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Review

Climate Change, Environmental Degradation, and Human Health: A Converging Crisis

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ABSTRACT

Climate change and environmental degradation represent the defining public health challenges of the twenty-first century, exerting profound direct and indirect impacts on global well-being. Their effects are far-reaching from increased incidence of vector-borne diseases and heat-related illnesses to disruptions in food and water systems, mental health burdens, widening health inequities, socioeconomic collapse, and conflict. This review integrates multidisciplinary evidence across climatology, ecology, medicine, and digital health to illuminate the complex linkages between environmental degradation and human health outcomes. Rising temperatures, altered precipitation patterns, oceanic disruption, and biodiversity loss are amplifying vector-borne diseases, food insecurity, and heat-related morbidity. These systemic stresses disproportionately affect vulnerable populations, accelerating inequities and threatening societal stability. Building on recent frameworks, this paper advances a holistic Climate–Health Nexus model that emphasizes adaptive resilience through surveillance, early warning systems, and decision intelligence. Professor Hugh Montgomery's analogy of climate change as a critically ill patient underscores the urgency for coordinated, evidence-based intervention. Integrating insights from digital health platforms such as MyJEEVA, we outline how community-level engagement, real-time data, and AI-enabled decision support can enhance climate preparedness and health system responsiveness. The synthesis concludes with actionable pathways linking mitigation, adaptation, and governance to safeguard planetary and human health.

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Research Highlights

- Multidisciplinary evidence linking environmental degradation and human health
- Amplified vector-borne diseases, food insecurity, and heat-related morbidity
- Community-level engagement, real-time data, and AI-enabled decision support can enhance climate preparedness and health system responsiveness.

1. Introduction

Climate change and environmental degradation are the most complex and consequential challenges facing humanity in the twenty-first century [1, 2]. Rising global temperatures, erratic precipitation patterns, melting glaciers, and biodiversity loss have cascading effects across natural and human systems [1, 2]. These phenomena not only alter ecological balance but also threaten the fundamental determinants of health like clean air, safe water, sufficient food, and secure shelter [1–3]. The World Health Organization (WHO) identifies climate change as the single greatest threat to global health, estimating that between 2030 and 2050, it will cause approximately 250,000 additional deaths per year from malnutrition, malaria, diarrhea, and heat stress [1].

Beyond direct physical impacts, climate change exacerbates pre-existing health disparities, disproportionately affecting vulnerable populations such as children, the elderly, and those in low-income regions [1, 2, 4]. Environmental degradation through deforestation, pollution, and loss of arable land further amplifies these risks, weakening social resilience and destabilizing healthcare systems [5, 6]. The result is a complex web of interconnected threats that blur the boundaries between environmental science, public health, economics, and policy [4, 5].

1.1. The Climate–Health Nexus Framework

This paper adopts a Climate–Health Nexus framework to conceptualize these interconnected challenges [4, 5]. The framework emphasizes that climate, environment, and human systems are interdependent components of a unified planetary health continuum [4, 5]. Changes in one domain reverberate through others; for instance, temperature fluctuations influence disease vector behavior, which in turn affects human morbidity and productivity, ultimately shaping economic and policy responses [2, 5].

The Climate–Health Nexus serves as both an analytical and operational model. Analytically, it integrates data from climatology, epidemiology, and socioeconomics to understand causal relationships [2, 4, 5]. Operationally, it guides interventions across three levels:

1. Surveillance and Early Detection using environmental and health data integration to predict emerging risks [2, 5].
2. Adaptive Response deploying digital health systems and AI-enabled platforms, such as MyJEEVA, to improve real-time communication, care coordination, and resilience.
3. Mitigation and Governance designing policy frameworks that link emission control, healthcare infrastructure, and equitable access to resources [1, 2, 4, 5].

By framing climate change as a health emergency rather than merely an environmental issue, the Climate–Health Nexus underscores the urgency for cross-sectoral collaboration [4, 5]. This approach moves beyond reactive healthcare toward proactive prevention and systems-level resilience, aligning science, policy, and technology in pursuit of planetary health [4–6].

The aim of this paper is to synthesize current scientific evidence on the pathways linking climate change, environmental degradation, and human health; evaluate emerging technological and public-health approaches, including digital health platforms and decision intelligence systems, to strengthen climate resilience; and identify policy, research, and governance priorities required to advance integrated climate-health action. By combining insights from climatology, public health, and digital transformation, this manuscript provides a comprehensive framework to guide future climate–health adaptation strategies.

2. Climate Warming and Mechanisms of Heat Impact

2.1. Climate Physics and Warming Trends

Greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane, and nitrous oxide allow short-wave solar radiation to pass through the atmosphere but trap long-wave infrared radiation, thereby retaining heat [7]. Anthropogenic GHG emissions have risen steeply from approximately 196.75 million tonnes of CO_2e in 1850 to 40.9 billion tonnes in 2023 and continue to do so [2].

Once released, many of these gases persist in the atmosphere for extended timescales for CO_2, around 20% remains for more than 33,000 years and $\sim$7% for 100,000 years [7]. Consequently, the accumulation of these gases is rising the atmospheric CO_2 concentration has increased from a pre-industrial baseline of 280 ppm to $\sim$430 ppm in May 2025 [2, 7]. Collectively, these gases trap the energy equivalent of more than eleven Hiroshima bombs every second [7].

The world's oceans have absorbed vast amounts of this excess heat 345×10^{21} Joules since 1955, equivalent to $\sim$19 billion Hiroshima bombs [2]. These shifts translate into lived realities of warming seas, intensified storms, and marine-ecosystem disruption that jeopardize food security for billions [2, 6].

Meanwhile, the cryosphere shows equally dramatic changes. Antarctica lost 7.5 trillion tonnes of ice between 1997–2021, Greenland has lost over 1 trillion tonnes since 1985, and Swiss glaciers alone lost 10% of their ice volume between 2022–2023 [7]. These irreversible changes foreshadow profound consequences for sea-level rise, freshwater availability, and widespread displacement [2, 6].

Melt of land ice into oceans is disrupting ocean-circulation patterns, threatening the weather systems upon which agriculture and civilization depend [7]. Likewise, thermal expansion of oceans, together with added water from ice melt, is causing sea levels to rise, already by $\sim$1 cm every 2 years [2].

In the twelve months leading to May 2025, the Earth's mean surface temperature rose by 1.57 °C above pre-industrial levels, reaching ~ 14.96 °C, with land areas warming by more than 2 °C. Such uneven heating drives lethal heatwaves, droughts, wildfires, and regional water scarcity now affecting populations across every continent [7].

During the COVID-19 pandemic, unprecedented lockdowns briefly altered the drivers of the climate–heat system but did not meaningfully slow global warming. Near–real-time analyses showed that daily global CO_2 emissions decreased by nearly 17% during the peak of restrictions in April 2020 relative to 2019 levels, resulting in an estimated 4–7% reduction in annual emissions [8]. Yet atmospheric GHG concentrations continued to rise, and 2020 effectively tied 2016 as the warmest year on record despite a cooling La Niña. Studies concluded that the climatic effects of lockdown-related emission reductions were limited and short-lived, as they were far smaller than the cumulative stock of long-lived greenhouse gases [9]. At the same time, rapid regional declines in aerosol pollution reduced their short-term cooling influence, contributing to anomalous heat extremes, including a pronounced North Pacific marine heatwave in spring 2020. In India, these global dynamics coincided with dangerous heat conditions during lockdown: Delhi experienced a severe May 2020 heatwave, and temperatures approached 50 °C in parts of northern India, demonstrating that extreme heat risk persisted, and in some cases intensified, despite the temporary dip in emissions.

2.2. Extreme Weather and Heat Stress

Heatwaves, especially in urban centers, have become more frequent and severe, leading to increased mortality and hospital admissions. Vulnerable populations such as the elderly and outdoor laborers face disproportionate risks [10–12].

Vulnerable populations, such as the elderly and outdoor laborers, face disproportionate risks [10–12]. The average temperature in India has risen significantly from 1971 to 2007, and projections indicate that this trend will continue, with expected temperature increases ranging from 2.2 °C to 5.5 °C by the end of the 21st century. The northern, central, and western regions of India are anticipated to experience even higher temperature increases [10].

The 2015 heatwave, which affected several parts of India, caused the deaths of approximately 2,248 people [11]. This was an extreme and abnormal event, caused by atmospheric conditions influenced by the delayed onset of the southwest monsoon [13]. Experts predict that heatwaves over India will intensify in terms of both frequency and severity in the near future [14].

2.2.1. Drivers of Heatwaves in India

Extreme temperature events over India have been linked to the El Niño-Southern Oscillation (ENSO) [15]. Increasing heat waves frequencies over India during post-El Niño Spring and early summer seasons. Global and Planetary Change, 241, 104561. In addition, recurving tropical cyclones and anomalies in sea surface temperature (SST) in the Bay of Bengal have been identified as potential drivers of heatwaves over the Indian subcontinent [16]. These cyclones can alter wind patterns and prevent moisture from reaching inland areas, exacerbating heatwave conditions [16].

Recent studies have also identified a significant connection between atmospheric blocking over the Northern Atlantic Ocean and heatwaves over north-central India, while heatwaves along the coastal areas are often linked with cyclonic anomalies across the equator in the west Pacific [16]. Further studies by Rohini et al. have highlighted that heatwave events in India are associated with sub-tropical blocking, Indian Ocean SST anomalies, and ENSO events [17].

The increasing frequency and intensity of heatwaves in India has also been closely linked to the phenomenon of Great Agrarian Distress, reflected in rising incidences of farmer suicides in several states. Prolonged extreme temperatures aggravate pre-existing structural vulnerabilities in the agricultural sector by causing recurrent crop failures, increased evapotranspiration, depletion of soil moisture, and enhanced water stress, especially in rain-fed regions. These conditions reduce agricultural productivity, harm livestock health, increase irrigation and input costs, thereby deepening farmers' indebtedness and economic insecurity. For small and marginal farmers, repeated heatwave-induced losses, combined with limited access to formal credit, crop insurance, and effective risk-transfer mechanisms, can result in acute financial and psychological stress. Thus, heatwaves act not only as a climatic hazard but also as a socio-economic stressor that intensifies agrarian distress and contributes indirectly to the growing incidence of farmer suicides in India.

2.2.2. Heatwave Classification by India Meteorological Department (IMD)

The India Meteorological Department (IMD) has specific criteria for declaring a heatwave [18]. A heatwave is declared when the maximum temperature departure from the normal maximum temperature is 5 °C to 6 °C for stations with a normal temperature of less than 40 °C, or 4 °C to 5 °C for stations with a normal temperature greater than 40 °C. A severe heatwave is declared when the departure is 7 °C or more for stations with normal temperatures less than 40 °C, or 6 °C or more for stations with normal temperatures greater than 40 °C. If the temperature exceeds 45 °C, a heatwave is declared at that station [18].

2.2.3. Alternative Heatwave Threshold Approaches

An alternative to the IMD's fixed threshold approach is the percentile-based approach, proposed by researchers such as Dietz & Chatterjee [19], Zhu et al. [20], and others. This method uses percentiles as thresholds based on prevailing conditions in a region, ranging from the 80th to the 98th percentiles of temperature over a base period [19, 20].

Perkins et al. suggested three definitions of heatwaves: (a) the 90th percentile of maximum temperature, (b) the 90th percentile of minimum temperature, and (c) positive extreme heat factor (EHF) conditions [21]. The EHF-based approach, which combines T_{max} and T_{min}, is considered best for assessing human health and climatological impacts. T_{max} and T_{min} influence the relief experienced at night and adaptability, with T_{min} being particularly relevant for assessing the effects on crop growth and yield. On the other hand, T_{max}-based approaches are valuable for understanding impacts on infrastructure, as high temperatures contribute to the wear and tear of engineering structures [22].

2.2.4. Vulnerability to Heatwaves

The vulnerability of different populations to heat stress is a critical issue. According to the World Bank, over 20% of the Indian population lives on less than $1.25 per day, and about 25% lack access to electricity [12, 23]. This makes these individuals highly susceptible to heat-related mortality. In 2010, over 1,300 people died due to heatwaves in Ahmedabad [12, 24]. This tragedy led to the development of Heat Action Plans, but heatwave-related deaths persisted in 2013 and 2015, killing approximately 1,500 and 2,500 people, respectively [12, 24].

Studies predict that if the summer mean temperature increases by 0.5 °C, the probability of mass heat-related mortality could jump from 13% to 32%. Similarly, the probability of mass mortality rises from 46% to 82% if the average number of heatwave days across India increases from six to eight [10]. This highlights the critical importance of improving vulnerability assessments and heat action plans to protect at-risk populations.

2.3. Vector-Borne and Zoonotic Diseases

2.3.1. Impact of Climate Change on Vector-Borne Diseases

Climate change is altering the environmental conditions necessary for the proliferation of disease vectors, such as mosquitoes and ticks (Figure 1). As global temperatures rise, vectors like Aedes aegypti, Anopheles mosquitoes, and ticks are expanding their geographic range [25]. This shift is making previously unaffected regions susceptible to diseases such as malaria, dengue, Lyme disease, and West Nile virus (Figure 2). Warming temperatures, changes in precipitation patterns, and increased humidity are creating favorable conditions for these vectors to thrive, leading to a rise in vector-borne diseases in new areas [26].

2.3.2. Thermal Performance Curves and Disease Spread

The physiological and life-history traits of vectors, pathogens, and hosts are sensitive to temperature [26]. Thermal performance curves are commonly used to predict the impact of rising temperatures on disease transmission. These curves represent the temperature ranges within which vectors, pathogens, and hosts can survive and reproduce. As temperatures rise, these curves shift, influencing the potential for disease spread. If vectors can adapt to these changes, they may carry new pathogens or spread existing ones to new regions. This complicates the modeling and prediction of disease emergence, as the interactions between temperature, vector biology, and pathogen behavior are highly complex and context specific [26].

2.3.3. Key Vector-Borne Diseases Affected by Climate Change

1. Malaria: Malaria, caused by Plasmodium species and transmitted by Anopheles mosquitoes, is one of the most climate-sensitive diseases. Temperature increases of 0.2 °C per decade in the highlands of Colombia and Ethiopia have been linked to the spread of malaria to higher elevations. Malaria's seasonal nature means that it responds rapidly to short-term changes in rainfall, temperature, and humidity. However, broader climate-related changes, such as increasing droughts, may reduce malaria prevalence in some regions while increasing vulnerability in others due to migration, food insecurity, and weakening of control efforts. Enhanced surveillance, control strategies, and targeted adaptation measures are needed to address these shifts [27].

2. Dengue: Dengue fever, caused by the dengue virus and transmitted by Aedes aegypti and A. albopictus mosquitoes, is becoming a growing concern due to its expanding geographic range. In recent decades, the disease has spread globally, with 390 million cases occurring annually. Climate change is predicted to be the dominant factor driving the northward expansion of these mosquito vectors. As temperatures rise, these mosquitoes can survive in previously unsuitable regions, facilitating the spread of dengue viruses. The presence of water-storage containers in many regions provides optimal breeding grounds for mosquitoes, further exacerbating the risk. Modeling efforts are increasingly focusing on how climate change will influence the geographic spread of dengue, helping predict future risks [26].

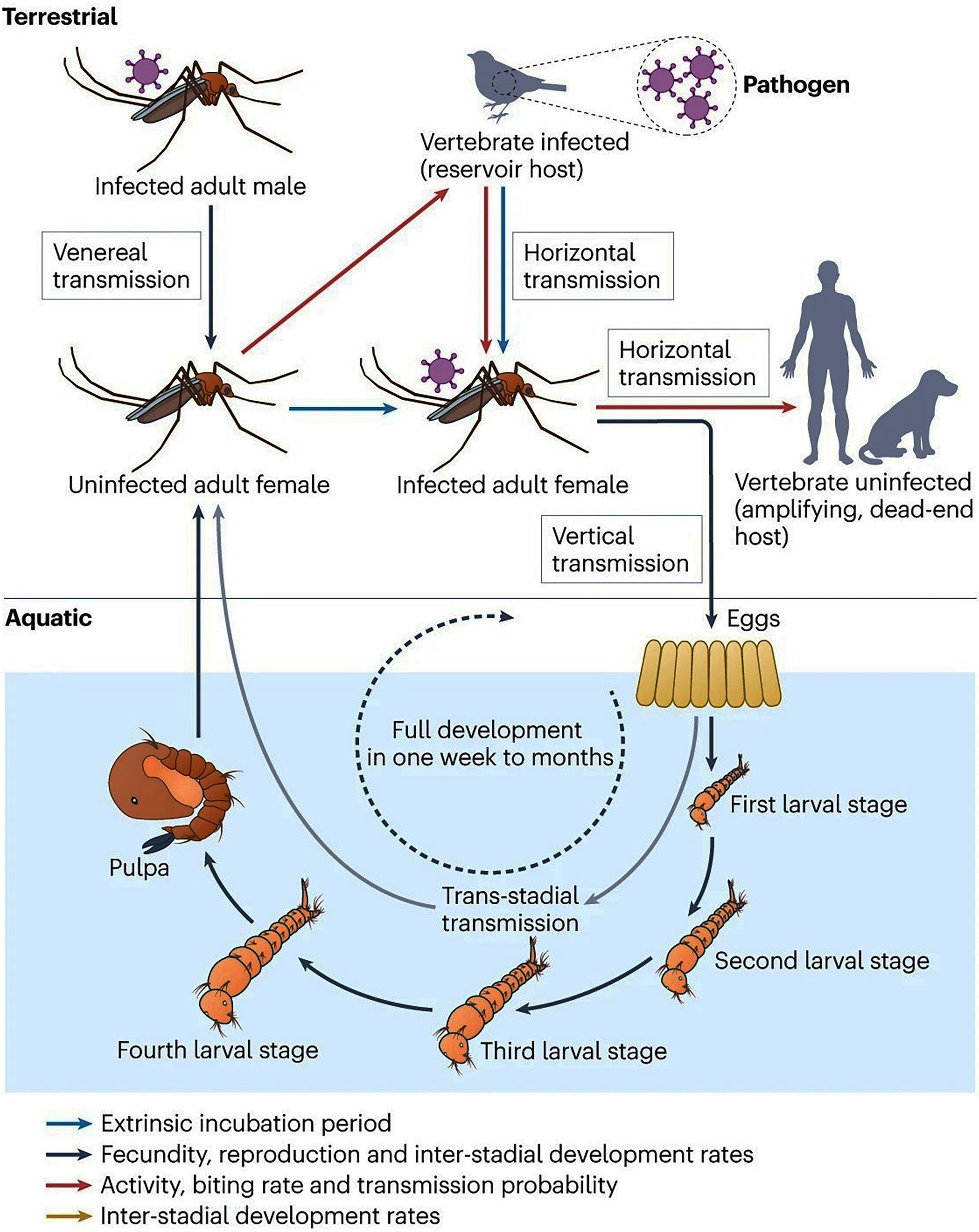

Figure 1. Vector life cycles and pathogen transmission dynamics in mosquitoes. Reproduced with permission from [12]. Reproduced with permission from Springer Nature. License ID: 6141621099833.

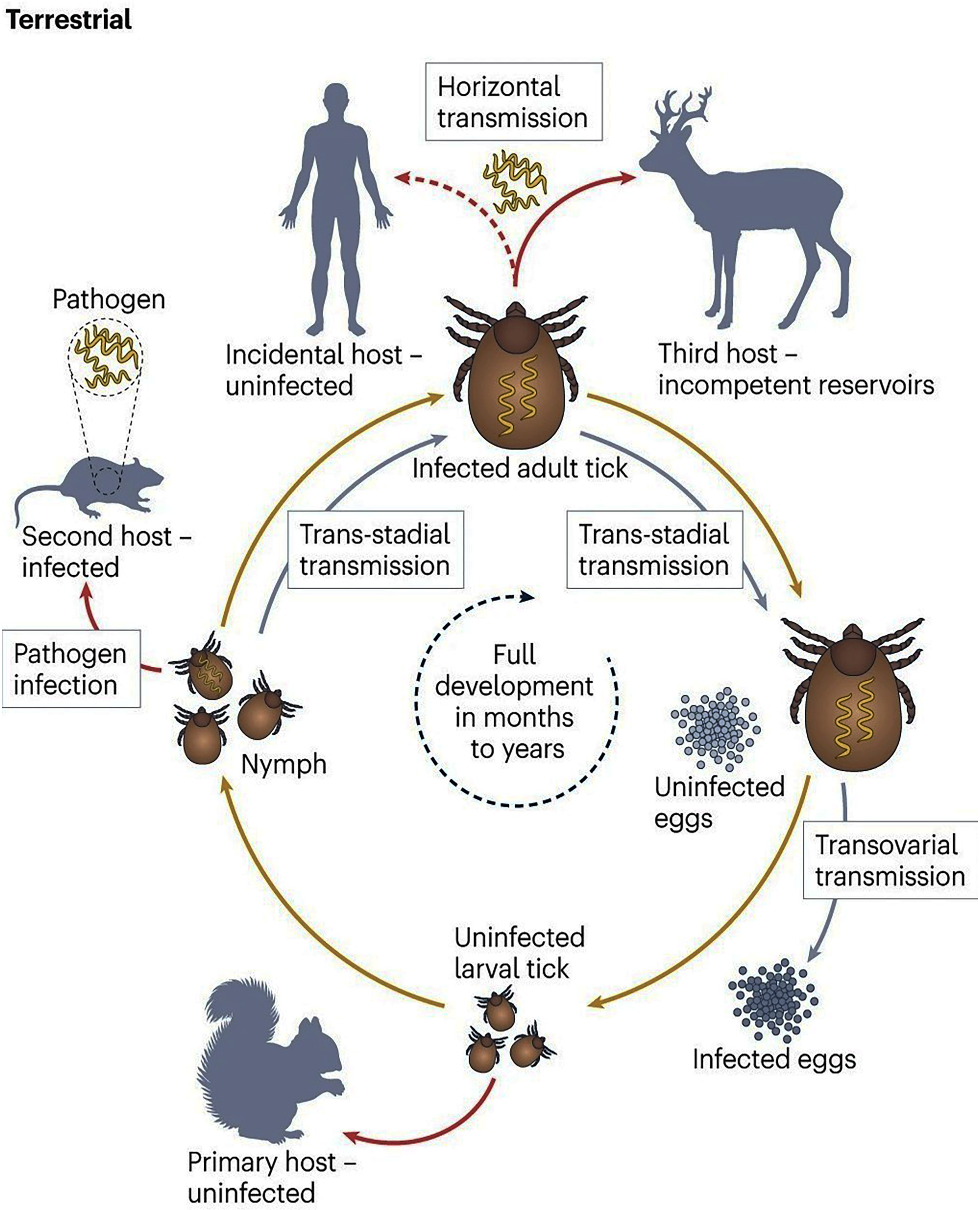

Figure 2. Vector life cycle and pathogen transmission dynamics in ticks. Reproduced with permission from [26]. Reproduced with permission from Springer Nature; License ID: 6141621099833.

3. Lyme Disease: Lyme disease, caused by the bacterium Borrelia burgdorferi and transmitted by ticks, is heavily influenced by climate change. Ticks, such as Ixodes scapularis in North America and Ixodes ricinus in Europe, depend on temperature and the abundance of reservoir hosts (such as rodents and deer). As temperatures rise, ticks are expanding into new areas, including parts of Canada and Norway, where they previously did not thrive. The changing climate is also influencing the seasonality and duration of tick activity, prolonging the period during which Lyme disease transmission occurs. In addition to temperature, increased deer populations are facilitating the spread of Lyme disease in regions like the northeastern United States [26].

4. West Nile Virus: West Nile virus (WNV) is another vector-borne disease that is expanding due to climate change. Transmitted by mosquitoes, the virus circulates in a bird-mosquito cycle, with humans acting as incidental hosts. The incidence of WNV is closely linked to temperature (Table 1), with a peak incidence observed around 24 °C to 25 °C, a range predicted by climate models. As temperatures increase, the range of WNV transmission is expected to shift northward. This shift is already visible in parts of Europe, where warmer weather has led to new cases of WNV infection. The virus poses a significant risk to older adults and immunocompromised individuals, making climate-related changes in transmission patterns a public health concern [28].

2.3.4. Data Integration and Epidemiological Modeling

Effective forecasting of vector-borne disease outbreaks requires robust epidemiological models that integrate climate data with historical disease incidence. These models help predict how vector populations, pathogen dynamics, and host interactions will evolve in response to changing climatic conditions. Advances in climate-sensitive disease data integration have improved our understanding of these complex systems one such example is EpiClim, a comprehensive dataset created by integrating climate data with epidemiological health outcomes for all over India. The integration of these variables creates an opportunity for predictive modelling of disease outbreaks. By analyzing temporal trends and spatial distributions of diseases alongside climatic patterns, the EpiClim dataset supports the development of early-warning systems and allows for proactive public health interventions. These models can predict where and when disease outbreaks are likely to occur, enhancing the ability of public health systems to respond effectively [29].

2.4. Food and Water Insecurity

Climate change increasingly threatens food and water security through rising temperatures, erratic precipitation, and soil degradation. Shifts in rainfall and drought frequency disrupt crop yields, reduce nutritional quality, and intensify competition for freshwater resources. According to the FAO Climate Change, Water, and Food Security Report [30], more than two billion people currently face moderate to severe food insecurity, with projections suggesting up to a 30% decline in major cereal production in low-latitude regions by 2050.

Droughts, floods, and salinization are reducing arable land and freshwater reserves, leading to cascading public health effects particularly malnutrition, stunting, and micronutrient deficiencies. Concurrently, warmer temperatures accelerate microbial contamination of water supplies, increasing outbreaks of diarrhea and vector-borne diseases. These risks disproportionately affect climate-sensitive populations in sub-Saharan Africa, South Asia, and the Middle East, where adaptive infrastructure is limited [30].

Integrated food–water–health surveillance systems are therefore essential to monitor early warning indicators and to inform climate-resilient agricultural and public health policies.

Table 1. Representative temperature ranges associated with mosquito biting behavior, reproductive output, larval development, and immature survival across major vector species. Values summarize experimentally observed or modeled optima and tolerance ranges reported in the literature. Modified after de Souza and Weaver (2024).

Species	Associated Pathogens	Biting Activity (°C)	Fecundity (°C)	Larval Development Rate (°C)	Immature Survival (°C)
Aedes aegypti	Dengue, Zika, Chikungunya viruses	33.8 (13.8–40.0)	29.6 (14.7–34.4)	32.7 (11.6–33.0)	25.9 (13.6–38.3)
Aedes albopictus	Dengue, Zika, Chikungunya viruses	31.8 (10.4–38.1)	29.4 (7.9–35.6)	32.6 (8.7–39.6)	24.2 (9.1–39.3)
Culex pipiens	West Nile, Usutu viruses	32.7 (9.4–39.6)	22.1 (5.3–38.9)	30.9 (0.1–38.5)	23.1 (7.8–38.4)

2.5. Air Pollution and Respiratory Diseases

Air pollution remains one of the most pervasive global environmental risks linking atmospheric processes to human health across spatial and temporal scales. According to the State of Global Air 2025 report, exposure to air pollution was the second leading risk factor for premature mortality worldwide in 2023, responsible for approximately 7.9 million deaths (95% UI 6.4–9.4 million) [31].

Among these deaths, 4.9 million were attributed to long-term exposure to ambient fine particulate matter ($PM_{2.5}$), 2.8 million to household air pollution, and 470 000 to ozone exposure [31]. More than 85 percent of total mortality was associated with non-communicable diseases such as ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), diabetes, and dementia. The highest burdens occur in South Asia, East Asia, and sub-Saharan Africa, regions characterized by rapid urbanization, intensive emissions, and sparse monitoring capacity [31]. The link between pollution and health operates through three main mechanisms. First, atmospheric chemistry and microphysics determine the formation, transformation, and removal of pollutants, all of which vary with temperature, humidity, and boundary-layer dynamics. Second, meteorology and circulation control transport and stagnation, shaping spatial and temporal heterogeneity in exposure. Third, population distribution and behavior modify effective inhaled doses and susceptibility. Hence, accurate health assessment requires quantifying both emission sources and atmospheric processes that modulate exposure.

Satellite remote sensing has become central to modern exposure assessment and environmental health research [31]. It complements ground networks by providing continuous and spatially comprehensive measurements that allow consistent exposure estimates across local, regional, and global domains [32]. Observations of aerosol optical depth (AOD), tropospheric nitrogen dioxide (NO_2), and ozone columns from instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS), the Ozone Monitoring Instrument (OMI), the TROPOspheric Monitoring Instrument (TROPOMI), and the Geostationary Environment Monitoring Spectrometer (GEMS) have been widely used to estimate surface pollutant concentrations and to associate exposure with morbidity and mortality in population studies [33].

Recent advances in multi-sensor fusion and machine-learning algorithms have substantially improved the spatial and temporal resolution of satellite-derived datasets. These developments reduce exposure misclassification and provide stronger inputs for statistical and mechanistic health models [34]. New missions such as the Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument, the Multi-Angle Imager for Aerosols (MAIA), the Plankton Aerosol Cloud ocean Ecosystem (PACE) satellite, and GEMS now deliver near-real-time retrievals with kilometer-scale resolution, enabling detection of diurnal variation and characterization of pollution episodes [35, 36]. The integration of satellite data, chemical-transport models, and in-situ networks is forming an observational system that dynamically maps pollution exposure across climatic and socioeconomic gradients [37].

In South and East Asia, chronic $PM_{2.5}$ exposure commonly exceeds $60\ \mu g\ m^{-3}$, leading to sustained high rates of cardiopulmonary disease and emerging evidence of cognitive decline linked to long-term exposure [31]. Satellite retrievals show pronounced seasonal patterns associated with monsoon transitions and photochemical ozone formation [36]. In the Middle East and North Africa, desert dust and anthropogenic emissions combine to produce extreme aerosol concentrations that often surpass $100\ \mu g\ m^{-3}$; temperature inversions and regional subsidence further increase exposure persistence [31].

Across sub-Saharan Africa, satellite records document widespread biomass-burning plumes and transcontinental dust transport that exacerbate respiratory infection and cardiovascular risk [37]. In North America and Europe, long-term declines in pollutant levels have been achieved through stringent air-quality regulation, yet wildfire smoke and compound heat-pollution events are emerging as new challenges. Satellite sensors now enable rapid detection and tracking of smoke plumes, providing timely data to evaluate exposure to $PM_{2.5}$ and ozone during such episodes [38].

Satellite observations are evolving from a monitoring resource into a predictive and policy-relevant framework. Their ability to quantify exposures in data-scarce regions, capture transboundary transport, and inform early-warning systems makes them indispensable to the study of the Climate-Health Nexus [32, 37].

Integrating satellite products with ground networks, atmospheric models, and health datasets can strengthen causal inference, enhance surveillance, and guide mitigation policies [32, 37]. The continuing expansion of missions such as TEMPO, GEMS, MAIA, and PACE, together with advances in data assimilation and artificial-intelligence-based modeling, will improve spatial and temporal precision in exposure assessment [35–37]. This integration will allow scientists to anticipate pollution-related health risks and to support proactive public-health interventions [32, 37].

2.6. Mental Health Effects

Climate-related stressors such as forced displacement, disaster trauma, prolonged droughts, and the chronic anxiety arising from ecological degradation are intensifying global mental-health burdens. The Lancet Countdown on Health and Climate Change (2024) reports that approximately one in five individuals affected by climate disasters experience depression, anxiety, or post-traumatic stress disorder [39].

Extreme heat events, wildfire exposure, and chronic air pollution are associated with cognitive decline, mood instability, and increased suicide risk [39]. In addition to direct psychological trauma from disasters, "eco-anxiety" and "solastalgia" emotional distress caused by environmental loss, are increasingly recognized among youth and vulnerable communities [40]. These effects are compounded in regions where mental-health services are scarce and stigmatization persists [39, 40].

Integrating mental-health support into climate-adaptation planning through community-based interventions, telepsychiatry, and psychosocial first aid has become essential for strengthening public-health resilience in the face of accelerating environmental change [39].

Digital-health tools such as MyJEEVA can play a transformative role by offering personalized health information, mental-wellness prompts, and journaling interfaces that track behavioral and emotional responses to environmental change. These data-driven insights enable individuals to recognize stress patterns and help public-health systems allocate timely psychosocial support. Integrating mental-health surveillance and AI-based early-warning mechanisms into climate-adaptation frameworks can thus bridge personal well-being and community resilience [41].

2.7. Migration and Health Displacement

Environmental degradation, climate-related disasters, and conflicts are now among the leading drivers of human migration, creating complex health challenges that span borders [41–43]. According to the World Bank Groundswell Report (2024), climate change could displace over 216 million people by 2050 across sub-Saharan Africa, South Asia, and Latin America [41]. Rising sea levels, desertification, and crop failure are forcing communities to relocate often abruptly and without access to adequate sanitation, nutrition, or healthcare [41, 42]. Displaced populations face heightened risks of infectious diseases, malnutrition, and mental-health disorders, while host regions experience strained healthcare infrastructures and increased disease transmission [44].

Moreover, migration often amplifies existing inequities: marginalized populations, particularly women and children, face disproportionate exposure to exploitation and violence in displacement settings [42]. Health systems in receiving areas frequently lack surveillance mechanisms to monitor mobile populations, complicating the containment of vector-borne and communicable diseases and requiring migration-aware health and social protection policies [42, 44].

Digital health platforms could enhance resilience by enabling mobile, patient-centered health records, real-time symptom tracking, and resource localization for displaced populations. Such tools, when integrated into public-health surveillance frameworks, can improve continuity of care and strengthen the adaptive capacity of both migrants and host communities. Addressing the intersection of climate migration and health thus requires an integrated response combining humanitarian aid, digital innovation, and climate-resilient health policy [42].

3. Climate Vulnerability and Health Inequities

The health impacts of climate change are not uniformly distributed; rather, they are mediated by socioeconomic status, geography, and pre-existing health inequities [4, 39, 45]. Vulnerable populations including children, the elderly, indigenous groups, and residents of low-income and marginalized communities bear a disproportionate burden of climate-related health risks [4, 39, 45]. These groups often live in areas with higher environmental exposure, such as urban heat islands, flood-prone regions, or zones with inadequate sanitation and infrastructure [39, 42, 45].

Underserved communities frequently lack access to reliable healthcare, insurance coverage, and early-warning systems, which exacerbates the effects of extreme weather, vector-borne diseases, and air pollution [4, 39, 42, 45]. Environmental justice frameworks emphasize that structural inequities such as discriminatory zoning, industrial siting, and resource allocation amplify these vulnerabilities by placing marginalized populations in closer proximity to environmental hazards [4, 45]. In SSA, climate–livelihood stresses push rural households toward towns and secondary cities, amplifying health inequities along migration pathways [44]. In addition, many low- and middle-income countries remain "data deserts," where the absence of robust monitoring and reporting systems limits the ability to detect and address health inequities linked to climate exposure [39, 45]. Targeted, place-based policy responses along migration corridors are essential to mitigate these compounded risks [44].

Dr. Hang's research in vulnerability mapping and exposure modeling underscores the need for high-resolution, spatially explicit data to identify at-risk populations [37]. Integrating satellite-based surveillance, community health records, and geospatial analytics can illuminate local variations in exposure and resilience capacity [32, 37, 42].

Digital health platforms can complement these approaches by capturing individual- and community-level health data in real time, offering an avenue for continuous monitoring of climate-sensitive health outcomes in resource-limited settings [41, 42]. Embedding such data within a Climate-Health Nexus framework ensures that adaptation policies are guided by equity, precision, and sustainability bridging environmental justice and public-health resilience [4, 39, 45].

4. Case Studies

Understanding the health consequences of climate change requires examining real-world examples where environmental disruptions intersect with social, economic, and health systems. The following case studies illustrate this continuum, from localized heat-related morbidity to global ecosystem destabilization, demonstrating how climate impacts scale from individual exposure to societal collapse.

The following sections explore specific contexts such as urban heat stress, extreme weather events, and migration patterns, each revealing how environmental stressors interact with public-health vulnerabilities. The final case, 4.5 Socioeconomic and Ecosystem Collapse [46], synthesizes these patterns at a planetary scale. It frames climate change not only as a health and environmental emergency but also as a systemic threat to economic and geopolitical stability, setting the stage for adaptive solutions discussed in Section 5.

4.1. Air Pollution Crisis in Delhi and Respiratory Impacts

4.1.1. Introduction to Air Pollution in Delhi

Delhi, the capital city of India, has been grappling with severe air pollution for decades, and it consistently ranks among the most polluted cities in the world. The city's air quality frequently surpasses hazardous levels, especially during the winter months, with pollutants such as particulate matter (PM2.5), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) reaching alarming concentrations [31–38]. This air pollution crisis has become a major public health issue, contributing to a surge in respiratory illnesses and exacerbating pre-existing health conditions among the city's population. The crisis is largely driven by vehicular emissions, industrial activities, construction dust, and agricultural residue burning in nearby states like Punjab and Haryana [47].

4.1.2. Climate-Health Correlations in Delhi

The relationship between air pollution and health outcomes in Delhi is complex and multifaceted, with climate change playing an increasingly prominent role. Rising temperatures and altered precipitation patterns due to climate change are contributing to the intensity and persistence of air pollution. For instance, higher temperatures in the summer can accelerate the chemical reactions that lead to increased ozone levels, while the winter months often exacerbate particulate pollution due to lower wind speeds and temperature inversions that trap pollutants in the air [31, 39, 45]. These climate-related changes are creating a hazardous environment, particularly in urban areas like Delhi, where the pollution levels frequently exceed the safe limits recommended by the World Health Organization [1].

4.1.3. Respiratory Impacts of Air Pollution

The respiratory impacts of air pollution in Delhi are severe, with an increasing number of individuals suffering from chronic respiratory diseases, including asthma, chronic obstructive pulmonary disease (COPD), and bronchitis. The exposure to fine particulate matter, especially PM2.5, has been linked to a range of respiratory problems, as these tiny particles can penetrate deep into the lungs and even enter the bloodstream, leading to systemic inflammation [48]. Studies indicate that the long-term exposure to high levels of air pollution in Delhi is directly associated with an increase in respiratory hospital admissions and mortality rates due to respiratory diseases [49].

- Asthma: The rise in asthma cases among both children and adults in Delhi can be attributed to the chronic exposure to high levels of air pollution. A study by Salvi et al. [50] found that air pollution, particularly PM2.5, is a significant trigger for asthma exacerbations, contributing to higher rates of emergency room visits and hospitalizations in Delhi.
- Chronic Obstructive Pulmonary Disease (COPD): Air pollution is also a major risk factor for the development and progression of COPD. A study found that long-term exposure to ambient air pollution in Delhi significantly increases the risk of COPD, leading to long-term health consequences, reduced lung function, and increased premature mortality [51].
- Lung Cancer: In addition to respiratory diseases, exposure to air pollution in Delhi has also been associated with an increased risk of lung cancer. According to a study by Dutta & Jinsart [51], the risk of lung cancer is elevated among individuals living in highly polluted areas of Delhi, with the carcinogenic effects of particulate matter contributing to the high incidence of the disease.

4.1.4. Burden and Mortality

The health burden of air pollution in Delhi is staggering. A report by Singh et al. [52] estimated that air pollution in Delhi contributes to over 10,000 premature deaths annually due to respiratory and cardiovascular diseases. The economic burden of air pollution is also significant, with healthcare costs related to treating pollution-induced diseases escalating rapidly.

4.1.5. Epidemiological Data and Exposure Correlations

Epidemiological studies have shown strong correlations between air pollution exposure and respiratory health outcomes in Delhi. Data from the India-specific climate-health datasets, such as those provided by the Indian Council of Medical Research (ICMR) and Delhi Pollution Control Committee (DPCC) [53, 54], have been instrumental in analyzing the effects of long-term exposure to air pollutants on the population's health. These datasets integrate air quality data with health outcomes, enabling a more comprehensive understanding of the links between pollution levels and respiratory diseases.

For example, a study analyzed the correlations between PM2.5 levels and hospital admissions for respiratory diseases in Delhi. The study found that a 10 $\mu g/m^3$ increase in PM2.5 levels was associated with a significant increase in hospital admissions for conditions such as asthma and COPD, especially among children and the elderly [51]. Additionally, the study revealed that the seasonal variation in air quality had a substantial impact on the frequency of respiratory disease exacerbations, with pollution spikes during winter leading to a marked increase in the number of emergency visits and hospitalizations [51].

4.1.6. Public Health Implications

The air pollution crisis in Delhi has serious public health implications, particularly for vulnerable groups such as children, the elderly, and individuals with pre-existing respiratory conditions [55]. Public health authorities are increasingly focusing on interventions aimed at reducing exposure to air pollution, including enhancing air quality monitoring systems, implementing stricter emission controls, promoting cleaner energy sources, and encouraging the use of public transportation. Additionally, increasing public awareness about the health risks of air pollution and encouraging behaviors such as the use of air purifiers, masks, and avoiding outdoor activities during high pollution periods are also vital measures to protect public health [56].

4.2. Climate Migration in Sub-Saharan Africa

Desertification and drought are driving migration, impacting health outcomes across borders. Desertification and recurrent droughts reduce agricultural productivity and heighten food insecurity, prompting rural-to-urban migration and cross-border displacement [42–44, 57, 58]. Climate migration in Sub-Saharan Africa (SSA) is shaped by hazard–exposure–vulnerability pathways that link environmental stressors to human mobility [45].

Historical evidence shows significant increases in drought frequency and intensity, with major continental events in 1972–73, 1983–84, and 1991–92, and the Horn of Africa drought of 2010–11 among the worst in six decades [57]. These climate-related events intersect with rapid urbanization, and entrenched service gaps, pushing rural households toward towns and secondary cities even as those destinations face mounting risk [58, 59]. These movements follow hazard–exposure–vulnerability pathways and are mediated by local governance capacity, labor markets, and social protection coverage [44].

Intensifying heatwaves compound these vulnerabilities, with projections indicating that over 60% of urban populations in West and Central Africa will experience strong to extreme heat stress by late century under high-emission scenarios [60, 61]. Together, recurrent drought, agricultural losses, escalating heat, and fragile urban governance convert climate hazards into mobility pressures, from short-term, seasonal movements to protracted displacement [42, 43, 45, 59]. The time series (Figure 3) highlights punctuated, high-severity drought episodes consistent with continent-scale events in 1972–73, 1983–84, 1991–92, and the 2010–11 Horn of Africa drought, reflecting the documented rise in the frequency, intensity, and spatial extent of African droughts over the last five decades [57].

Land-use and land-cover change (LULCC) in SSA amplifies (Figure 4) climate risks and migration pressures. Remote sensing analyses covering 1993 to 2023 demonstrate a 134% increase in built-up areas between 1993 and 2023, accompanied by declines in grasslands (-14%) and farmlands (-15%), while water bodies expanded by 72% [62, 63]. These transformations intensify the urban heat island effect, raising land surface temperatures and exacerbating heat stress. Causal analyses confirm that built-up growth strongly drives higher temperatures, whereas forests and water bodies exert cooling effects and correlate positively with rainfall [62, 63]. Forward simulations to the 2033–2053 horizon indicate continued urban expansion ($+41.5\%$), vegetation loss, and peak temperatures approaching $36.9\ ^{\circ}$C, alongside declining rainfall in several zones. These hydro-climatic shifts intersect with demographic growth and economic precarity to increase exposure to heat waves, floods, and water scarcity, key drivers of rural-to-urban migration and cross-border displacement [45, 63].

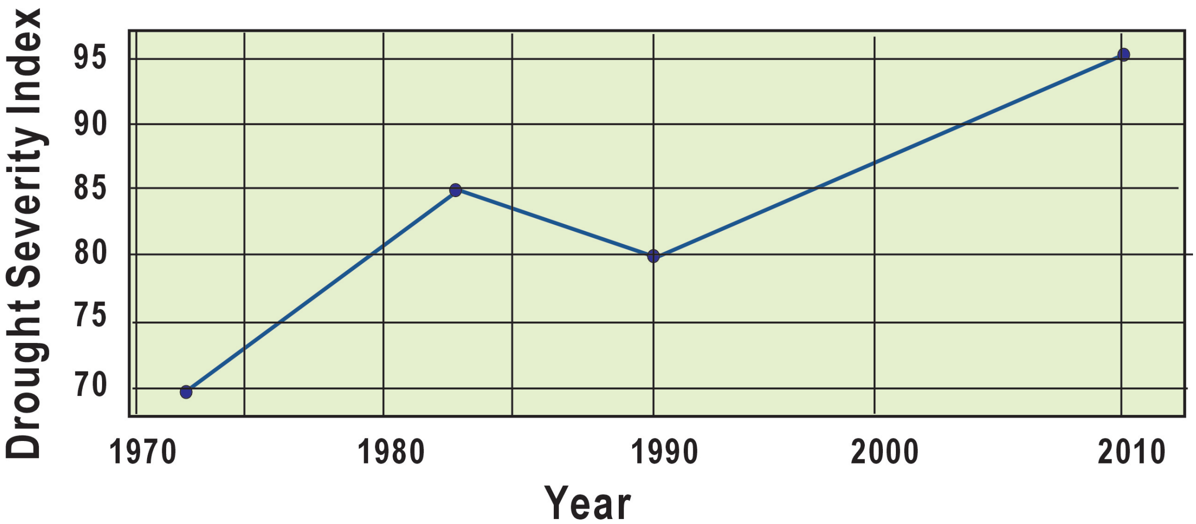

Figure 3. Historical drought frequency and intensity in SSA (1972–2011) based on droughts frequency/intensity with landmark events in 1972–1973, 1983–1984, 1991–1992, & 2010–2011 from [57].

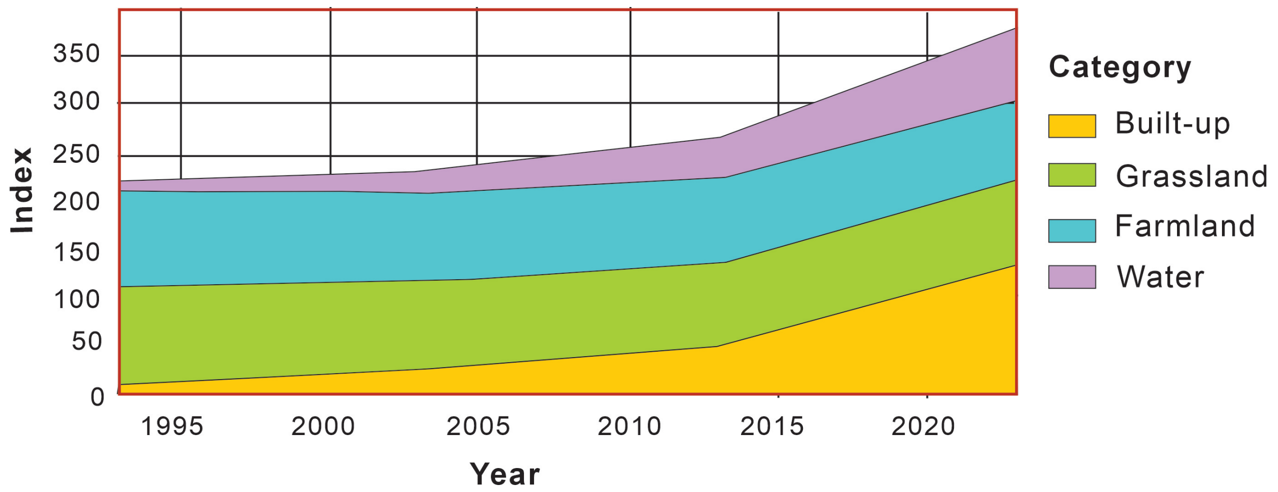

Figure 4. Land-use/land-cover change trends in SSA (1993-2023) based on remote sensing derived estimated indices for built-up area, grassland, farmland, and water bodies between 1993 and 2023 and documents continentwide LULCC trends using Landsat imagery & machine learning [62].

Reducing involuntary displacement in SSA requires integrated, justice-centered adaptation that couples early warning with service delivery and social protection. Urban water insecurity remains a proximate trigger of mobility; despite investments, many cities experienced limited gains in access and persistent inequities, particularly in informal settlements [58]. Children and migrants face elevated risks of malnutrition, heat-related illness, infectious disease, and mental-health stress in overcrowded, under-serviced settings, demanding climate-resilient health systems and targeted WASH interventions [45, 64]. At regional scale, cross-border public-health surveillance rooted in One Health and mobility-aware risk communication can strengthen preparedness for climate-sensitive outbreaks and coordinate responses along migration corridors [65].

Finally, trade and investment can complement adaptation by de-risking critical infrastructure (e.g., ports and corridors), expanding access to clean energy, and mobilizing private capital for resilience, provided policies are designed to reduce inequities and close the adaptation finance gap [66, 67].

4.3. Socioeconomic and Ecosystem Collapse

Climate change has evolved beyond a public health issue it represents a national and global security emergency. Indeed, the Intergovernmental Panel on Climate Change warns that "Any further delay in concerted global action will miss a brief and rapidly closing window to secure a liveable future" [45].

"At $3\ ^\circ$C or more of warming by 2050, projections indicate the potential for more than 4 billion deaths, significant sociopolitical fragmentation, widespread state failure, and irreversible losses of ecosystems and capital, conditions consistent with planetary-scale collapse".

Environmental degradation erodes economic stability, displaces populations, and accelerates inequality [45, 68]. We are already warned that "Yield, quality, and predictability of [food] supply from many of our most critical sourcing regions is not something we will be able to rely upon over the coming years" [68]. Economic collapse is already beginning, actuaries warning that "our economy may not exist at all if we do not mitigate climate change" [69]. Already, "the world economy is committed to an income reduction of 19% within the next 26 years independent of future emission choices" corresponding to, "global annual damages in 2049 of 38 trillion in 2005 international dollars" [70]. But this may be an underestimate: "The global economy could face a 50% loss in GDP between 2070 and 2090, unless immediate policy action on risks posed by the climate crisis is taken" [66].

As agricultural productivity declines and water scarcity intensifies, competition for essential resources fuels social unrest, migration, and armed conflict. These stresses destabilize governments, overwhelm public-health systems, and fracture already fragile supply chains [7, 45, 71].

The interconnected nature of modern economies amplifies these vulnerabilities. A drought in one region can spike global food prices, while flooding elsewhere may cripple transport networks or energy grids. These cascading failures form a self-reinforcing cycle: environmental loss undermines economic resilience, which in turn weakens health infrastructure and social order [7, 71].

Maintaining human health and societal stability in the coming decades will require an integrated strategy that unites economic, environmental, and security planning. Policies that mitigate emissions must be matched by investments in sustainable infrastructure, equitable access to resources, and community-level resilience [67, 68, 72]. Addressing these interlinked systems holistically will be critical to preventing ecosystem collapse from translating into global human catastrophe: without action, "accelerating greenhouse gas emissions.... culminate in a mass extinction rivalling those in Earth's past" [67].

5. The Role of Technology in Adaptation

As Section 4 highlighted, the escalating effects of climate change are no longer confined to local or sector-specific impacts, they now threaten the stability of societies, economies, and global health systems (Figure 5).

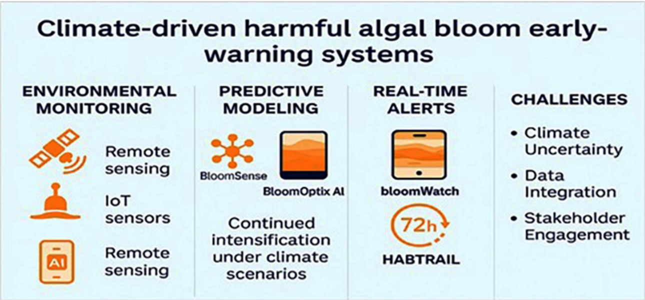

Figure 5. Technological innovations and policy frameworks for climate-driven HAB early-warning systems, including AI platforms, citizen science apps, and integrated management strategies.

In this context, technology emerges as a critical enabler of adaptation and resilience. From predictive analytics and early-warning systems to digital platforms that connect individuals with care and information in real time, technological innovation provides the tools to bridge awareness, prevention, and response.

Building upon Montgomery's framing of climate change as a systemic crisis, this section explores how digital health solutions, environmental sensing, and decision intelligence platforms can mitigate climate-driven risks. At the forefront is MyJEEVA, a human-centered digital-health ecosystem originally designed to reduce hospital readmissions but now evolving into a climate-health adaptation framework [72]. MyJEEVA demonstrates how patient-engagement tools can be expanded to deliver localized environmental alerts, behavioral guidance, and community feedback loops; transforming the public from passive recipients of information into active participants in climate resilience [73].

The subsections that follow examine how technology can:

1. Translate environmental and health data into actionable insights
2. Enable real-time risk communication and early-warning systems, and
3. Foster adaptive, equitable health responses through AI-driven personalization and data integration.

Together, these technological interventions form the foundation of a Decision Intelligence driven public-health network, capable of supporting both individual well-being and systemic climate resilience.

To avoid conceptual overlapping, it is important to distinguish between Decision Intelligence (DI) and digital health systems. DI refers to the analytical and modeling framework that integrates climate, environmental, and health data to support forecasting, scenario planning, and policy decision making. In contrast, digital health systems, such as MyJEEVA, OBIS, HAB dashboards, and Pathway Analytics, are the operational platforms that deliver real-time monitoring, patient engagement, and care coordination. While complementary, DI functions as the strategic decision support layer, and digital health systems serve as the implementation layer that translates insights into clinical and public-health action.

5.1. Digital Health Platforms and Climate Intelligence

Digital health platforms are uniquely positioned to connect environmental risk information with clinical and community-level action. MyJEEVA, a human-centered digital-health ecosystem originally designed to reduce hospital readmissions, illustrates how patient-care technology can evolve into a climate-health intelligence system [72].

The platform's architecture enables continuous data exchange among patients, caregivers, and providers through adaptive dashboards and mobile engagement. This same infrastructure can be expanded to integrate real-time environmental alerts, such as air-quality indices, heat-stress warnings, or flood notifications.

Through localized geospatial mapping and user profiling, MyJEEVA can deliver personalized protective guidance, for instance, advising hydration during heatwaves or restricting outdoor exposure during high-pollution events. Its feedback-loop capability further empowers communities to report symptoms or environmental observations, creating a dynamic population-level dataset. When aggregated, these data provide early indicators for health departments to deploy resources or issue public advisories.

Thus, MyJEEVA demonstrates how digital-health systems can transcend the clinic to become decision intelligence platforms for adaptive public-health management [72, 73].

5.2. Early-Warning Systems and Predictive Analytics

Effective climate adaptation requires identifying threats before they escalate into full-scale crises. The Climate-Driven HABs exemplifies a One Health-based predictive-surveillance model [74, 75]. Early warning systems for Climate-driven HABs are evolving to address the accelerating occurrence and severity of blooms under climate change. Historical analyses reveal that HABs prevalence were relatively low before the mid-20th century but have expanded dramatically since the 1960s due to coastal development, elevated nutrient levels in water, and warming trends [76–78]. Global satellite-based assessments show that bloom frequency in large lakes has increased by 1.8% annually from 2003 to 2022, with the most prominent surge after 2015, strongly correlated with rising temperatures [79]. U.S. data compiled in the ArcGIS HAB Explorer indicate that inland waterbodies managed by the U.S.

Army Corps of Engineers have found escalating HAB intensity and spatial extent since the early 2000s, prompting the development of Sentinel-2 and Sentinel-3-based screening tools for chlorophyll-a mapping [80]. Long-term records also highlight that HAB-related health advisories and economic losses have multiplied over decades, with cyanobacterial blooms now affecting drinking water supplies and recreation nationwide [81].

To address these risks, modern early-warning systems integrate AI-driven platforms like BloomSense [82], citizen science apps such as bloomWatch [81], and commercial solutions like BloomOptix AI [83] and HABTRAIL [84]. These systems combine drone imagery, microscopy, and predictive analytics for near-real-time alerts. These innovations complemented by policy frameworks, coupled with climate-informed risk models, underscore the need for culturally tailored, adaptive, multi-scale forecasting frameworks that incorporate historical baselines, remote sensing, and socio-economic vulnerability to safeguard water security and public health.

By integrating ecological, veterinary, and clinical datasets, the system forecasts bloom events that release toxins capable of contaminating water and seafood, impairing respiratory health, and destabilizing coastal livelihoods. This HAB framework serves as a prototype for how environmental intelligence can interface with digital-health ecosystems like MyJEEVA [44, 72–75]. When HAB detection thresholds are reached, the system could automatically trigger MyJEEVA's notification module, alerting at-risk populations through geotargeted messages. Conversely, user-reported symptoms such as coughing, rashes, or gastrointestinal distress could feed back into the predictive model, enhancing its accuracy and spatial sensitivity. The result is a bi-directional surveillance loop, where environmental sensors and citizen health data reinforce one another to produce rapid, evidence-based responses. Collectively, climate-adaptive HAB early-warning systems represent a critical intersection of environmental monitoring, AI-driven analytics, and governance strategies to protect water security and ecosystem health.

Beyond algal blooms, the same analytic architecture can be scaled to other hazards including heat stress, vector outbreaks, and wildfire smoke. In sum, One Health and digital health together form essential and complementary pillars in a global early-warning system.

5.3. Decision Intelligence for Adaptive Health Systems

Decision Intelligence (DI) represents the fusion of analytics, behavioral science, and systems thinking to guide complex decisions under uncertainty [73]. It integrates data, models, and outcomes into a closed loop that continuously learns from results, transforming raw information into strategic action. This framework has already demonstrated success in oncology and can be repurposed for climate-health adaptation.

At MD Anderson Cancer Center, the Oncology Business Intelligence System (OBIS) and Partner Assessment Tool for Healthcare (PATH) serve as flagship examples of Decision Intelligence in practice. As outlined in Nair et al. [73], these platforms synthesize large datasets spanning clinical performance, market demand, population demographics, and financial trends. Through predictive modeling and scenario simulation, OBIS enables health-system leaders to identify growth opportunities, optimize resource allocation, and quantify risk across the oncology service continuum. PATH extends this capability by integrating partner hospital data and geospatial analytics to inform strategic expansion and network coordination. Together, they illustrate how Decision Intelligence can transform traditional business analytics into a continuous learning ecosystem.

Translating these principles to climate adaptation, the same analytical architecture can ingest environmental and epidemiological data to model regional health vulnerabilities. By coupling temperature, air-quality, and vector-surveillance datasets with socioeconomic indicators, DI frameworks can forecast disease burdens and predict systemic stress on health-care capacity. When embedded within digital-health platforms such as MyJEEVA [72], Decision Intelligence can generate context-aware recommendations, alerting users to environmental hazards, optimizing treatment pathways during disruptions, and helping policy makers prioritize preventive interventions.

Beyond prediction, Decision Intelligence also enables feedback-driven evaluation. Each policy or clinical action feeds data back into the system, refining future decisions in a cycle of evidence-based learning. In this way, OBIS and MyJEEVA offer a template for how Decision Intelligence can evolve into a core component of climate-resilient health systems, linking environmental monitoring, clinical operations, and community engagement into a single, adaptive continuum of care.

5.4. One Health–Digital Health Integration

True resilience requires the convergence of two knowledge domains: One Health concept, which is a collaborative, multisectoral, transdisciplinary, and transdisciplinary framework that recognizes the interconnection between people, animals, plants, and their shared environment to address complex health risks. This combination unites environmental and biological surveillance, and Digital Health, which engages communities through data-driven care. Integrating these approaches creates a closed-loop system of awareness, prediction, response, and robust foundation for proactive health management in the face of increasing climate-driven challenges.

In this hybrid model, One Health frameworks for HAB Early-Warning System could feed ecological and toxicological signals into MyJEEVA's digital infrastructure. MyJEEVA then returns real-time human health feedback to refine predictive accuracy [44, 72–75]. The synergy of these platforms forms the foundation for Decision Intelligence-driven public-health networks. In these networks, data from satellites, sensors, and citizens converge to protect both people, animals, plants, and the entire ecosystems [85, 86]. The emerging concept of One

Digital Health operationalizes this integration by leveraging machine learning models powered by AI, big data, and federated data systems. The federated data system ensures datasets remain distributed across multiple sources but analyzed collaboratively without centralizing sensitive identifiers. This will help [87, 88]. Digital health platforms could strengthen this framework to overcome fragmented data landscapes and enhance predictive capabilities for zoonotic disease, antimicrobial resistance, and climate-linked health threats.

Digital health platforms, such as telemedicine, IoT-enabled biosurveillance, and citizen-reporting apps, extend this framework by fostering participatory monitoring and equitable access to care [89, 90]. By enabling this integration, technology transitions from a passive monitoring tool to an active adaptation agent. It serves as a distributed nervous system for planetary health capable of sensing, learning, and responding to environmental change in real time. Together, these integrated systems exemplify a significant shift toward data-driven, ecosystem-aware health governance, aligning with WHO's global digital health strategy to strengthen universal health coverage and pandemic preparedness [91].

5.5. Feasibility Considerations for Digital and AI-Driven Climate–Health Systems

While digital platforms and Decision Intelligence frameworks offer powerful tools for climate–health adaptation, their implementation faces several feasibility constraints. Integrating climate, environmental, and health data requires standardized data architectures, interoperable systems, and strong governance structures, elements that are often lacking in low-resource settings. Ethical considerations also arise, particularly around data privacy, algorithmic bias, and equitable access to AI-enabled services. Furthermore, institutional fragmentation and variations in data ownership can impede cross-sector collaboration. Addressing these challenges will require investment in digital infrastructure, clear governance policies, capacity-building within health systems, and transparent ethical frameworks to ensure that the benefits of AI and digital innovations are equitably distributed.

6. Mitigation and Resilience Strategies

Climate change presents a dual imperative for humanity: mitigation to prevent further damage and resilience to adapt to the changes already underway. Professor Hugh Montgomery's analogy of the climate crisis to a critically ill patient offers a powerful and urgent framework for understanding the stakes [7, 46, 71]. In medicine, clinicians recognize that survival depends on interventions that are both necessary and sufficiently coordinated, and comprehensive. Half measures fail; hesitation can be fatal. Montgomery (2024, 2025) asserts that humanity faces an equally time-sensitive emergency and must act with comparable urgency and precision [7, 46, 71].

Mitigation remains the foremost priority. Reducing greenhouse gas emissions is the single most effective way to avert worsening outcomes. Yet, the healthcare sector itself contributes nearly 5% of global CO_2 emissions, underscoring the need for internal reform [5]. Hospitals and health systems must lead by example through decarbonization, renewable energy adoption, sustainable procurement, and waste reduction. As Montgomery (2024) notes, "the lowest-carbon healthcare is that which prevents disease in the first place." Public health prevention thus becomes both a climate and ethical mandate [7, 71].

At the same time, adaptation and resilience strategies are indispensable. Even with mitigation, many of the health impacts of climate change like extreme heat, infectious disease spread, malnutrition, and mental health stress are already "baked in" by past emissions [71]. Health systems must therefore anticipate surging patient volumes and emerging conditions through improved infrastructure, early-warning systems, and integrated data platforms such as those outlined in Section 5. These capabilities enable proactive responses to climate-related health threats and protect vulnerable populations during environmental crises.

Montgomery's analogy introduces a profound moral dimension to climate action. Framing the planet as a critically ill patient positions the global health community not as passive observers but as active responders with both the authority and obligation to intervene [7, 71]. By adopting this framing, clinicians and scientists can engage policymakers and the public in terms that resonate deeply linking planetary health directly to human survival.

Integrating this ethical urgency with the adaptive frameworks of Decision Intelligence and digital health creates a cohesive strategy for planetary triage [72, 73]. Together, mitigation, adaptation, and innovation form a unified care plan for the Earth, one that demands the same rigor, urgency, and compassion that clinicians bring to the bedside of a critically ill patient.

7. Research and Policy Gaps

Despite the growing awareness of these issues, there remain significant gaps in both research and policy that limit the effectiveness of climate-health interventions. Addressing these gaps requires comprehensive, integrated research across disciplines, enhanced funding for climate-health studies, and inclusive policies that prioritize the most vulnerable populations.

7.1. Data-Driven Gaps in Climate-Health Surveillance

One of the most critical gaps in the current climate-health research landscape is the lack of comprehensive data-driven surveillance systems that integrate climate, environmental, and health data. Although climate-related health impacts are becoming more visible, there is limited real-time, granular data that tracks the correlations between environmental factors (like air quality, temperature fluctuations, and extreme weather) and specific health outcomes, especially in low- and middle-income countries where the impacts are often most severe [31, 39, 91].

Currently, climate-health data is often fragmented across sectors, with climate data typically housed within meteorological or environmental agencies, while health data remains separate in healthcare systems. Bridging these data silos through integrated surveillance systems is essential for monitoring the ongoing impacts of climate change on health, enabling the development of predictive models and early-warning systems for diseases that are climate-sensitive, such as malaria, cholera, and heat-related illnesses. Such integration is crucial for tracking the health burden of climate change, especially as it relates to vulnerable groups such as children, the elderly, and low-income communities, who are disproportionately affected by these environmental shifts [92].

7.2. Expanding Funding for Climate-Health Studies

Another pressing issue is the lack of adequate funding for climate-health research. While there is increasing recognition of the links between climate change and health, funding for interdisciplinary studies that explore the full scope of climate-health interactions remains limited. This lack of funding hinders efforts to conduct large-scale longitudinal studies that would provide critical insights into the long-term health impacts of climate change, as well as the social and economic costs associated with these effects.

There is a need for increased investment in research that focuses on climate-induced health risks in regions with limited resources. For instance, research on the impact of extreme heat on mortality, the spread of vector-borne diseases in newly affected regions, or the mental health consequences of climate-induced displacement is essential but underfunded. To address these challenges, both public and private sectors must commit to increasing the financial resources allocated to climate-health research, as well as fostering international collaborations to enhance data collection and sharing [93].

7.3. Inclusive Policies for Vulnerable Populations

A key area where research and policy gaps converge is in the development of inclusive policies that prioritize vulnerable populations. Climate change exacerbates existing health inequalities, disproportionately affecting marginalized communities who often have limited access to healthcare, live in high-risk areas, or have pre-existing health vulnerabilities. Vulnerable populations, such as women, children, the elderly, refugees, and those living in poverty, are particularly at risk of the health impacts of climate change, including increased morbidity and mortality from heat stress, infectious diseases, and food and water insecurity [93].

However, policies aimed at mitigating these risks often fail to adequately consider the unique needs and experiences of these groups. Inclusive climate-health policies should prioritize the most vulnerable and ensure that they are central to climate adaptation strategies.

This includes developing specific health interventions, such as improving access to clean water and sanitation, providing community-based health services, and expanding social safety nets to protect these populations from climate-related health threats [94]. Moreover, there is a critical need for policies that integrate climate adaptation with public health objectives. For instance, enhancing the resilience of healthcare systems to climate change should be a key policy priority, with investments in infrastructure, healthcare workforce training, and the provision of essential medicines and equipment. Additionally, community-driven approaches that involve vulnerable groups in the planning and implementation of health and climate policies are essential for ensuring that these interventions are effective and equitable [70].

7.4. Recommendations for Addressing Research and Policy Gaps

1. Integrated Surveillance Systems: Governments and international organizations should prioritize the creation of integrated climate-health surveillance systems that combine environmental, health, and socio-economic data. This would enable the real-time tracking of climate-sensitive diseases and health impacts, as well as the development of early-warning systems to mitigate the spread of these diseases.

2. Increased Funding for Interdisciplinary Research: There should be a concerted effort to increase funding for interdisciplinary research that explores the links between climate change and health outcomes. Research priorities should include the health impacts of extreme weather events, air pollution, vector-borne diseases, mental health, and the health consequences of migration and displacement.

3. Inclusive and Equitable Policies: Policymakers must develop and implement climate-health policies that specifically address the needs of vulnerable populations. This includes prioritizing climate adaptation and mitigation measures that reduce health risks, improve access to healthcare, and strengthen community resilience to climate-related health impacts.

4. Global Collaboration: Climate-health research requires global collaboration to share data, best practices, and resources. This can be achieved through international partnerships and funding mechanisms that focus on addressing the global health risks associated with climate change.

5. Digital-Health and Decision Intelligence Platforms for Climate Resilience: Health systems should expand the deployment of digital-health and decision intelligence platforms, including MyJEEVA, climate-driven HAB early-warning systems, OBIS, and PATH, to strengthen climate-health preparedness. These tools integrate environmental, clinical, and population-

level data to provide real-time risk communication, predictive analytics, and adaptive decision support. Scaling such platforms can enhance surveillance capacity, support timely interventions during climate extremes, and improve resilience for vulnerable communities.

8. Conclusion

The convergence of climate science, health systems research, and digital innovation highlights both the magnitude of the climate crisis and the pathways toward resolution. This review underscores that climate change is not only an environmental or economic challenge but also a profound public-health emergency one that demands the same urgency, coordination, and precision as the care of a critically ill patient.

Across the sections of this paper, a consistent theme emerges technology and intelligence systems can serve as instruments of resilience. MyJEEVA demonstrates how digital-health ecosystems [72, 73] can connect individuals, clinicians, and communities through adaptive decision frameworks, while One Health models such as Dr. Adamu's Harmful Algal Bloom (HAB) Early-Warning System show how environmental intelligence can protect both human and ecosystem health [74, 75]. The integration of Decision Intelligence, as reflected in OBIS and PATH, expands these capabilities to institutional and policy levels, transforming data into foresight and foresight into action.

Dr. Montgomery's critical care analogy reinforces that survival depends on rapid, comprehensive, and coordinated intervention [7, 46, 71]. The same principle must guide planetary health: mitigation to prevent further harm, adaptation to manage current impacts, and innovation to sustain life on a changing planet. The healthcare community, armed with both scientific authority and moral responsibility, must lead this transformation by embedding sustainability, preparedness, and equity into the very structure of care delivery.

Ultimately, the solution to the climate-health crisis lies not in isolated disciplines but in integration between environment and medicine, data and decision, prevention and resilience. Through collective intelligence and coordinated action, humanity can shift from crisis response to adaptive stewardship, treating the planet itself as a patient whose recovery depends on our shared capacity to act, learn, and heal.

Author Contributions

A.K.S.N.: Conceptualization; Methodology; Writing original draft; Supervision; Project administration. Y.A.: Formal analysis; Writing—review & editing; Validation; Visualization. H.M.: Conceptualization; Writing—review & editing; Resources. G.K.: Data curation; Visualization; Writing—review & editing. M.S.: Methodology; Validation; Writing—review & editing. N.S.: Software; Visualization; Writing—review & editing. Y.H.: Investigation; Data curation; Writing—original draft; Writing—review & editing.

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Institutional Review Board Statement

This study did not involve human participants, human data, or human tissue, and therefore did not require institutional review board (IRB) approval or informed consent.

Informed Consent Statement

Not applicable. This study did not involve human participants, human data, or identifiable personal information; therefore, informed consent was not required.

Data Availability Statement

Not applicable. No new data were created or analyzed in this study. All information presented is derived from previously published, publicly available sources that are properly cited within the manuscript.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Corresponding author Ajith Kumar S. Nair is a Co-Editor-in-Chief of Habitable Planet and was not involved in the editorial review or the decision to publish this article.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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