery, mobile health services, and continuity planning for vulnerable patients. Telehealth HIV care may also help maintain clinical monitoring and psychosocial support during periods of healthcare disruption, although evidence regarding its effectiveness in climate-vulnerable settings remains limited.

Food insecurity represents another important mechanism linking climate change and advanced HIV disease. Climate variability and declining agricultural productivity contribute to malnutrition and micronutrient deficiencies, particularly among socioeconomically disadvantaged populations

[11,12,22]. Malnutrition among PLWH is associated with impaired immune responses, increased susceptibility to opportunistic infections, and higher mortality risk [29]. Deficiencies in zinc, selenium, magnesium, and vitamin C may exacerbate oxidative stress and inflammatory responses, further accelerating HIV progression. The bidirectional relationship between HIV and malnutrition creates a vicious cycle in which HIV worsens nutritional status while malnutrition accelerates immune suppression. Local food systems and wild edible plants may provide nutritional resilience in climate-affected communities by improving dietary diversity and food availability [22]. These findings support the growing relevance of agro-nursing and nutrition-sensitive HIV interventions within climate-responsive healthcare approaches.

Psychosocial stress and mental health challenges also contribute substantially to HIV vulnerability in the context of climate change. Environmental disasters, economic instability, displacement, and uncertainty may increase chronic stress, anxiety, and depression among vulnerable populations [14,21]. Chronic psychosocial stress may dysregulate the hypothalamic–pituitary–adrenal (HPA) axis and alter cortisol production, leading to immune suppression and increased viral replication [21]. Depression and psychological distress can reduce ART adherence and engagement in HIV care [30]. These findings emphasize the need to integrate mental health support, psychosocial assessment, and community resilience interventions into HIV care programs. Nurses play an important role in identifying stress-related vulnerabilities and strengthening coping mechanisms among PLWH affected by climate-related stressors.

Climate-driven migration and displacement further increase HIV vulnerability and disrupt continuity of care. Environmental degradation, crop failure, and economic instability may force populations to migrate from rural to urban areas or across regions in search of survival opportunities [3,13,18,23,24]. Migration often disrupts social support systems and access to healthcare services while increasing engagement in high-risk sexual behaviors and unstable living conditions [24]. Migrants and displaced populations may face substantial barriers to HIV testing, ART access, and long-term treatment follow-up [18,23]. These findings highlight the importance of protecting vulnerable populations through inclusive healthcare policies, mobile HIV services, and community-based support systems.

The influence of social determinants of health further strengthens the relationship between climate change and advanced HIV disease. Poverty, limited education, inadequate healthcare access, and economic instability increase structural vulnerability to both climate-related hazards and HIV-related complications [18,19,20]. Climate change disproportionately affects populations already experiencing social and health inequities, particularly in low-resource settings [4]. Consequently, addressing the intersection between climate change and HIV requires multisectoral collaboration involving healthcare, environmental, agricultural, educational, and social welfare sectors. Climate-resilient health systems, food security policies, social protection programs, and disaster preparedness strategies should be integrated into HIV prevention and treatment programs.

From a nursing perspective, these findings have important implications for HIV, community, and disaster nursing practice. HIV nurses should strengthen climate-sensitive assessment by identifying patients at risk of treatment interruption, food insecurity, psychosocial distress, and climate-related health vulnerabilities. Community health nurses can support ART adherence through patient education, community outreach, and linkage to social support and nutrition programs, particularly in climate-affected areas. Disaster nurses play a critical role in ensuring the continuity of HIV care during environmental emergencies by preparing for emergencies, decentralizing ART distribution, providing mobile health services, and coordinating with local health systems. Integrating climate adaptation strategies into nursing practice may help reduce HIV-related morbidity and improve resilience among people living with HIV in vulnerable settings.

Despite growing evidence, several limitations remain. Most existing studies are observational and cross-sectional, limiting the understanding of causal pathways between climate stressors and HIV progression. Longitudinal and mixed-methods studies are needed to better understand the biological and psychosocial impacts of chronic climate exposure among PLWH. Evidence from Southeast Asia and other climate-vulnerable regions also remains limited, while marginalized populations such as migrants and indigenous communities remain underrepresented. Future research should prioritize climate-adaptive HIV interventions, integrated climate-health datasets, and community-based resilience models to strengthen evidence-based responses for PLWH living in climate-vulnerable settings.

CONCLUSION

The interplay between climate change and HIV disease progression is multifaceted, operating through direct biological mechanisms, such as temperature influences on viral replication and immune regulation, and indirect pathways related to socioeconomic disruptions, food insecurity, and psychosocial stress. There is a critical need for interdisciplinary research frameworks that integrate environmental, clinical, and social data to better understand and mitigate these effects, particularly in vulnerable regions. Addressing these research gaps will be pivotal in shaping adaptive healthcare strategies that enhance HIV treatment outcomes in the era of climate change. Proactive, interdisciplinary, and equity-focused approaches are urgently needed to mitigate the compounded impacts of climate change on HIV. This includes expanding research in underrepresented regions, integrating climate resilience into HIV care, and fostering multisectoral collaboration for policy and program development.

Future research should prioritize longitudinal cohort studies to clarify causal relationships between climate exposures and HIV progression, the development of climate–health surveillance systems to monitor emerging vulnerabilities, and intervention studies evaluating the effectiveness of

climate-resilient HIV care models in improving treatment continuity and health outcomes among people living with HIV.

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