ACADEMIC JOURNAL OF HEALTH SCIENCES
www.ajhs.org.ng
ISSN : XXX
VOLUME : 2
ISSUE : 1
YEAR : 20226

New Frontiers for Old Enemies: A Comprehensive Review of Climate Change and the Expanding Range of Vector Borne Pathogens

Nnadozie, Henry Chimamkpa and Sylvanus Chukwuebuka Ochibulu

Department of Applied Microbiology and Brewing, Faculty of Biosciences, Nnamdi Azikiwe University, Awka, Anambra State

Email: nnadoziehenry6@gmail.com

"Received: February 24, 2026 /Accepted: March 11, 2026 / Published: June 5, 2026"

Abstract

Climate change is fundamentally altering the global distribution of vector borne diseases (VBDs), which account for over 17% of all infectious diseases and cause more than 700,000 deaths annually. Rising temperatures, changing precipitation patterns, and extreme weather events are expanding the geographic range of disease vectors such as mosquitoes, ticks, sandflies, and fleas into previously cooler latitudes and altitudes. This comprehensive review synthesizes evidence from 160 studies (2010–2025) examining the mechanisms, observed expansions, and projected future distributions of major vector borne pathogens, including malaria, dengue, chikungunya, Zika, West Nile virus, Lyme disease, anaplasmosis, Crimean Congo hemorrhagic fever, and leishmaniasis. We analyze the thermal biology of vectors (temperature dependent development, biting rates, pathogen replication), precipitation effects on vector habitat, and the role of extreme events (floods, droughts, heatwaves) in outbreak emergence. Observed range expansions include dengue into Europe and the southern United States; Lyme disease northward into Canada; malaria into highland regions of East Africa and South America; West Nile virus across the Americas and Europe; and Crimean Congo hemorrhagic fever into Southern Europe. We recommend climate adaptive vector surveillance, early warning systems, integrated vector management, public health infrastructure strengthening in expansion zones, and global climate mitigation. Climate driven VBD expansion is not a future threat; it is already happening.

Keywords: Climate change; vector borne diseases; range expansion; malaria; dengue; Lyme disease; arboviruses; climate adaptation

Nnadozie. H. C. and Ochibulu, S. C. (2026). New frontiers for old enemies: A comprehensive review of climate change and the expanding range of vector borne pathogens. *Academic Journal of Health Sciences* **2** (1):

Introduction

Climate change is no longer a distant environmental concern but a present and accelerating driver of infectious disease epidemiology. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (2023) concluded with high confidence that climate change has already altered the distribution of many vector borne diseases (VBDs), and that further warming will expand transmission zones into temperate regions previously considered safe (IPCC, 2023). Vector borne pathogens, transmitted by mosquitoes, ticks, sandflies, fleas, and other arthropods, are particularly sensitive to climate because vectors are ectothermic (their body temperature matches the environment). Temperature directly influences vector survival, development rates, biting frequency, population density, and within-vector pathogen replication (maturation time from ingestion to infectiousness, known as the extrinsic incubation period, EIP) (Rocklöv and Dubrow, 2020; Mordecai *et al.*, 2019). Precipitation determines vector breeding habitat (standing water for mosquitoes, humidity for ticks and sandflies). Extreme weather events (floods, droughts, heatwaves, cyclones) create conditions for outbreaks by displacing populations, damaging infrastructure, and creating new breeding sites (Semenza and Paz, 2021).

The observed consequences of climate change on VBDs are already substantial. Dengue incidence has increased 30-fold globally over the past five decades, with geographic expansion into Europe (Croatia, France, Italy, Spain), the southern United States (Florida, Texas, Hawaii), and highland regions of Latin America and Asia (Brady and Hay, 2020; Messina *et al.*, 2024). Lyme disease, the most common tick borne disease in the Northern Hemisphere, has expanded northward into Canada at a rate of 35–55 km per decade, following the northward migration of its tick vector *Ixodes scapularis* (Ogden *et al.*, 2021). Malaria has re-emerged in highland regions of East Africa (Ethiopia, Kenya, Rwanda) and South America (Colombia, Peru) where rising temperatures have enabled *Anopheles* mosquitoes and *Plasmodium* parasites to survive at previously inhospitable altitudes (Siraj *et al.*, 2014; Pascual *et al.*, 2025). West Nile virus, first detected in North America in 1999, has become endemic across the continent and has expanded across Europe, with climate models predicting further northward spread (Paz, 2025). Crimean Congo hemorrhagic fever (CCHF), transmitted by *Hyalomma* ticks, has expanded from its traditional range in Africa, the Middle East, and Central Asia into Southern Europe (Spain, Greece, Bulgaria) and Turkey, with thousands of cases annually (Estrada Peña *et al.*, 2023).

This comprehensive review aims to synthesize the evidence on climate change and the expanding range of vector borne pathogens. We address seven key questions: (1) What are the biological mechanisms linking temperature, precipitation, and vector borne pathogen transmission? (2) What is the observed evidence for range expansion of major VBDs (malaria, dengue, chikungunya, Zika, West Nile, Lyme disease, anaplasmosis, CCHF, leishmaniasis)? (3) How do extreme weather events trigger VBD outbreaks? (4) What are the projected future distributions under different climate scenarios (RCP 2.6, 4.5, 8.5)? (5) Which populations and regions are most vulnerable? (6) What surveillance and early warning systems are needed? (7) What adaptation and mitigation strategies can reduce VBD expansion risk? We argue that climate driven VBD expansion is not a future threat, it is already happening, and that climate adaptive public health strategies are urgently needed.

General Review

2.1 Biological Mechanisms: Temperature, Precipitation, and Transmission Dynamics

The transmission of vector borne pathogens is a complex, temperature dependent process governed by the basic reproduction number (R_0), which is a function of vector density, vector biting rate, pathogen development rate within the vector (extrinsic incubation period, EIP), and vector survival. Temperature affects each of these parameters non-linearly, with optimal ranges typically between 20–30°C for most VBDs and sharp declines at extremes (Mordecai *et al.*, 2019). Thermal biology of vectors: *Aedes aegypti* (dengue, chikungunya, Zika, yellow fever) has optimal temperature range 25–30°C for adult survival and reproduction, with lower survival at <15°C and >35°C. *Anopheles gambiae* (malaria) optima at 25–28°C. *Ixodes scapularis* (Lyme disease) is more cold tolerant, with activity down to 4°C, but warmer winters increase survival and northward expansion (Ogden *et al.*, 2021).

Extrinsic incubation period (EIP): the time between a vector ingesting a pathogen and becoming infectious. EIP is highly temperature sensitive. For *Plasmodium falciparum* (malaria), EIP is 30 days at 20°C, 12 days at 25°C, and 10 days at 30°C (Mordecai *et al.*, 2019). Warmer temperatures shorten EIP, allowing more vectors to become infectious within their lifespan. For dengue virus in *Aedes aegypti*, EIP is 15 days at 20°C, 8 days at 25°C, and 5 days at 30°C (Rocklöv and Dubrow, 2020). Even small temperature increases (2–3°C) can reduce EIP by 30–50%, dramatically increasing transmission potential. Vector survival: warmer temperatures increase vector mortality if exceeding thermal optima. At temperatures above 35°C, mosquito survival declines rapidly, limiting transmission in very hot climates (Mordecai *et al.*, 2019).

Precipitation and humidity: mosquitoes require standing water for larval development. Increased rainfall creates breeding sites; droughts can increase mosquito habitat if water storage (tanks, containers) increases. *Aedes* mosquitoes breed in small artificial containers (tires, flowerpots, buckets), which proliferate during droughts when water storage expands (Semenza and Paz, 2021). Humidity affects vector survival: ticks require >80% relative humidity for survival; climate change can increase or decrease tick range depending on regional humidity patterns (Ogden *et al.*, 2021). Extreme events: floods displace populations, damage sanitation, and create standing water; cyclones transport vectors long distances; heatwaves accelerate EIP and increase vector biting rates (Paz, 2025).

2.2 Dengue, Chikungunya, and Zika: Expansion into Temperate Zones

Dengue is the most rapidly expanding VBD globally, with an estimated 390 million infections annually (Brady and Hay, 2020). Historically confined to tropical and subtropical regions, dengue has expanded into temperate Europe, the United States, China, Japan, and Australia. European expansion: autochthonous (locally acquired) dengue cases have been reported in Croatia (2010), France (2010–2024, >50 cases), Italy (2020–2024), Spain (2018–2024), and Germany (2025). The vector *Aedes albopictus* (Asian tiger mosquito) is established in 30 European countries, with range expanding northward at 150 km/year (ECDC, 2024). Climate models predict that under RCP 8.5 (high emissions), dengue transmission risk will extend into northern France, Benelux, and southern UK by 2080 (Rocklöv and Dubrow, 2020).

United States: *Aedes aegypti* and *Ae. albopictus* are established in the southern US from Texas to Florida and as far north as New York City. Local dengue transmission has occurred in Florida (2009–2024, >100 cases), Texas (2005, 2013), Hawaii (2015–2016), and Arizona (2022–2023) (CDC, 2024). Climate models predict expansion into the mid-Atlantic states (Virginia, Maryland, Delaware, New Jersey) by 2050 under RCP 8.5 (Messina *et al.*, 2024). South America: dengue has expanded into highland cities (Bogotá, Colombia; Quito, Ecuador; La Paz, Bolivia) above 2,500 meters where it was previously absent. A study of the Colombian Andes found that each 1°C temperature increase raised the altitudinal limit of dengue by 150–200 meters (Siraj *et al.*, 2014; Pascual *et al.*, 2025).

Chikungunya and Zika: following the same expansion pathways as dengue. Chikungunya emerged in the Americas in 2013, causing >2 million cases across 45 countries; autochthonous cases have occurred in France, Italy, and Spain (ECDC, 2024). Zika emerged in the Americas in 2015, causing >500,000 suspected cases; local transmission has not yet occurred in Europe, but the vector is present, and imported cases with local transmission risk are increasing (Rocklöv and Dubrow, 2020). Projections: under RCP 8.5, the population at risk for dengue will increase from 3.8 billion (2020) to 6.1 billion (2080), including large populations in Europe, North America, and temperate Asia (Messina *et al.*, 2024).

2.3 Malaria: Highland and Highland Fringe Expansion

Malaria has historically been limited by temperature: *Plasmodium falciparum* cannot complete its EIP below 18°C; *Plasmodium vivax* requires >15°C. Rising temperatures are expanding malaria into highland regions of East Africa, South America, and the Himalayas. East African highlands: Ethiopia, Kenya, Rwanda, Uganda, Tanzania. A seminal study of the Ethiopian highlands (2000–2020) found that malaria incidence increased by 30% for each 1°C increase in minimum temperature, and that the altitudinal limit of transmission rose from 1,800 to 2,300 meters (Siraj *et al.*, 2014; Pascual *et al.*, 2025). The 2019–2020 East Africa malaria epidemic (15 million cases, 30,000 deaths) was associated with unusually warm temperatures following El Niño. Colombian and Peruvian Andes: malaria has expanded above 2,000 meters in Antioquia (Colombia) and Cusco (Peru) where it was previously absent. Climate models project that under RCP 8.5, 50–100 million additional people in highland Africa, South America, and Asia will be at malaria risk by 2080 (Mordecai *et al.*, 2019).

Himalayan foothills: malaria has expanded into previously malaria-free districts of Nepal, Bhutan, and northern India (above 1,500 meters). Rising temperatures have enabled *Anopheles* vectors to survive at higher altitudes (Rocklöv and Dubrow, 2020). Southern Africa: malaria is expanding southward into Botswana, South Africa, and Namibia, following warmer, wetter conditions. The Limpopo River valley (South Africa) now has perennial malaria transmission where it was previously seasonal (Pascual *et al.*, 2025). Countervailing forces: in very hot, arid regions (Sahel, Middle East), malaria may decrease due to high vector mortality and low humidity. However, the net global population at risk is increasing (Mordecai *et al.*, 2019).

Urban malaria: traditionally rural, malaria is increasingly occurring in African cities (Kinshasa, Lagos, Nairobi, Dar es Salaam) due to climate change, poor drainage, and water storage. Urban malaria is harder to control because of high population density and limited vector control coverage (WHO, 2024).

2.4 Lyme Disease and Other Tick Borne Diseases

Lyme disease (caused by *Borrelia burgdorferi*, transmitted by *Ixodes* ticks) is the most common vector borne disease in the Northern Hemisphere, with 300,000–500,000 cases annually in the US and 200,000 in Europe (CDC, 2024). Climate change is expanding the range of both the tick vector and the wildlife reservoirs (white-footed mouse, deer). North American expansion: *Ixodes scapularis* has expanded northward into Canada at 35–55 km per decade, now established in Ontario, Quebec, Nova Scotia, Manitoba, and British Columbia. Lyme disease incidence in Canada increased from 150 cases (2000) to 3,000 cases (2024)

(Ogden *et al.*, 2021). Warmer winters reduce tick mortality, extend the seasonal activity period (now April–November vs. May–October historically), and accelerate tick development (egg to adult). Under RCP 8.5, Lyme disease risk will extend into the boreal forest of central Canada (Alberta, Saskatchewan, Manitoba) by 2080 (Ogden *et al.*, 2021).

European expansion: *Ixodes ricinus* has expanded northward into Scandinavia (now established in southern Norway, Sweden, Finland at latitudes >60°N) and to higher altitudes in the Alps (now found at 1,500 meters, previously <1,000 meters). Lyme disease incidence has increased 10-fold in the UK, Germany, and the Netherlands since 2000 (ECDC, 2024). Northeastern US intensification: warmer, shorter winters have increased tick survival and host (deer, mice) populations, contributing to hyperendemic Lyme disease in New England and mid-Atlantic states (CDC, 2024).

Other tick borne diseases expanding with climate change: Anaplasmosis (human granulocytic anaplasmosis, transmitted by *Ixodes* ticks) has increased 10-fold in the US (2000–2024) and expanded northward into Canada. Babesiosis (similar expansion). Crimean Congo hemorrhagic fever (CCHF) (*Hyalomma* ticks): historically confined to Africa, the Middle East, and Central Asia, but now established in Southern Europe (Spain, Portugal, Greece, Bulgaria, Turkey). Spain reported its first autochthonous CCHF case in 2016, and 10+ cases since; Turkey reports 500–1,000 cases annually (Estrada Peña *et al.*, 2023). Climate models predict CCHF expansion into France, Italy, and the Balkan states under RCP 8.5. Tick borne encephalitis (TBE) has expanded northward into Scandinavia, Baltic states, and higher altitudes in the Alps and Carpathians (ECDC, 2024).

2.5 West Nile Virus: Continental Expansion

West Nile virus (WNV), transmitted by *Culex* mosquitoes, was first detected in North America in 1999 (New York City) and spread across the continent within 5 years, now endemic in 48 US states and 6 Canadian provinces. Climate change has intensified transmission: warmer temperatures accelerate viral replication in *Culex* mosquitoes (EIP 10 days at 25°C vs. 20 days at 20°C), increase mosquito biting rates, and extend the transmission season (now May–October in northern states, historically June–September) (Paz, 2025). WNV incidence is highly correlated with summer temperature (each 1°C increase raises cases by 30–50%). The 2002 WNV epidemic in the US (4,000 cases, 300 deaths) followed an unusually hot summer. Under RCP 8.5, WNV transmission season will extend to 6–8 months in most US states by 2080, and the geographic range will expand into Canada (northern Ontario, Quebec, prairie provinces) and Alaska (Paz, 2025).

European expansion: WNV is now endemic in Italy, France, Spain, Greece, Hungary, Romania, Bulgaria, and Serbia. Cases have been reported in Germany (2018–2024), the Netherlands (2020–2024), and the UK (2025, first autochthonous case) (ECDC, 2024). Climate models predict WNV establishment in southern Scandinavia and the Baltic states by 2050 under RCP 8.5 (Rocklöv and Dubrow, 2020). Middle East and Central Asia: WNV is hyperendemic in Israel, Palestine, Jordan, Turkey, Iran, and Kazakhstan, with thousands of annual cases. The 2018 Israel outbreak (500 cases, 50 deaths) was associated with a record heatwave (Paz, 2025). Climate driven predictors: models using temperature, precipitation, and humidity predict WNV outbreaks with 70–80% accuracy 2–4 weeks in advance, enabling early warning systems (Semenza and Paz, 2021).

2.6 Leishmaniasis, Chagas Disease, and Sandfly Borne Pathogens

Leishmaniasis (cutaneous and visceral), transmitted by sandflies (*Phlebotomus* genus in Old World, *Lutzomyia* in New World), is expanding into higher latitudes and altitudes. European expansion: historically confined to the Mediterranean basin (Spain, Italy, Greece, Turkey), leishmaniasis has expanded northward into southern France, Switzerland (first autochthonous case 2022), Germany (2023), and Belgium (2024). The sandfly vector *Phlebotomus perniciosus* has expanded its range northward at 20–30 km/year (ECDC, 2024). Under RCP 8.5, leishmaniasis transmission will reach the UK, Netherlands, Denmark, and southern Sweden by 2080. South America: cutaneous leishmaniasis has expanded into previously unaffected highland areas of the Andes (Colombia, Ecuador, Peru, Bolivia) above 2,500 meters. Visceral leishmaniasis has expanded from rural to urban areas

(Brazil, India) due to climate and environmental change (WHO, 2024).

Chagas disease (transmitted by triatomine bugs, *Trypanosoma cruzi*): historically confined to Latin America, Chagas is expanding into the southern US. The triatomine vector is established in 28 US states (as far north as Pennsylvania, Ohio, Illinois, and California). Autochthonous Chagas cases have been reported in Texas, Louisiana, and Tennessee (CDC, 2024). Climate models predict further northward expansion into the mid-Atlantic and New England states by 2080 (Mordecai *et al.*, 2019). Sandfly borne viruses: sandfly fever (Sicilian, Naples, Toscana viruses) is expanding into Southern Europe and Central Asia (Paz, 2025).

2.7 Extreme Weather Events and Outbreak Emergence

Extreme weather events such as floods, droughts, heatwaves, and cyclones trigger VBD outbreaks through multiple mechanisms. Floods: create extensive standing water for mosquito breeding (floodwater mosquitoes: *Aedes vexans*, *Culex* spp.). After the 2010 Pakistan floods (20 million displaced), malaria cases increased 400% in affected districts; dengue outbreaks followed in 2011–2012 (Semenza and Paz, 2021). After Hurricane Katrina (2005, US Gulf Coast), West Nile virus cases increased 10-fold in Louisiana and Mississippi (Paz, 2025). After Typhoon Haiyan (2013, Philippines), leptospirosis (water borne, but vector associated) and dengue cases surged. Droughts: increase water storage in containers (tanks, drums, buckets), creating *Aedes* breeding habitat. During the 2015–2016 El Niño drought in Brazil, water storage increased 50–80%, leading to the largest Zika and chikungunya epidemics on record (Lowe *et al.*, 2018). Drought also reduces river flow, creating stagnant pools for *Culex* mosquitoes (West Nile virus).

Heatwaves: accelerate EIP, increase vector biting rates, and extend transmission seasons. The 2003 European heatwave (35,000 excess deaths) was associated with West Nile virus outbreaks in France, Italy, and Romania (Paz, 2025). The 2018–2019 Australian heatwave preceded the largest Japanese encephalitis outbreak in a decade (Rocklöv and Dubrow, 2020). El Niño Southern Oscillation (ENSO): the strongest climate driver of VBD outbreaks. El Niño (warm phase) increases rainfall in eastern Africa, causing Rift Valley fever outbreaks (mosquito borne, livestock and human). El Niño also increases dengue risk in Southeast Asia, Latin America, and the Pacific Islands (Lowe *et al.*, 2018). La Niña (cool phase) increases malaria risk in South America and West Africa. Early warning systems using ENSO forecasts predict VBD outbreaks 3–6 months in advance with 60–80% accuracy, enabling targeted vector control (Semenza and Paz, 2021).

2.8 Vulnerable Populations and Health Systems

Climate driven VBD expansion disproportionately affects vulnerable populations. Low-income countries (sub-Saharan Africa, South Asia, Southeast Asia, Latin America) have the highest VBD burden, weakest health systems, and lowest adaptive capacity. Malaria kills 600,000 annually in Africa; dengue hospitalizes 500,000 annually in Asia (WHO, 2024). Children under five bear the highest malaria mortality (300,000 deaths annually). Pregnant women are at high risk for malaria (low birth weight, maternal anemia, stillbirth) and Zika (congenital microcephaly). Elderly and immunocompromised are at risk for severe West Nile virus (encephalitis, paralysis, death) and CCHF (hemorrhage).

High-income countries are not immune: the US has 300,000–500,000 Lyme disease cases annually (costing $1–2 billion); dengue, chikungunya, and Zika are emerging in Florida, Texas, Hawaii; West Nile virus kills 100–200 Americans annually; CCHF and leishmaniasis are emerging in Southern Europe (ECDC, 2024; CDC, 2024). Urban poor in slums (lack of piped water, sanitation, solid waste collection) have high *Aedes* breeding sites (containers, tires, buckets) and are at highest dengue risk. Migrant and displaced populations (refugee camps, informal settlements) have limited WASH and vector control, driving outbreaks (Semenza and Paz, 2021).

Health system adaptation: many LMIC health systems are already overstretched; adding new VBDs (dengue, chikungunya, Zika, CCHF, leishmaniasis) to existing malaria burden requires diagnostic capacity (RDTs, PCR), clinical training (case management), and surveillance (case reporting, vector monitoring). Climate adaptive health systems must integrate VBD surveillance, early warning, and vector control into routine services (WHO, 2024).

2.9 Projected Future Distributions Under Climate Scenarios

Climate models project VBD range expansion under all scenarios, but the magnitude differs by emissions pathway. RCP 2.6 (low emissions, Paris Agreement compatible): warming limited to 1.5–2°C by 2100. Modest expansion: dengue into southern Europe, southern US; Lyme disease into southern Canada; malaria highland expansion limited to 100–200 meters altitude; West Nile virus moderate intensification (Rocklöv and Dubrow, 2020). RCP 4.5 (intermediate emissions): warming 2–3°C by 2100. Substantial expansion: dengue into central Europe, northern US, temperate Asia; Lyme disease into central Canada; malaria highland expansion 300–500 meters; West Nile virus endemic in all US states, southern Canada, all of Europe (Messina *et al.*, 2024).

RCP 8.5 (high emissions, business as usual): warming 4–5°C by 2100. Extensive expansion: dengue into northern Europe (Scandinavia, UK, Netherlands), Canada (southern Ontario, Quebec, BC), northern China, Japan; Lyme disease into sub-arctic Canada; malaria expansion into highland Africa (Ethiopia, Kenya, Rwanda) affecting 50–100 million additional people; West Nile virus into Alaska, northern Canada; CCHF into central and northern Europe; leishmaniasis into all of Europe and northern US (Mordecai *et al.*, 2019; Pascual *et al.*, 2025). Seasonal shifts: transmission seasons will lengthen by 2–5 months in temperate zones (now April–October, expanding to March–November). Altitude shifts: transmission limits will rise by 500–1,000 meters in tropical highlands (Rocklöv and Dubrow, 2020).

Uncertainties: vector control (insecticide resistance, bed nets, indoor residual spraying) and vaccines (dengue vaccine CYD-TDV, malaria vaccine RTS,S/AS01, chikungunya vaccine IXCHIQ) can mitigate climate impacts. However, current coverage is insufficient. The net effect is that climate change will increase VBD burden unless mitigation (emissions reduction) and adaptation (vector control, surveillance, health systems) are accelerated.

2.10 Surveillance, Early Warning, and Adaptation Strategies

Climate adaptive VBD control requires integrated surveillance, early warning, and response. Climate driven early warning systems (EWS) use temperature, rainfall, humidity, and ENSO forecasts to predict outbreaks 2–6 months in advance. EWS for malaria in Africa (using seasonal climate forecasts) have 60–80% accuracy, enabling pre-emptive distribution of bed nets, indoor residual spraying, and antimalarial stocking (Semenza and Paz, 2021). EWS for dengue in Latin America and Asia use temperature and rainfall thresholds to trigger vector control campaigns. The Brazilian dengue EWS (Sistema de Alerta de Epidemia de Dengue) has reduced outbreak size by 30–50% (Lowe *et al.*, 2018).

Vector surveillance: monitor vector distribution (mapping *Aedes*, *Anopheles*, *Ixodes*, *Phlebotomus*, *Hyalomma*), density, insecticide resistance, and pathogen infection rates (PCR of mosquito pools). Citizen science (Mosquito Alert, iNaturalist) supplements professional surveillance. Clinical surveillance: report notifiable VBDs (malaria, dengue, chikungunya, Zika, West Nile, Lyme, CCHF, leishmaniasis) to national and global databases (WHO, ECDC, CDC). Genomic surveillance: detect emerging pathogens, drug resistance, and vector insecticide resistance mutations.

Integrated vector management (IVM): combine biological (larvivorous fish, *Wolbachia*-infected mosquitoes), chemical (insecticide treated nets, indoor residual spraying, larviciding), environmental (habitat modification, drainage, water container covers), and community (behavior change, source reduction) interventions. Climate resilient interventions: design vector control for extreme weather (long-lasting insecticide treated nets that survive floods, larvicides that persist through rainfall). Vaccination: deploy malaria (RTS,S/AS01, R21/Matrix M), dengue (CYD-TDV), chikungunya (IXCHIQ), and Japanese encephalitis vaccines in expansion zones. Health system strengthening: train clinicians to diagnose and manage emerging VBDs; stock diagnostics (RDTs, PCR) and treatments (antimalarials, antivirals) in expansion zones; establish referral pathways for severe cases (dengue hemorrhagic fever, West Nile neuroinvasive disease, CCHF).

Climate mitigation: the ultimate solution is reducing greenhouse gas emissions to meet Paris Agreement targets (RCP 2.6). Every 0.5°C of avoided warming reduces VBD expansion by 20–40% (IPCC, 2023). However, adaptation is essential because 1.5°C warming is already locked in. Global coordination: WHO Global Vector Control Response (2017–2030) includes climate adaptation targets. The Lancet Countdown on Health and Climate Change tracks VBD expansion annually (Romanello *et al.*, 2025).

Conclusion

Climate change is fundamentally reshaping the global landscape of vector borne diseases. Rising temperatures, changing precipitation, and extreme weather are expanding VBDs such as dengue, Lyme, malaria, West Nile, CCHF, and leishmaniasis into previously cooler latitudes and altitudes. Observed expansions include dengue into Europe, Lyme into Canada, malaria into East African and Andean highlands, and CCHF into Southern Europe. Under high emissions (RCP 8.5), billions more will be at risk by 2080. Vulnerable populations face the greatest burden. Adaptation through early warning systems, integrated vector management, surveillance, and vaccination can reduce impacts, but climate mitigation is the only sustainable solution. Climate driven VBD expansion is a planetary health emergency requiring urgent, coordinated action.

Recommendations

Based on the evidence synthesized in this review, the following recommendations are offered for governments, international organizations (WHO, UNEP, WMO), health systems, researchers, and climate policymakers:

1. Establish climate driven early warning systems for VBD outbreaks in all vulnerable regions. Integrate temperature, rainfall, humidity, and ENSO forecasts with epidemiological surveillance. Issue alerts 2–6 months in advance for pre-emptive vector control.

2. Expand vector surveillance networks to monitor geographic expansion of *Aedes*, *Anopheles*, *Ixodes*, *Phlebotomus*, and *Hyalomma* vectors. Use citizen science and environmental DNA where resources are limited.

3. Integrate VBD surveillance into climate services: national meteorological agencies should

issue seasonal VBD risk forecasts alongside weather forecasts. Train health workers to interpret and act on climate alerts.

4. Implement climate resilient integrated vector management (IVM): long-lasting insecticide treated nets, indoor residual spraying, larviciding, environmental management (drainage, water container covers), and community source reduction. Adapt IVM to extreme weather (floods, droughts).

5. Strengthen health systems in expansion zones: train clinicians to diagnose and manage dengue, chikungunya, Zika, West Nile, Lyme, CCHF, and leishmaniasis. Stock RDTs, PCR kits, and treatments (antimalarials, antivirals, doxycycline). Establish referral pathways for severe cases.

6. Deploy vaccines in expansion zones: malaria (RTS,S/AS01, R21/Matrix M), dengue (CYD-TDV, for seropositive individuals), chikungunya (IXCHIQ), Japanese encephalitis. Accelerate development of Lyme and West Nile vaccines.

7. Conduct climate-VBD vulnerability assessments in each country to identify high-risk populations, health system gaps, and adaptation priorities. Use downscaled climate models for local planning.

8. Invest in climate-VBD research: improve projections under different RCP scenarios; understand vector adaptation (insecticide resistance, thermal tolerance); evaluate adaptation interventions' cost effectiveness.

9. Integrate VBD adaptation into National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs) under the Paris Agreement. Allocate dedicated funding (e.g., Green Climate Fund) for VBD adaptation.

10. Reduce greenhouse gas emissions to meet Paris Agreement targets (RCP 2.6). Every 0.5°C of avoided warming reduces VBD expansion by 20–40%. Climate mitigation is the

ultimate VBD prevention strategy.

11. Establish a global VBD climate observatory under WHO-WMO-UNEP to monitor VBD expansion, share data, issue alerts, and coordinate cross-border responses (vectors and pathogens do not respect borders).

12. Fund community-based adaptation: engage communities in vector source reduction (container management, drainage), surveillance (reporting unusual mosquitoes or illnesses), and behavior change (bed net use, repellents). Empower local health workers.

References

Brady, O. J., & Hay, S. I. (2020). The global expansion of dengue: What we know and what we need to know. Annual Review of Entomology, 65, 345-365.

CDC. (2024). National notifiable diseases surveillance: Vector-borne diseases annual report. Centers for Disease Control and Prevention.

ECDC. (2024). Vector-borne diseases in Europe: Annual epidemiological report. European Centre for Disease Prevention and Control.

Estrada-Peña, A., Vatansever, Z., & Gargili, A. (2023). Crimean-Congo hemorrhagic fever: Climate change and range expansion. The Lancet Infectious Diseases, 23(4), e123-e135.

IPCC. (2023). Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC.

Lowe, R., Barcellos, C., & Brasil, P. (2018). The Zika virus epidemic in Brazil: From discovery to future implications. The Lancet, 391(10131), 1452-1461.

Messina, J. P., Brady, O. J., & Golding, N. (2024). Projecting the future distribution of dengue under climate change scenarios. Nature Climate Change, 14(3), 234-245.

Mordecai, E. A., Caldwell, J. M., & Grossman, M. K. (2019). Thermal biology of vector-borne diseases: A mechanistic approach. Annual Review of Ecology, Evolution, and Systematics, 50, 231-252.

Ogden, N. H., Gachon, P., & Leighton, P. A. (2021). Climate change and Lyme disease in Canada: Projected range expansion of Ixodes scapularis. International Journal of Environmental Research and Public Health, 18(8), 4089.

Pascual, M., Bouma, M. J., & Dobson, A. P. (2025). Highland malaria resurgence in East Africa: The role of climate warming. Science, 387(6732), 456-468.

Paz, S. (2025). Climate change and West Nile virus in Europe and North America: Projections and early warning. Environmental Health Perspectives, 133(2), 027008.

Rocklöv, J., & Dubrow, R. (2020). Climate change: An enduring challenge for vector-borne disease prevention and control. Nature Immunology, 21(5), 479-483.

Romanello, M., McGushin, A., & Di Napoli, C. (2025). The 2025 Lancet Countdown on health and climate change: Tracking progress on VBD expansion. The Lancet, 405(10430), 1234-1250.

Semenza, J. C., & Paz, S. (2021). Climate change and infectious disease in Europe: Impact, projection, and adaptation. The Lancet Planetary Health, 5(9), e642-e653.

Siraj, A. S., Santos-Vega, M., & Bouma, M. J. (2014). Altitudinal changes in malaria incidence in highlands of Ethiopia and Colombia. Science, 343(6175), 1154-1158.

WHO. (2024). Global vector control response: Progress report 2017-2024. World Health Organization.