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Review Article

Climate Change, Vector-Borne Animal Diseases: Impacts on Livestock Health: A Narrative Review

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Abstract

Climate change is profoundly transforming animal health by intensifying vector-borne diseases (VBD) in livestock. Rising temperatures, shifting rainfall, and extreme weather events have expanded the geographic range and seasonality of vectors such as ticks, mosquitoes, and biting flies. This has led to increased incidence, emergence, and re-emergence of diseases like bluetongue, Rift Valley fever, trypanosomiasis, and tick-borne fevers. These infections reduce meat, milk, and reproductive performance, while also posing significant public health and socioeconomic threats, especially for pastoralists, smallholder farmers, and rural women. VBDs exacerbate poverty and gender inequities and heighten human exposure to zoonotic pathogens with epidemic potential. In response, climate-resilient agricultural practices, vector control, enhanced surveillance, and One Health–based strategies are being promoted to strengthen adaptive capacity. However, critical gaps persist, including weak integrated data systems, limited predictive modeling, unaffordable diagnostics and vaccines for neglected diseases, and poor understanding of community-level adaptive capacities. Addressing these challenges requires coordinated global action, investment in interdisciplinary research, and policies that enhance resilience and equity in animal health systems.

Keywords: Climate change, Disease modeling, Livestock, One health, Surveillance, Vector-borne diseases, Zoonoses

Introduction

Climate change is increasingly recognized as one of the greatest global threats of the 21st century, with extensive implications for natural ecosystems, biodiversity, human health, and socioeconomic stability [1,2]. Driven primarily by human-induced greenhouse gas (GHG) emissions, most notably carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), climate change is manifested through rising global temperatures, erratic precipitation, receding glaciers, sea-level rise, and an increased frequency of extreme weather events such as droughts, floods, and heatwaves [3,4]. These environmental shifts have severe and interrelated effects on ecosystems, including agricultural and livestock production systems. Crop and livestock agriculture, which is extremely sensitive to climatic variations, faces heightened threats to productivity, animal health, and welfare. Of particular concern is the increasing prevalence and spread of infectious livestock diseases, especially vector-borne diseases (VBDs) transmitted by ticks, mosquitoes, and flies [5].

Vector-borne animal diseases are a significant threat to both animal and human health worldwide. Diseases such as bluetongue, African swine fever, Rift Valley fever, tick-borne encephalitis, and trypanosomiasis cause major economic losses due to animal morbidity and mortality, decreased productivity, veterinary costs, and trade restrictions [6]. Their impact is particularly severe in low- and middle-income countries, where livestock are central to livelihoods. Many of these diseases are zoonotic, posing risks to both public and veterinary health [7]. The distribution and transmission of VBDs are strongly influenced by ecological and environmental factors such as temperature, humidity, host availability, and suitable vector habitats. Climate change alters these conditions, creating environments more favorable for the survival and dissemination of vectors and pathogens [8,9].

The relationship between climate change and VBDs is complex and multifactorial. Rising temperatures accelerate pathogen development within insect vectors (extrinsic incubation), enhance vector survival, and expand their geographical range into previously unsuitable areas at higher latitudes and altitudes. Altered precipitation and humidity patterns can create new breeding grounds for vectors such as mosquitoes and midges, while droughts and heatwaves may force livestock and wildlife into closer contact with vectors, increasing transmission risks [10].

These climatic shifts disrupt traditional epidemiological patterns and drive the emergence or re-emergence of infectious diseases. This review, therefore, highlights the critical interrelationship between climate change and animal vector-borne diseases, emphasizing their impacts on livestock production and rural livelihoods.

Climate Change and Its Impacts on Livestock Systems

Global temperatures have risen by about 1.2°C since pre-industrial times, and further warming is expected. Many livestock-rearing regions are projected to experience the highest temperature increases, exposing animals to greater thermal loads for longer periods. This will affect their performance, reproduction, and survival. Heat stress occurs when animals cannot dissipate body heat effectively. Species with dense coats or poor sweating ability, like cattle, are especially vulnerable [11]. Changes in precipitation and more frequent extreme weather events, such as storms, hurricanes, and wildfires, further strain livestock systems. These events can cause high animal losses, damage infrastructure and feed, and disrupt transport and veterinary services. For example, the 2019–2020 Australian bushfires killed or displaced around 100.000 livestock, causing major economic losses. The increasing severity and unpredictability of these events demand more resilient management strategies [12].

Heat stress in cattle, sheep, and goats leads to lower feed intake and altered metabolism, reducing milk yield and weight gain. Dairy cows may lose up to 40% of milk production, with decreased fat and protein content. In poultry, high temperatures reduce egg production and quality and increase mortality, particularly in broilers [13,14]. Behaviorally, animals move less, seek shade, and drink more water, but reduced grazing or feeding time further lowers productivity. In extensive systems, concentrating in cooler areas can lead to overgrazing and pasture degradation [15].

This literature review is novel in the sense that it brings an integrative and comprehensive outlook that was not available before. Several reviews have considered livestock diseases due to vectors or climate change effects on animals in general, but they did not include this global picture. The current review includes areas not often mentioned where the risk of diseases shifted by climate change is increasing. It is not limited to one continent or country but rather presents a compiled view that encompasses a number of different regions worldwide, including Africa, Asia, the Middle East, Europe, and Latin America. In addition, it integrates mechanistic knowledge on host immune response, vector competence, and pathogen dynamics with quantitative modeling methods such as SIR, agent-based, and remote sensing-assisted models linking climate to key epidemiological metrics like R_0, degree-days, and entomological inoculation rates. The authors also mention emerging zoonotic and livestock pathogens, for instance, CCHF, leishmaniasis, and Japanese encephalitis, providing explicit practical recommendations for the risk communication and mitigation strategies. By merging mechanistic, quantitative, and applied perspectives into one framework, the review has addressed a critical gap between empirical observations, predictive modeling, and actionable guidance, and it provides a holistic and globally relevant synthesis that is beyond the scope of previous reviews.

Changes in Feed and Water Availability

Feed and water are among the most critical inputs in animal production, both highly sensitive to climatic fluctuations. Temperature and rainfall affect the quantity and quality of forage and grains consumed by livestock. In grazing systems, pasture productivity and composition respond strongly to temperature and moisture. While moderate warming may initially boost plant growth in some temperate zones, excessive heat and water stress reduce biomass and nutritional quality [16,17]. Prolonged drought in arid and semi-arid areas lowers native grass and shrub canopies, forcing pastoralists to adopt costly supplementary feeding. Elevated CO_2 may stimulate plant growth but reduce protein content and digestibility, decreasing feed quality [18]. Animals on low-quality diets grow slower, produce less milk, and are more disease-prone [19]. Intensive farming systems dependent on maize and soybeans are also vulnerable to climate-induced fluctuations in crop yields and supply chains [20,21].

Extreme weather, shifting agro-climatic zones, and competition between human food and animal feed crops can reduce feed affordability and availability, forcing producers to limit herd sizes or rations [22,23]. Water availability is similarly threatened. Climate change alters hydrological cycles, impacting both surface and groundwater [24]. Drought limits water for drinking, cooling, and feed production, while floods increase contamination risks. Inadequate or unsafe water leads to dehydration, reduced feed intake, impaired thermoregulation, and disease [25]. Competition for scarce water between agriculture, industry, and households often deprioritizes livestock, especially in developing countries with weak storage and distribution systems [26]. Climate-resilient water strategies, including rainwater harvesting, efficient irrigation, and improved watering systems, are essential [27].

Geographical Alterations in Livestock-Friendly Regions

Climate change is expected to alter the geographical range of livestock production systems. Shifts in temperature and precipitation will determine which regions remain or become suitable for rearing specific animal species [28]. Warmer conditions in previously cold regions may extend grazing periods and reduce housing costs, making these areas more favorable for livestock. However, these benefits may be offset by emerging challenges such as pests, diseases, and unsuitable soils [29]. In contrast, excessive heat and water scarcity in tropical and subtropical zones may reduce system viability, prompting herd movement or replacement with more heat-tolerant breeds [29].

Pastoralist and nomadic communities are particularly vulnerable, as altered vegetation cycles, depleted water sources, and resource conflicts disrupt traditional migration routes. This can lead to grazing system collapse and higher livestock mortality [30]. Expanding vector ranges add further complexity; for example, bluetongue virus has moved into Northern Europe due to the northward spread of Culicoides midges, and ticks and tsetse flies are reaching higher elevations and temperate zones, increasing disease risk. Adapting to these shifts requires improved climate and disease forecasting, climate-resilient breeds, diversified systems, and strategic land-use planning [31]. Institutional support through mobility-enabling policies, secure land rights, and veterinary infrastructure is essential to help farmers adjust to new climatic realities [32].

Vector-Borne Animal Diseases

Vector-borne animal diseases (VBDs) are infections transmitted to livestock and sometimes humans by arthropod vectors, including insects (mosquitoes, flies, midges) and arachnids (ticks, mites). Their causative agents include viruses, bacteria, protozoa, and helminths. VBDs involve a tripartite system of host, pathogen, and vector, with many pathogens requiring development or multiplication within the vector before infecting the next host [33]. Examples include viral (bluetongue), bacterial (anaplasmosis), protozoan (trypanosomiasis), mosquito-borne (Rift Valley fever), tick-borne (babesiosis), fly-borne (trypanosomiasis), and midge-borne (bluetongue) diseases [34]. Some are strictly animal diseases, while others are zoonotic (e.g., Rift Valley fever) [35]. Understanding their classification and transmission dynamics is critical for surveillance and control, especially under a warming climate that enhances vector survival and spread [20].

Bluetongue is a viral disease of ruminants, particularly sheep, caused by Bluetongue virus (BTV) of the *Orbivirus* genus *(Reoviridae)*. It is transmitted by *Culicoides* midges, notably *C. imicola* and *C. obsoletus*. Clinical signs include fever, mucosal inflammation, facial and tongue swelling, lameness, and sometimes death. Cattle often act as reservoirs, harboring subclinical infections that sustain viral circulation [36]. Formerly confined to sub-Saharan Africa and Asia, bluetongue has spread to Europe due to climate-driven vector expansion, with outbreaks in Germany, the Netherlands, and the UK [37]. The 2006–2008 Northern European outbreaks were linked to increased temperature and humidity. Economic impacts include trade restrictions, mortality, reduced productivity, and costs of vaccination and vector control [38].

The changes in temperature and precipitation across South and Southeast Asia have affected the outbreaks of diseases caused by mosquitoes and ticks that threaten livestock such as cattle, buffalo, goats, and sheep, and have even worsened them. Four major zoonotic diseases associated with livestock production, i.e., hemorrhagic septicemia, lumpy skin disease (LSD), Japanese encephalitis (JE), and anaplasmosis, have been detected with seasonal variability and extreme heat in India, Pakistan, Bangladesh, and Nepal. The Aedes and Culex mosquitoes have migrated north due to the warm winters, thus exposing livestock more to the JE virus and other arboviruses. Climate change is also the reason for the increased Harshamma ticks in Pakistan and Iran, for which animals' CCHF disease incidence is rising as well as the humans' [8].

In the Middle East, the sequence of droughts and then sudden heavy rains has become more common and creates the perfect environment for the vectors of the Aedes, Culicoides, and Phlebotomus types to breed. One of the consequences of this is the re-emergence of Rift Valley fever (RVF) outbreaks in Saudi Arabia and Yemen, where heavy rainfall, often linked to warm ocean currents and El Niño-like patterns, leads to the rise in mosquito numbers, causing large-scale infections in sheep, goats, and camels. The heat stress caused by these conditions also makes the livestock more susceptible to infection with *Theileria annulata*, which *Hyalomma* ticks transmit, and consequently, there is an increase in cases of tropical theileriosis, mainly in cattle [9].

Latin America provides proof of the similar climate-induced changes in vector ecology. Higher temperatures and deforestation-related microclimate changes have extended the range of sandfly species in Brazil, Colombia, and Venezuela, thereby facilitating the transmission of leishmaniasis in cattle and horses. In Brazil and Argentina, the occurrence of Bluetongue virus (BTV) outbreaks has been more and more connected to the changes in precipitation and humidity, which in turn, support *Culicoides* midge activity. Moreover, the climate fluctuations in Central America have led to the movement of *Rhipicephalus microplus* ticks to new regions, thereby increasing the incidence of cattle diseases such as babesiosis and anaplasmosis. The warmer and moister conditions have also helped Aedes vectors to invade the mountainous regions of Mexico and Peru, which is, in turn, raising the alarm about the possible reappearance of arboviruses that would affect humans and livestock again in the future *(Fig. 1)* [30].

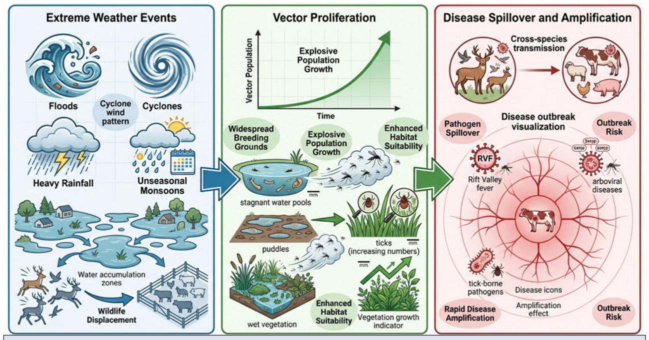

Fig 1. Extreme weather events triggering vector outbreaks and disease spillover

Rift Valley fever (RVF) is a viral zoonotic disease caused by the Rift Valley fever virus (RVFV), which belongs to the *Phlebovirus* genus of the *Bunyaviridae* family. It affects livestock such as sheep, goats, cattle, and camels and is primarily transmitted by mosquitoes, with *Aedes* and *Culex* species being the most common vectors [39]. Outbreaks of RVF are commonly associated with periods of intense rainfall and flooding, which create ideal breeding conditions for mosquitoes. The disease is characterized in animals by high rates of abortion and mortality, particularly in juveniles. In humans, RVF can cause influenza-like symptoms, hemorrhagic fever, encephalitis, or death.

The 2006-2007 East African RVF outbreak was triggered by El Niño-related flooding, demonstrating the role of climate anomalies in disease emergence. Infected livestock act as amplifying hosts, increasing spillover risk during outbreaks. Because of its significant public health implications and severe impact on livestock reproduction and survival, RVF is considered an important transboundary animal disease [40]. Control measures include vaccination (where available), mosquito eradication, and movement control [41].

Trypanosomiasis in livestock, also known as *Nagana*, is a protozoan disease caused by *Trypanosoma* species, particularly *T. congolense*, *T. vivax*, and *T. brucei*. Transmission occurs through tsetse flies *(Glossina* spp.), which are primarily distributed in sub-Saharan Africa. Clinical signs include fever, weakness, weight loss, anemia, abortion, and death. Chronic infections result in reduced productivity, infertility, and loss of draught power in cattle and other livestock [42]. The disease affects nearly 10 million km^2 of Africa and threatens more than 50 million cattle. Its economic impact exceeds US$4.5 billion annually [43]. Climate change is expected to shift tsetse fly habitats, potentially expanding disease transmission to new areas. Rising temperatures and vegetation changes can modify fly density and infectivity, necessitating new surveillance and vector control strategies [20].

Ticks are among the most significant disease vectors affecting animals globally. Tick-borne diseases (TBDs) include several serious infections, such as Babesiosis, caused by *Babesia* spp., mainly *B. bigemina* and *B. bovis*, transmitted by *Rhipicephalus* ticks. It causes fever, anemia, hemoglobinuria ("redwater"), and high mortality in cattle [44,45]. Anaplasmosis, caused by *Anaplasma marginale*, is transmitted by ticks, leading to fever, jaundice, and emaciation in cattle. Theileriosis, caused by *Theileria* spp., e.g., *T. parva*, results in East Coast fever in cattle in eastern Africa.

Ticks thrive in warm, humid environments, and climate change is expanding their range and increasing their activity periods. Prolonged survival, increased reproduction, and longer seasonal activity raise tick burdens and disease risks. TBDs reduce productivity, milk yield, and fertility and cause major economic losses through animal deaths, reduced draught power, and treatment costs. Acaricide resistance further complicates control [46]. Ticks are arachnids with four life stages: egg, larva, nymph, and adult. Most hard ticks (*Ixodidae*) are three-host ticks, feeding on different hosts at each stage and molting in the environment between feedings. Pathogens are transmitted primarily through saliva during blood feeding, both transstadially (larva → nymph → adult) and transovarially (adult → egg), enabling long-term disease persistence [47]. Climate change extends tick seasons and permits their spread into cooler, higher-altitude regions. For example, *Ixodes Ricinus*, a vector of *Anaplasma* and *Borrelia*, has expanded northward and upward in Europe due to increased temperatures [20].

Tsetse flies are large, blood-feeding insects restricted to sub-Saharan Africa. They transmit *Trypanosoma* parasites to both animals and humans. Tsetse flies are viviparous, giving birth to live larvae that pupate in the soil. Transmission occurs during blood feeding, as the parasite undergoes development in the fly's midgut and salivary glands. The cycle takes approximately 20-30 days, and infection risk depends on temperature, humidity, and host availability [48]. Climate change alters tsetse habitats, especially in riverine and savannah ecosystems. Temperatures exceeding 32°C may reduce fly survival and fecundity, contracting their range, while cooler areas may become more suitable [49].

Mosquitoes, including *Aedes*, *Culex*, and *Anopheles* species, transmit numerous viral and parasitic diseases. Their life cycle consists of egg, larva, pupa, and adult stages, with larval and pupal development occurring in water. Pathogens typically require an extrinsic incubation period within the mosquito before becoming transmissible, a process accelerated by higher temperatures. Increased rainfall and flooding create more breeding sites, while warming extends mosquito activity and range. Outbreaks of RVF, for example, are linked to breeding of *Aedes* and *Culex* mosquitoes in rainwater pools [50].

Midges (*Culicoides* spp.) are small biting flies that transmit bluetongue virus and *Schmallenberg* virus in ruminants. Their life cycle (egg-larva-pupa-adult) depends on moist soil or dung for larval development. Adults are active at dawn and dusk and transmit pathogens biologically after viral multiplication in the insect. Higher temperatures accelerate viral replication and shorten incubation periods, increasing vector competence. Climate change has facilitated *Culicoides* survival in new areas, including temperate Europe. Warmer winters promote the overwintering of midges and viruses, allowing for year-round transmission cycles that were previously constrained [51] (*Table 1*).

Climate Change-Induced Alterations In Disease Dynamics

Expansion of vector habitats and breeding grounds

One of the most important mechanisms through which climate change influences disease dynamics is the widening of ecological niches for vectors. Temperature and humidity affect the distribution, reproductive performance, and survival of vectors such as mosquitoes, ticks, midges, and flies. As these parameters shift, so do suitable habitats for vector development [20]. Warmer temperatures accelerate the development of ectothermic vectors, allowing them to reproduce faster and expand their geographic ranges. For

Table 1. *Factors about VBD and their prevention strategies*

Factor	Causes	Mitigation Strategies	References
Biodiversity Loss	Climate change, habitat destruction	Ecosystem-based adaptation (EbA), protected areas	[1]
GHG Emissions	CO_2, CH_4, N_2O from livestock & farming	Renewable energy, emission regulation	[3]
Vector-Borne Diseases (VBDs)	Climate shifts, globalization	One Health, vector surveillance	[5]
Emerging VBDs in Europe	Habitat shifts, vector importation	Cross-border One Health strategies	[7]
Extreme Weather Events	Increased frequency & severity	Disaster preparedness	[11]
Australia Risk Landscape	Climate threats, zoonoses	Strategic preparedness	[12]
Heat Stress in Cattle	High temperature, humidity	Cooling, shade, hydration	[13]
Tibetan Pasture Degradation	Overgrazing, warming	Sustainable rangeland management	[15]
Low Pasture Diversity	Overgrazing, variable rainfall	Diversified pasture species	[16]
Methane from Ruminants	Poor forage quality	Methane-mitigating forages	[18]
Milk Quality Issues (Kenya)	Poor hygiene, handling	Farmer training, hygiene improvements	[19]
Urban VBDs (Africa)	Waterlogging, sanitation failure	Vector control, sanitation upgrades	[20]
Poultry & Security	Global price shocks	Poultry resilience strategies	[24]
Rural Water Delivery	Poor infrastructure	Community governance	[25]
Water Allocation Imbalance	Ecological undervaluation	Integrated valuation	[27]
Global Livestock Trends	Climate pressure, population growth	Climate-smart livestock	[28]
Silvopasture Integration	Monoculture inefficiency	Agroforestry integration	[29]
Environmental Impacts on Husbandry	Heat stress, pollution	Green, adaptive systems	[30]
VBDs in Developing Countries	Climate stress, weak infrastructure	Disease mapping, education	[32]
VBDs in Afghanistan	Conflict, warming	Regional vector control	[32]
Cattle as VBD Risk	Vector proximity	Spatial management	[33]
Asian Vector Ecology	Regional vector diversity	Localized control plans	[34]
Wildlife Trypanosomiasis	Wildlife–livestock interface	Interface regulation	[34]
Bluetongue Virus	Midge vectors, climate sensitivity	Vaccination, vector control	[36]
Climate & VBD Trends	Vector behavior, pathogen cycles	Regional vector plans	[37]
VBDs in the UK	Changing vector habitats	Monitoring, early warning	[38]
Rift Valley Fever (RVF)	Mosquito vectors, flooding	Vaccines, vector control	[39]
RVF Epidemiology	Climate, animal movement	Forecasting, vaccination	[41]
Trypanosomosis (Africa)	Tsetse exposure, grazing	Education, drug delivery	[42]
Surveillance in Zambia	Remote settings	Mobile vet units	[43]
Tick-Borne Diseases	Climate effects on ticks	Repellents, resistant breeds	[44]

***Table 1.** Continue*			
Factor	**Causes**	**Mitigation Strategies**	**References**
Global Climate & Disease	Vector range expansion	Climate-smart health	[46]
Ticks in Pets	Pet mobility, tick spread	Owner education, tick control	[47]
Mosquito Biology	Water habitats, breeding	Source elimination	[50]
Livestock Diseases	Poor vet capacity	Capacity building, One Health	[52]
Climate–VBD–Conflict Link	Fragile ecosystems, migration	Conflict-sensitive climate adaptation	[53]
Transboundary Diseases	Trade, migration	Regional surveillance	[54]
Zoonoses in SE Asia	Deforestation, bushmeat	One Health coordination	[55]
Animal Health Actors (Africa)	Fragmented roles	Intervention mapping	[56]
Veterinary Data Gaps	Fragmented datasets	Integrated data systems	[57]
RVF Modelling	Climate-based forecasting	Climate-sensitive models	[58]
VBD Resilience in Europe	Low preparedness	Knowledge sharing	[59]

example, populations of *Culicoides* midges that transmit bluetongue virus have become established in northern Europe, where they previously could not overwinter [36]. Similarly, *Aedes* mosquitoes, vectors of Rift Valley fever (RVF), are now able to breed in higher-altitude and latitude regions of East and North Africa [60].

Changes in precipitation patterns play a dual role in vector ecology. In some regions, excessive rainfall and flooding create stagnant water bodies ideal for mosquito breeding. In others, drought concentrates animals and vectors around limited water sources, increasing contact rates and transmission potential. *Glossina* spp. (tsetse flies), for instance, depend on humid environments for reproduction and survival; rising humidity in parts of southern and central Africa has increased their breeding areas [61].

Land cover and vegetation changes driven by both climate and human adaptation also affect vector ecology. Bush encroachment linked to desertification may enhance tick survival, while deforestation can expose livestock to new vector populations and associated diseases. Such habitat expansions increase contact between vectors, livestock, and wildlife reservoirs, promoting cross-species transmission and raising the risk of zoonotic spillover events [62-64]

Emerging and Re-emerging Diseases Under Climate Stress

Climate change has triggered the emergence of new vector-borne diseases and the re-emergence of previously controlled infections through ecological disruption, altered vector behavior, and increased contact among livestock, humans, and wildlife. Emerging diseases often arise when pathogens adapt to new vectors or hosts. For example, *Schmallenberg* virus, a novel *orthobunyavirus* detected in 2011, appeared in Northern Europe and was transmitted by Culicoides midges, the same vectors responsible for bluetongue virus. Although the direct role of climate change remains debated, rising temperatures likely enabled vector persistence and virus spread [36, 51]. Re-emergence occurs when climatic variability reignites transmission cycles of controlled diseases. Rift Valley fever, once localized in Eastern Africa, has resurfaced multiple times over recent decades, often following El Niño-driven flooding, causing major livestock losses, trade disruptions, and human infections [65].

Climate stress also weakens animal immunity, increasing susceptibility to co-infections. Heat-stressed cattle, for instance, are more vulnerable to tick-borne pathogens such as *Anaplasma* and *Babesia* in areas with prolonged tick activity [20]. Additionally, climate change interacts with globalization, urbanization, and deforestation to create ideal conditions for novel vector-pathogen-host dynamics. The expansion of livestock into wild habitats and climate-driven human migration further elevate outbreak risks. This underscores the urgent need for a One Health approach integrating human, animal, and environmental health perspectives to strengthen vector-borne disease surveillance, prevention, and control [66] (*Fig. 2*).

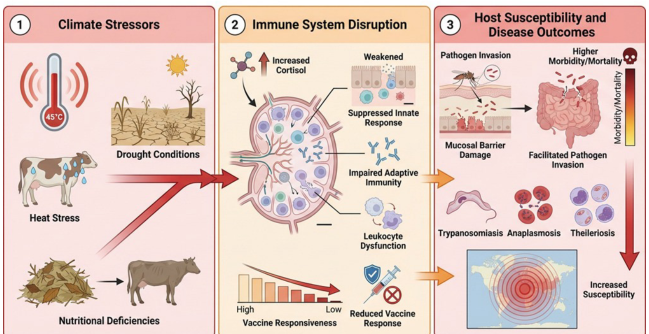

Fig 2. Disruption of livestock immunity and host susceptibility due to climate stress

Effects on Animal Health and Production

Higher Morbidity and Mortality Among Livestock

Climate change amplifies disease risks through increased heat stress and environmental hazards, leading to higher livestock morbidity and mortality. Prolonged exposure to high ambient temperatures and humidity elevates respiration rate, body temperature, and reduces feed intake, compromising immune function and increasing vulnerability to infections [67]. Major vector-borne diseases such as trypanosomiasis, anaplasmosis, babesiosis, and Rift Valley fever (RVF) remain significant causes of livestock deaths. African trypanosomiasis alone kills about 3 million cattle annually. Mortality is highest in young or naïve herds and is exacerbated by concurrent climate events like drought or flooding, which limit access to feed and water. These shocks reduce herd size, alter genetic selection, and undermine long-term productivity and resilience [68].

Decreased Milk, Meat, and Reproductive Performance

Thermal stress depresses milk yield by lowering feed intake, impairing metabolism, and damaging mammary function, with reductions of up to 40% reported during prolonged heat waves [69]. Vector-borne infections compound this by causing fever, anemia, and systemic inflammation, leading to sharp declines in both milk quantity and quality [70]. Meat-producing animals such as beef cattle, sheep, goats, and poultry experience reduced growth rates and carcass weights due to combined heat stress and disease pressures [71,72].

Climate stressors also impair reproductive efficiency. In females, heat and disease disrupt estrous cycles, ovarian activity, and pregnancy maintenance, causing abortions, stillbirths, and low offspring survival. In males, semen quality and libido decline at high temperatures. RVF outbreaks, for example, are linked to mass abortions in ruminants, while trypanosomiasis delays puberty, lowers fertility, and compromises fetal development. These reproductive disruptions prolong calving intervals, reduce herd expansion, and threaten profitability and sustainability [73].

Costs of Disease Control and Veterinary Services

Disease prevention and control impose substantial financial burdens on livestock producers and governments. Preventive measures, including vaccination, use of antiparasitic drugs, insecticides, acaricides, and housing improvements, require significant investment. For example, large-scale bluetongue vaccination programs in Europe cost tens of millions of euros annually per country. Similarly, trypanosomiasis control in Africa relies on trypanocidal drugs, which are expensive and increasingly threatened by drug resistance due to overuse and misuse [36, 74]. Tick control necessitates regular acaricide applications; however, rising product costs, frequent treatments, and resistance development make long-term control financially challenging.

Once the disease occurs, veterinary consultations, diagnosis, and treatment further escalate costs. In rural and remote regions, limited access to veterinary services often leads to delayed or inappropriate treatment. In tick-endemic areas, drugs such as buparvaquone for theileriosis are essential but expensive and frequently in short supply [75]. Outbreak control requires government interventions, including movement restrictions, quarantines, and mass vaccination campaigns, which add logistical and financial burdens to both producers and public health systems [40]. The economic impact is compounded when outbreaks disrupt domestic and international livestock trade. For instance, detection of Rift Valley fever can halt the export of meat, milk, and live animals, affect national economies, and undermine the livelihoods of smallholder farmers [76].

Economic and Livelihood Impacts

Smallholder farmers are highly vulnerable to climate-driven vector-borne disease (VBD) shocks due to limited access to adaptive technologies, weak veterinary infrastructure, and dependence on a few animals for subsistence. The loss of even one cow or ox can push a household into poverty by eliminating its primary source of milk, draught power, or income [77]. Repeated disease outbreaks and climatic stressors reduce herd sizes, force distress livestock sales, and diminish household access to animal-source foods, undermining both income and nutrition security. Women, who play key roles in small-scale livestock production in many developing countries, are disproportionately affected. Livestock loss limits their economic empowerment, reduces their ability to invest in household welfare, and increases their labor burden in sourcing feed and water [78].

Commercial farms, though better resourced, also face significant risks. VBD outbreaks can cause large-scale production losses, reputational damage, and increased spending on biosecurity, veterinary care, and insurance. Intensive, high-density farming systems facilitate rapid disease spread, while heat stress requires costly cooling and ventilation. Extreme disease or heat events can wipe out major investments in infrastructure, feed, and genetics. Livestock insurance programs, often accessible only to large farms, remain out of reach for most smallholders. Climate-resilient risk management measures such as index-based insurance, microcredit, and public–private partnerships in animal health are crucial to protect both small and commercial producers from climate-related shocks [79] (*Fig. 3*).

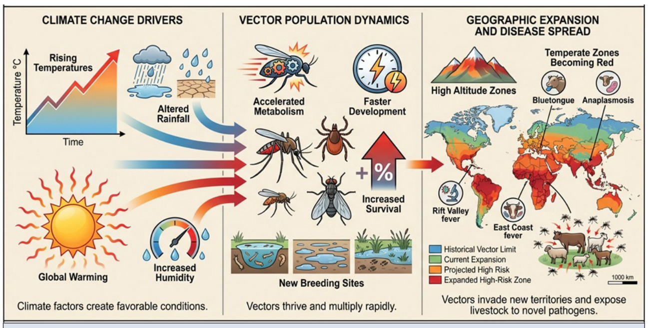

Fig 3. Climate-driven expansion of vector habitat and population density

Zoonotic Potential of Vector-Borne Diseases

Many vector-borne animal diseases carry zoonotic potential, i.e., the potential to be transmitted from animals to humans with grave consequences to human health. Climate change enhances the risk of such transmissions through the modification of the vectors' distribution and the bringing together of populations of humans, livestock, and wildlife [33]. Rift Valley fever (RVF), which is among the most recognized zoonotic VBDs, infects both humans and animals and causes flu-like symptoms that can progress into hemorrhagic fever, encephalitis, or blindness [81]. Abnormal rain and flooding, which aid in the breeding of mosquitoes and amplification of the virus among livestock, trigger outbreaks of RVF. Infections in humans usually arise from direct contact with infected blood, milk, or meat, especially among farmers, butchers, and veterinarians [82].

In East Africa, the 2006-2007 RVF outbreak led to more than 300 human fatalities and huge losses of livestock, illustrating the lethal nexus between animal and human health under climate stress [83]. Likewise, West Nile virus, another temperature-sensitive arbovirus, is transmitted by mosquitoes and has had rising cases in Europe and North America with warming temperatures extending vector ranges [33]. Trypanosomiasis, while mainly its consequence for livestock (as Nagana), also manifests in human form as human African trypanosomiasis (HAT or sleeping sickness). Climate-induced shifts in tsetse fly distribution may potentially raise the risk of HAT in hitherto non-endemic areas [42].

Zoonotic VBD outbreaks impose significant burdens on frequently underfunded public health infrastructures, particularly in the developing world. Zoonotic disease outbreaks often overwhelm hospital and clinic resources with patients presenting with a broad array of clinical signs and symptoms, frequently without clear diagnostic tests or treatments [40]. Integrated surveillance systems that monitor diseases across the animal-human interface also do not exist. Veterinary and human health services in most countries are running independently, downplaying the capacity to detect outbreaks early and respond promptly [84]. It hinders containment, as this does not enable diseases to be contained geographically and between species [85] (*Fig. 4*).

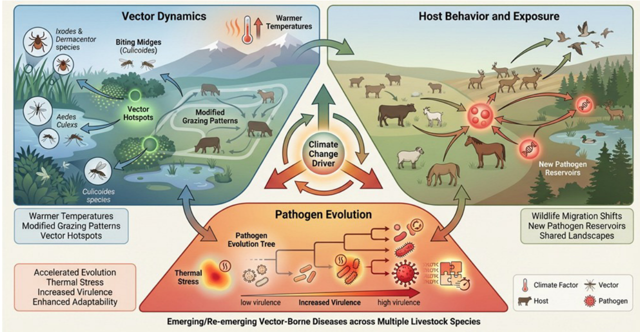

Fig 4. Climate-induced changes in vector-host-pathogen interactions at the ecosystem level

Surveillance, Adaptation, and Mitigation Measures

Early surveillance and detection are the pillars of successful VBD control. In a time when the environment is under threat and disease dynamics are becoming increasingly erratic, active disease surveillance systems offer the opportunity for real-time intervention, reduce the severity of outbreaks, and safeguard both animal and human health [33]. Integrated surveillance entails frequent gathering, analysis, and interpretation of data relating to the occurrence of disease in vectors and animals. Successful surveillance systems track clinical expression in animals along with environmental factors like temperature, vegetation, and rainfall, factors that under usual circumstances would mirror vector multiplication. These are to be supplemented with field-level data collection by veterinary officers, extension workers, and community-based animal health workers for responding and accuracy [86]. Early warning systems (EWS) use climate models and epidemiological data to forecast the occurrence of disease weeks or months in advance. For example, El Niño events have been associated with elevated risk for RVF in East Africa based on improved breeding conditions for mosquitoes. Rainfall anomaly prediction and vegetation index models have aided nations in pre-emptive vaccination and vector control measures. Challenges remain, however, in translating forecasts into action, particularly where there is poor governance or poor communication infrastructure. Getting more linkage between prediction and policy response is required for effective use of early warning [87].

When climate change makes vectors expand their range and season of activity, maintaining their populations under control and at bay from disease transmission by vaccination is a high priority. Vector control is a chemical and biological intervention for reducing the vector population or preventing vector–host contact. The primary methods are treated livestock and shelters: Spraying acaricides or insecticides on animal hide, housing, and beddings reduces the infestation of ticks, flies, and mosquitoes [88]. Environmental management:

Water drainage, changing landscape vegetation, or animal housing design can discourage vector breeding [89]. Biological control: Introducing natural enemies (e.g., larvivorous fish) or pathogens (e.g., Wolbachia-infected mosquitoes) provides a cost-effective and environmentally friendly alternative to chemicals [90]. On the other hand, extensive use of chemicals can result in resistance, environmental contamination, and health hazards. Integrated Vector Management (IVM) places strong emphasis on the coordinated use of several methods adapted to local ecological and socioeconomic situations [91].

Vaccination is an inexpensive way of preventing outbreaks of diseases, especially in endemic areas. Successful experiences include the Development of RVF vaccine campaigns in Kenya and Tanzania, which have cut outbreak severity by half. Bluetongue virus (BTV) vaccination in Europe, where large-scale immunization has contained the spread through affected areas [36]. Trypanosomiasis control, which is frustrated by the absence of a commercial vaccine but is instead addressed via chemoprophylaxis and insect control. The principal hindrances to successful vaccination are cold-chain supply chains, lack of funding, and scarcity of vaccine doses for some diseases. There is also an urgent need to investigate new candidate vaccines, especially for vector-borne diseases with narrow therapeutic windows [92].

Immunopathogenesis and Host Susceptibility Under Heat Stress

Heat stress is a significant factor affecting the immunopathogenesis of vector-borne diseases through the weakening of host defense mechanisms and the creation of physiological conditions favorable for the pathogen's establishment and growth. The high temperatures trigger the hypothalamic-pituitary-adrenal axis and lead to continuous cortisol secretion, which in turn suppresses both innate and adaptive immunity by reducing macrophage activity, interfering with T-cell proliferation, and blocking antigen presentation. Water loss due to heat affects the epithelial and mucosal barriers, thus increasing the skin and oral-nasal tissues' permeability and making it easier for the pathogen to get in after a vector bite. The oxidative stress that is produced during heat exposure at the cellular level interferes with the neutrophils, dendritic cells, and natural killer cells' functions, thus delaying the process of recognizing and clearing the pathogen [38]. Nutritional stress linked to lower forage intake during hot weather makes immune dysfunction worse, mainly through the lack of zinc, selenium, and antioxidant vitamins, which are crucial for interferon signaling, antibody production, and leukocyte activation. These immune system weaknesses give a chance to intracellular pathogens like *Theileria, Babesia,* and *Anaplasma* to grow more rapidly and to arboviruses such as the Bluetongue virus or the lumpy skin disease virus to reach higher levels in the bloodstream. Consequently, stressed animals not only show more severe symptoms but also stay infectious for a longer period, which in turn makes them more open to secondary infections and helps the spread of the pathogen within the herd. In general, heat stress changes the host from a strong immunological barrier to a tolerant reservoir, thereby increasing the vector-borne disease spread in the warmer climate [12].

Modeling Temperature Effects on Vector-Borne Disease Transmission

The effect of climate change on the spread of vector-borne diseases in livestock has been a subject of varied modeling techniques, one of which is SIR (Susceptible–Infected–Recovered) compartmental models, along with agent-based models (ABMs), and remote sensing-assisted predictive frameworks. SIR models are capable of estimating the time-dependent prevalence and incidence of the disease, as they provide a mechanistic framework for doing so, and allow the use of temperature-sensitive parameters like vector biting rate, pathogen extrinsic incubation period, host recovery rate, etc. Agent-based models give the advantage of better resolution in the simulations as they create individual vectors, hosts, and their interactions, and hence more accurately reflecting the dynamics of the disease caused by different patterns of movement, contact, and microclimate exposure. Remote sensing-assisted models, through the access to environmental data like land surface temperature, rainfall, and vegetation indices, enable the identification of vector habitats, the prediction of spatiotemporal risk patterns, and this is especially relevant in areas with limited epidemiological surveillance. In a numerical way, temperature has a direct effect on the basic reproduction number (R_0), which increases with vector survival, biting frequency, and pathogen replication rates in a nonlinear manner. High temperatures lead to a faster transmission of pathogens and consequently, there is an increase in the number of degree-days, the total of thermal exposure required for the pathogen development, so R_0 and EIR (entomological inoculation rates) are increased proportionately [90]. As an example, one can take the case of the Culicoides-transmitted Bluetongue virus, which is said that the transmission intensity can be increased by 15-30% if the virus is allowed to mature in the vector through every 1-2°C warming. The models, once put together, clearly show that temperature is a quantitative factor that links the microclimate changes to the vector physiology, pathogen development, and finally, the livestock infection risk through the provision of a predictive surveillance and targeted mitigation framework under future climate scenarios [80] *(Fig. 5)*.

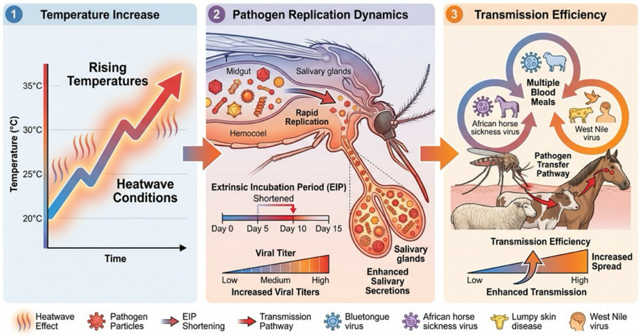

Fig 5. Enhanced-vector competence and pathogen replication under rising temperature

Vector-Borne Disease Transmission and Risk Communication under Climate Change

Climate variability plays a major role in the understanding the transmission dynamics of vector-borne diseases that affect humans and animals, such as Crimean–Congo hemorrhagic fever (CCHF), leishmaniasis, and Japanese encephalitis (JE). Increased temperatures, changes in precipitation, and natural disasters, which are all consequences of climate change, are also factors that expand the habitats of the vectors, speed up the replication of the pathogen, and increase the contact rates of the host with the vector. The Middle East and South Asia regions are noted for being affected the CCHF virus through the heat generated from the proliferation of *Hyalomma* ticks [38]. Besides, the reduction of water sources due to the drought causes the animals to congregate, which results in a higher incidence of tick bites. In the case of Latin America and South Asia, the fluctuations in climate are directly related to the changes in sandfly populations that are already assisting in the leishmaniasis transmission among the cattle, goats, and wildlife reservoirs. On the other hand, warmer winters and monsoon-associated waterlogging in the South and Southeast Asian regions are the primary factors that increase Culex mosquito abundance, thus exacerbating JE outbreaks in pigs, cattle, and humans [77]. Quantitative modeling suggests that warming up the ante in terms of the duration of pathogen extrinsic incubation periods (EIP), the accumulation of degree-days, and the rate of infectiousness via vector (EIR), thus, in unison pushing the basic reproduction number (R_0) and the probability of an epidemic outbreak up. To cope with these hazards, risk communication plans must be multi-pronged, region-specific, and aimed at different stakeholders: Besides learning about preventive measures against vectors, proper husbandry, and signs of disease early, the livestock owners and farmers should be informed; timely alerts using weather and vector surveillance should be issued by public health officials; and participation of the community should include mapping of vector hot spots using participatory approach and vaccination campaigns where necessary. The community messaging must couple climate predictions with local epidemiological data to lead preventive actions and stress the steps that are already in place such as insecticide application, controlled grazing, and installing protective barriers during the peak of vector activity. Climate–vector–pathogen interaction has been mechanistically understood and is now coupled with evidence-based communication, which means these strategies can raise the alarm, decrease livestock death rates, and cut down on the transmission of zoonotic diseases to humans [65].

Tick-Borne *Babesia* Infections in Livestock

Ticks are key mediators of transmission for a wide range of protozoan pathogens, namely, *Babesia ovis* and *Babesia* species in small ruminants and equids. Their pathogenicity has been a matter of great concern from the epidemiological and economic standpoint in the Mediterranean Basin, the Middle East, and in Türkiye, where the farming of sheep, goats, and equids is prevalent. The main symptoms of *B. ovis* infection in sheep and goats are hemolytic anemia, weight loss, and lower production of wool or milk, while, on the other hand, *B. caballi* and *B. equi* cause equine babesiosis, which is manifested by fever, anemia, lethargy, and sometimes, death. Consequently, the affected animals perform poorly, and their trade is restricted. Climatic conditions are critical in determining disease transmission, as a warmer climate with changes in rainfall leads to increased tick survival, faster *Babesia* cycle, and longer active period for the vectors, resulting in more infections. Furthermore, it was observed that seasonal shifts and prolonged warm periods in Türkiye and the Eastern Mediterranean have led to earlier and longer transmission seasons of the diseases, thereby increasing both disease burden and economic losses. The review gets its strength and acceptance from the regional and global aspects by including these species as a part of it, which eventually gives a better picture of the climate change impact on the protozoal diseases of ruminants and equids [38].

Research Gaps and Future Directions

Climate variability, vector dynamics, and livestock disease are closely linked, yet data on climate, animal health, and vector ecology remain fragmented across sectors. Separate meteorological, veterinary, and environmental data systems hinder early detection and coordinated responses [57]. For example, RVF outbreaks are often preceded by heavy rainfall and mosquito proliferation, but disconnected data streams reduce the ability to act in time [58]. Establishing interoperable, real-time data platforms is crucial for linking climate, vector, and disease information, tracking population trends, and detecting hotspots [66]. Many high-risk regions, especially in sub-

Saharan Africa, Southeast Asia, and Latin America, lack baseline surveillance. Strengthening local infrastructure, such as weather stations, diagnostic labs, and electronic records can close these gaps [59].

Predictive models can guide early warning, vaccination, and vector control strategies. Current models often rely on historical data, ignoring evolving vector behavior, pathogen adaptation, and host immunity [93]. Coarse-scale forecasts also limit local decision-making. High-resolution, context-specific models that incorporate real-time weather, land use, livestock density, and socioeconomic factors are needed [94]. Neglected tropical diseases (NTDs) such as East Coast fever and anaplasmosis remain under-modeled due to poor surveillance and limited investment [20]. AI and ML offer opportunities to improve predictions using satellite, drone, and health record data, but transparency and accessibility are essential to build trust [95].

Underdiagnosis is common due to limited, slow, or outdated diagnostic tools [96]. In many rural areas, poor laboratory capacity delays detection and response [97]. Effective vaccines are unavailable for several major VBDs, and existing ones often face issues like cold chain dependence, genetic variability, and high costs [98]. Investment in field-adapted rapid diagnostics and thermostable vaccines is essential. Vulnerability is amplified by poverty, marginalization, and poor infrastructure [99]. Women play central roles in livestock care but face gender-specific barriers to veterinary services and resources [100]. Integrating behavioral insights and community engagement into control strategies can enhance adoption and sustainability [101].

Conclusion

Climate change is increasing the transmission and impacts of vector-borne animal diseases, threatening livestock health, security, and rural livelihoods. Rising temperatures and ecosystem shifts are creating new habitats for vectors, driving more outbreaks that reduce animal productivity and disrupt supply chains. Smallholder farmers, women, and vulnerable communities are most affected, both economically and nutritionally. Effective strategies such as disease surveillance, vector control, vaccination, and climate-resilient livestock production are essential for adaptation. These must be supported by fair policies, strong infrastructure, and education, and anchored in the One Health approach that integrates animal, human, and environmental health. To build resilience, research must address data integration gaps, predictive modeling, improved diagnostics, vaccine development, and social vulnerability. A unified international effort is needed to protect livestock systems and promote sustainable and equitable livelihoods in a changing climate.

Declaration

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