Evolving threats: How climate change provokes parasitic diseases?

Review Article

Amira Ismail, Wafaa A Aboukamar, Suzan H Elgendy

Department of Medical Parasitology, Faculty of Medicine, Mansoura University, Egypt

ABSTRACT

Climate change profoundly affects the epidemiology of parasitic diseases by altering environmental conditions, vector populations and parasite system biology. In this review, the recent literature concerning the influences of climate change on vector-borne and non-vector-borne parasitic diseases was explored. A primary objective was to clarify the underlying mechanisms of these epidemiological shifts and their impact on disease dynamics and transmission behaviors. Furthermore, strategies for climate change mitigation to minimize anticipated consequences on human health were proposed. This review aims to offer a comprehensive understanding of the complex relationship between climate change, ecosystem dynamics, and the epidemiology of parasitic diseases affecting human.

Keywords: climate; diseases; epidemiology; health; parasites; transmission; vectors.

Received: 23 July, 2025; **Accepted:** 29 August, 2025.

Corresponding Author: Amira Ismail, **Tel.:** +20 1116700240, **E-mail:** a.alazab@live.com

Print ISSN: 1687-7942, **Online ISSN:** 2090-2646, **Vol. 18, No. 2, August, 2025.**

INTRODUCTION

Climate change is an established and accelerating phenomenon. While the Earth's climate system is complex, strong evidence demonstrates that significant global warming and its associated changes are actively progressing. In modern civilization, the pace of this change is rapidly driven by human activities[1]. Unlike natural climatic shifts that occur over millennia, the current fast alterations are a direct consequence of this human-induced warming[2].

Although often used interchangeably, "global warming" and "climate change" have distinct meanings. Global warming refers specifically to the long-term heating of the Earth's surface since the pre-industrial period (1850–1900), while climate change involves the broad long-term alterations in climate patterns, including temperature, precipitation, and wind. The physical effects of climate change include rising sea levels, shrinking glaciers, accelerated ice melting in polar regions, and shifts in plant blooming cycles[3]. Since the early 20th century, the planet's average temperature has risen by approximately 0.8°C (1.4°F), with two-thirds of that increase occurring since 1980[4].

The primary cause of this late warming is the emission of greenhouse gases from human activities, particularly the burning of fossil fuels. These activities release gases, *i.e.*, CO_2 and water vapor which trap heat in the atmosphere by the greenhouse effect, warming the planet's surface and lower atmosphere[5]. While natural factors involving solar variations have influenced past climate shifts[6], their impact on recent warming has been minimal. Research suggests that solar activity in recent decades may have had a slight cooling effect or no net warming impact[7].

A critical consequence of climate change is its impact on the transmission of infectious diseases. By diminishing the quality and availability of drinking water, sanitation, and irrigation resources, climate change concentrates risk factors for food-, water-, and vector-borne illnesses[8]. The expansion of geographical areas and the lengthening of seasons suitable for pathogen survival increase the likelihood of disease outbreaks and facilitate their wider spread[9].

The present review focuses specifically on parasitic diseases, whose relationship to climate change is particularly complex. While it is widely affirmed that global warming will likely promote the emergence and spread of parasitic infections, the effects extend beyond simple increases in parasitism[10]. For instance, rising temperatures can hasten a parasite's infectious ability and weaken its hosts. However, the response is not uniform; parasite virulence may increase, decrease, or change unpredictably. Furthermore, while a parasite's vital rates may improve with warmth, they decline sharply once an optimal temperature is exceeded[11]. Hosts may even manipulate warmer temperatures to fight infections by altering their thermal environment. Given these intricate and often contradictory dynamics, predicting the long-term physiological outcomes for host-parasite relationships under a changing climate remains a significant scientific challenge[2].

Food- and water-borne parasites

Transmission pathways and human factors: Food and water are the primary vehicles for parasitic infections. Contaminated food can easily introduce

 DOI: 10.21608/puj.2025.406428.1309

parasites to humans, with many food-borne parasites being zoonotic and having a worldwide distribution[12-14]. Similarly, water contaminated with parasites is a major source of infestation[15]. Transmission occurs through various means, including the consumption of contaminated items, direct oral contact, and contact with infected food handlers[16]. In environments with poor sanitation, food handlers can act as reservoirs and vectors, enhancing the spread of parasites among humans and other hosts[17,18]. Furthermore, asymptomatic carriers can significantly contribute to the prevalence of intestinal parasitic diseases by unknowingly contaminating food and water sources[19].

General impact of climate change on transmission

Climate change significantly amplifies the transmission and prevalence of food- and water-borne parasites, posing serious health risks[20]. Rising temperatures can accelerate parasite metabolism, leading to higher reproductive rates and larger parasite populations. Altered precipitation patterns, combined with warmer temperatures, create environmental conditions more suitable for parasite survival and growth[21]. Of note, altered precipitation patterns refer to the changes in the type, intensity, and frequency of rainfall, snowfall, or other forms of atmospheric moisture. For example, some regions might experience longer periods of drought followed by extreme, heavy rainfall, or a shift from gentle, consistent showers to more intense, infrequent downpours. As parasite populations expand and their geographic ranges enlarge, the risk of food contamination and subsequent human infection increases[22,23]. Increased humidity from changing rainfall patterns further enhances the survival and transmission of many parasites[24]. Climate variability, including heavy rainfall, has been associated with a rising incidence of diseases like cryptosporidiosis and giardiasis in Europe and the USA[25]. Climate change also indirectly influences transmission by altering host behavior, as shifting temperature and precipitation patterns and its outcome can cause host species to move, allowing parasites to expand into new territories[26].

Impact on specific parasites and diseases: The influence of climate change on transmission dynamics is manifested among several parasites.

Helminths: Many helminths, such as hookworms, *A. lumbricoides*, and *T. trichiura*, have life cycle stages that exist in the environment, making them highly susceptible to climatic shifts. Higher temperatures can accelerate the development of hookworm eggs and larvae, shortening the time they need to become infectious[27]. Increased precipitation and humidity prevent the desiccation of these parasites in the soil, leading to higher survival rates[22]. Consequently, the prevalence of soil-transmitted nematodes like *S. stercoralis* and hookworms is expected to rise. These outcomes are often aggravated by poor sanitation, which can lead to higher infection rates of *T. trichiura, A. lumbricoides,* and *E. vermicularis*[2]. The transmission of trematodes (flukes) may also be reshaped. The transmission season of *F. hepatica*, which uses lymnaeid snails as intermediate hosts, is prolonged by warming temperatures in regions like the United Kingdom, potentially increasing infection levels during winter months[28]. Modeling studies from New Zealand project a significant rise in infection risk by 2090, especially in areas with high densities of sheep and cattle[29]. Similarly, while the precise impact of warming on schistosomiasis is still being studied, it is probable that climate change will alter the geographic distribution of the *Schistosoma* species and their freshwater planorbid snail hosts[30]. It has been suggested that increased warming in Africa, may adversely drive ubiquitous parasites beyond their thermal limits in some areas, while spreading to new ones. Additionally, any climate-induced water stress could unexpectedly concentrate snail populations, elevating disease incidence in certain locations[31,32].

Echinococcosis, caused by the *E. granulosus* tapeworm, is another example. Warmer temperatures may enhance the survival of its resistant, dormant infective stages in the environment, and its geographic range has already expanded due to the emergence of new definitive hosts like the raccoon dog[33]. Hence, merging of climate change with globalization and migration further contributes to the spread of cystic echinococcosis and schistosomiasis, leading to emergence of cases outside their traditional endemic zones, which can result in delayed diagnosis and inadequate management[32].

Protozoa: Most protozoans have resilient cyst or oocyst stages that can survive outside a host and contaminate food and drinking water, causing diseases like amebiasis, giardiasis, cryptosporidiosis, and toxoplasmosis[22]. Climate change, particularly through increased rainfall and flooding, can compromise water safety and raise the risk of outbreaks[34]. Giardiasis and cryptosporidiosis already exhibit seasonal patterns linked to precipitation, and models predict that by the 2080s, altered rainfall in regions like Vancouver, Canada, could increase the combined incidence of these diseases by 5.9–16.3% during wet seasons[35].

Climate change also affects agriculture. Farmers facing heavy rainfall or drought may increase their use of animal manures or human biosolids as fertilizers, which can contain parasitic cysts and oocysts[33]. Heavy rainfall can then wash these contaminants from soil and vegetation into water sources, increasing the risk of outbreaks of giardiasis and cryptosporidiosis[22]. For *T. gondii*, rising human population density and temperature fluctuations can increase environmental contamination, with stray domestic cats playing a key role in its spread[36].

Finally, the availability and quality of water are critical. In developing nations, the combination of inadequate sanitation, global warming, and reduced water availability elevates the risk of infections from

E. histolytica and *G. lamblia*[37]. Limited water resources can also hinder proper hygiene practices, further facilitating parasitic transmission[38].

Vector-borne diseases

Vector-borne diseases, transmitted by arthropods like mosquitoes and ticks, are particularly sensitive to climate-related changes, which significantly impact global morbidity and mortality[39,40]. These diseases are indirectly vulnerable to the effects of climate change, as alterations in temperature, rainfall patterns, and extreme weather events can profoundly influence the lifecycle of the vectors[9,41].

One of the primary means of climate change affection of these diseases is by altering the geographic distribution and behavior of the vectors themselves. As ectotherms, arthropods are highly sensitive to temperature, which directly impacts their survival, reproduction, and activity levels. Temperature also governs the development rate of pathogens within the vector; for instance, the extrinsic incubation period of the malaria parasite (*Plasmodium* spp.) is inversely related to ambient temperature[2]. Consequently, ecological modifications due to climate change can alter the incidence of vector-borne diseases and increase the risk of zoonotic transfer to humans[30,42].

Mosquito-borne diseases

As warmer temperatures enhance mosquito activity, reproduction, and blood-feeding frequency, and warmer water accelerates larval development, understanding climate change's impact on mosquito-borne illness patterns becomes essential[39,43,44].

Malaria: The parasitic disease caused by *Plasmodium* spp. and spread by female *Anopheles* mosquitoes, remains a major health challenge worsened by climate change. The parasite multiplies within the mosquito at specific temperatures before transmission to humans, causing symptoms like fever, chills, and vomiting that can be life-threatening if untreated[45]. Temperature and precipitation directly impact mosquito populations and malaria transmission, though the effect of temperature is complex and varies by species. While the lower temperature boundaries can enhance transmission, temperatures near the upper limit can inhibit both mosquito and parasite survival[30,32]. Overall, warmer conditions that accelerate the parasite's growth within the mosquito have been associated with higher malaria transmission rates in both tropical and temperate settings[46].

Lymphatic filariasis: This disease transmitted by a number of mosquitos (*Culex, Anopheles, Mansonia, Aedes*) species, is also expected to be influenced by climate change. Changes in temperature and precipitation affect soil moisture and plant shades, which create favorable breeding grounds for the mosquito vectors. While global warming may increase mosquito habitats, other socioeconomic factors are expected to play a significant role in the disease's global spread[2]. Attempted ecological models predict that the number of people at risk of lymphatic filariasis in Africa could increase dramatically by 2050, reaching 1.65 to 1.86 billion, depending on future climate developments[22].

Sand fly-borne zoonoses (leishmaniasis)

Sand flies, like mosquitoes, are highly sensitive to temperature, which affects both the development of the *Leishmania* parasite within the vector and the sand fly's biting rate[47]. Traditionally found south of 45°N latitude in Europe, sand flies are spreading towards the north as lower rainfall and higher temperatures create new suitable habitats for *Phlebotomus* spp.[2,44]. This extension increases the risk of leishmaniasis, a disease that ranges from localized skin lesions to disfiguring mucosal forms and imposes a significant health and financial burden[22]. Ecological models predict that sand fly habitats will continue to spread with climate change, with human exposure in the USA projected to quadruple by 2080 even under moderate conditions[22,48].

Tick-borne zoonoses

Tick-borne diseases (parasitic, bacterial, viral) may also be strongly affected by rising temperatures, due to tick dispersal, developmental cycles, population density, and survival over winter months. Warmer climates allow ticks to survive at higher latitudes and altitudes, widening their geographic range and augmenting risk of disease transmission[30]. Warmer temperatures can also accelerate transmission by improving the synchrony between larval and nymphal tick phases, which allows more virulent pathogen strains to persist[22].

Babesiosis: The hard tick *I. scapularis*, is the primary vector of babesiosis (*B. microti,* and *B. divergans*) in North America. It is a suitable model for predicting northward expansion into Canada by the 2080s[49]. This shift is expected to increase the risk of tick-borne infections. However, extreme conditions like severe droughts or floods could have a negative impact on tick populations[44]. Climate change also has indirect effects; for example, increased rainfall in Poland can promote mushroom growth, leading to more human activity in tick-infested forests[50]. As temperatures rise, cases of babesiosis have noticeably increased in countries like the USA, Canada, and the UK[51]. These trends are also influenced by changes in the populations and habitats of animal reservoirs like deer and rodents[30].

Other vector-borne diseases

Other vectors, including tsetse flies as *Glossina* spp. and *Simulium* spp. vectors of African trypanosomiasis and onchoceceriasis respectively, and triatomine bugs that transmits Chagas disease (*T. cruzi*), are also sensitive to meteorological factors like temperature, humidity, and rainfall[52].

Chagas disease and African trypanosomiasis: *Triatoma* spp. are predicted to expand into North America by 2050, while *T. b. rhodesiense* (sleeping sickness) may expand its range in Southern and Eastern Africa by 2090[11]. However, some habitats are expected to become less suitable; for instance, environments for forest tsetse flies in Liberia and savanna flies in Ghana are suggested to decline by 2040[52,53]. While a massive expansion of tsetse flies is not anticipated, significant population shifts could still affect disease transmission[22,54].

Onchocerciasis: For some diseases, major shifts are not expected. The *Simulium* spp. vector for onchocerciasis is not currently invading new climatically favorable areas, suggesting its distribution will remain relatively stable[2,55].

Finally, the complex interplay between climate change and urbanization further influences the distribution of vector-borne parasites. Despite sanitation advancements, the rising trend of parasitic infections in urban areas suggests that climate change may amplify vulnerability. Vector-borne parasites like *Leishmania* and *Plasmodium* are increasingly prevalent in urban settings, raising concerns about future disease patterns in a warming world[56].

Climate change: A magnifying threat to public health

Climate change is recognized by the World Health Organization as a major global health threat[9]. Its impact can create new relations between human populations and pathogens through mechanisms like forced migration, habitat degradation, and shifts in the geographic distribution of vectors and environmental infections. This increased contact can facilitate cross-species transmission and pathogen adaptation, potentially leading to the establishment of effective human-to-human (anthroponotic) transmission[25].

Furthermore, climate change can increase capacity of pathogens in animal reservoirs, with the risk of transfer to human populations. Climate-induced variations in temperature and precipitation can alter food availability, leading to the growth of reservoir populations[9]. The latter are organisms, often animals, in which an infectious agent naturally lives and reproduces. These animal populations can then become a source from which the pathogen is transmitted to other populations, including humans.

Changes in predator dynamics and habitat can also force animal populations to migrate, widening the range of disease reservoirs[57]. Such ecosystem disruptions can alter both human and animal behavior, leading to more frequent interactions with stressed or infected hosts and a higher risk of disease transmission[58].

Global and community-level action

Addressing climate change at a global scale is essential. Numerous countries are motivated to decrease greenhouse gas emissions by implementation of cleaner technologies and renewable energy policies to improve energy efficiency[9]. Locally, effective adaptation to climate-sensitive infections demands better sanitation, increased surveillance of animal reservoirs, and comprehensive public education on disease prevention. Furthermore, fostering resilience via community partnerships also plays an important role. This entails working with local, national, and international bodies to improve climate funding and policy, coupled with implementing strong education and awareness initiatives[59]. Specifically, outreach and education prove highly effective in reducing food-borne disease risks by delivering vital information and encouraging the use of prevention techniques[20].

Advanced surveillance and technology: Effective surveillance is the backbone of a strong defense against emerging infectious diseases.

Epidemiological and genomic surveillance: Complete epidemiological data, including contact location, is essential for mapping transmission patterns and understanding disease progression, as demonstrated in studies of tuberculosis transmission[60]. Genomic surveillance is crucial for monitoring pathogen evolution, vaccine and drug development, and facilitating responses to emerging variants. However, its effectiveness depends on representative population sampling particularly during outbreaks[61].

Predictive and monitoring technologies: Developing new technologies for screening and monitoring is crucial for early pathogen detection and diagnosis[9]. Modern tools like machine learning and artificial intelligence are already being used to identify trends, predict outbreaks, and enable timely public health interventions. These global tracking and modeling systems, driven by interdisciplinary collaboration, are essential for accurate disease forecasting and for informing strategies like early detection and vaccination campaigns[62].

Environmental technologies: Innovative environmental technologies also offer solutions. Environmental photocatalysis, which uses light-activated catalysts like titanium dioxide, provides a sustainable method for removing pathogens and pollutants from air and water[63]. This technology can be integrated into building materials to create self-cleaning surfaces. Additionally, nanotechnology can contribute by reducing CO_2 emissions from construction and improving overall environmental quality[64].

Ultimately, successful control of the health threats by climate change will depend on a concentrated effort that combines these advanced tools with community participation and coordinated action across all levels of governance, as well as sufficient funding[65].

CONCLUDING REMARKS

1. Effective management of the complex health impacts of climate change requires unified interdisciplinary collaboration by experts from diverse fields, including epidemiology, climatology, urban planning, and social sciences.
2. The relationship between climate change and public health is influenced by various factors such as urbanization, global mobility, and socioeconomic conditions, which must be considered in any response.

3. Advanced technologies like AI, remote sensing, and GIS must be used to monitor disease vectors, forecast outbreaks, and implement timely interventions.
4. Parasitic diseases, which affect susceptible communities, are highly sensitive to climate shifts, and require greater attention and resources.
5. Solutions must be comprehensive, integrating scientific research, technological innovation, and strategic policymaking to address the complex nature of these health threats.
6. The goal is not only to lessen immediate health impacts but also to develop resistant, long-term measures that enhance the well-being of vulnerable populations.
7. Protection of public health against climate change is a shared responsibility that requires urgent, collaboration from all interested parties to create a comprehensive and effective global response.

Authors contribution: All authors contributed equally in retrieving data, gathering scientific material, and composing the review. Moreover, they all participated in revising the manuscript and approved its final version.
Conflict of interest: None.
Funding statement: None.

REFERENCES

1. U.S. government departments and agencies. U.S. Government Departments and Agencies Index. 2018. Available online at: https://www.federalregister.gov/index/2018
2. Faheem M, Abougalalah DIM. A review on climate change and impact on parasitic diseases incidence and prevalence. J Egypt Soc Parasitol 2025; 55(1):47–56.
3. National Aeronautics and Space Administration (NASA). What's the difference between climate change and global warming? 2024. Available online at: https://science.nasa.gov/climate-change/faq/whats-the-difference-between-climate-change-and-global-warming/
4. U.S. Global Change Research Program. Fifth National Climate Assessment. Washington, DC, U.S. Government Publishing Office, 2023. Available online at: https://nca2023.globalchange.gov/
5. Kweku DW, Bismark O, Maxwell A, Desmond KA, Danso KB, Oti-Mensah EA, *et al*. Greenhouse Effect: Greenhouse gases and their impact on global warming. J Sci Res Rep 2018; 17(6):1–9.
6. Richardson TB, Forster PM, Smith CJ, Maycock AC, Wood T, Andrews T, *et al*. Efficacy of climate forcings in PDRMIP models. J Geophys Res Atmos 2019; 124(23):12824–12844.
7. The Royal Society and National Academy of Sciences. Climate change: Evidence and causes 2020. Available online at: https://www.google.com/search?q=https://royalsociety.org/-/media/policy/projects/climate-change-evidence-causes/climate-change-evidence-causes.pdf
8. Wang W, Li J, Ma X, Li X, Wu X, Zhang J. Nonlinear contributions from climate change and anthropogenic activity to the normalized difference vegetation index across China using a locally weighted regression approach. Environ Model Softw 2023; 165:105740.
9. Liao H, Lyon CJ, Ying B, Hu T. Climate change, its impact on emerging infectious diseases and new technologies to combat the challenge. Emerg Microbes Infect 2024; 13(1):2356143.
10. Kearney MR, Porter WP. Climate change and the niche: integrating behavior, physiology, and population dynamics. Glob Chang Biol 2017; 23(10):3959–3971.
11. Forsyth C, Agudelo Higuita NI, Hamer SA, Ibarra-Cerdeña CN, Valdez-Tah A, Stigler Granados P, *et al*. Climate change and *Trypanosoma cruzi* transmission in North and Central America. Lancet Microbe 2024; 5(9):e100946.
12. Gajadhar AA. Introduction to foodborne parasites. In: Gajadhar AA, ED. Foodborne Parasites in the Food Supply Web: Occurrence and control. Cambridge, UK: Woodhead Publishing (an imprint of Elsevier), 2015; 3–9. Available online at: https://www.sciencedirect.com/science/article/pii/B9781782423324000011
13. Torgerson P, Devleesschauwer B, Praet N, Speybroeck N, Willingham A, Kasuga F, *et al*. World Health Organization estimates of the global and regional disease burden of 11 foodborne parasitic diseases, 2010: A data synthesis. PLoS Med 2015; 12(12):e1001920.
14. Robertson LJ, Torgerson PR, van der Giessen J. Foodborne parasitic diseases in Europe: Social cost-benefit analyses of interventions. Trends Parasitol 2018; 34:919–923.
15. Hedman H, Varga C, Duquette J, Novakofski J, Mateus-Pinilla N. Food safety considerations related to the consumption and handling of game meat in North America. Vet Sci 2020; 7(4):188.
16. Kristensen A, Horneland R, Birn H, Svensson M. *Giardia lamblia* infection after pancreas-kidney transplantation. BMJ Case Rep 2016; 2016:bcr2016216488.
17. Kamau P, Aloo-Obudho P, Kabiru E, Ombacho K, Langat B, Mucheru O, *et al*. Prevalence of intestinal parasitic infections in certified food-handlers working in food establishments in the city of Nairobi, Kenya. J Biomed Res 2012; 26(2):84–89.
18. Ogolla J. Prevalence and factors associated with intestinal protozoan and helminthic infections among certified food handlers in Eldoret town, Uasin Gishu County in Kenya. Int Clin Pathol J 2018; 6(3):124–128.
19. Muhammad Bunza N, Sale Kumurya A, Muhammad A. Prevalence and associated risk factors of intestinal parasitic infections among food handlers in Kano Metropolis, Kano State, Nigeria. Microbes Infect Dis 2021; 2(3):590-596.
20. Awad DA, Masoud HA, Hamad A. Climate changes and food-borne pathogens: The impact on human health and mitigation strategy. Clim Change 2024; 177:92.
21. Dietrich J, Hammerl J-A, Johne A. Impact of climate change on foodborne infections and intoxications. J Health Monit 2023; 8:78–92.
22. Short EE, Caminade C, Thomas BN. Climate change contribution to the emergence or re-emergence of parasitic diseases. Infect Dis 2017; 10:1178633617732296.

23. Pandey RK, Dubey AK, Sharma S, Rani C. Climate Change and Zoonotic Diseases: Malaria, Plague, Dengue, and Encephalitis. In: Nazneen S, King Abia AL, Madhav S (Eds.) Emerging Pandemics: Connections with Environment and Climate Change. Boca Raton: CRC Press, 2023; 81–98.
24. Polley LR. Foodborne parasites and climate change: Possible impacts and challenges. In: Gajadhar AA, editor. Foodborne Parasites in the Food Supply Web: Occurrence and Control. Cambridge, UK: Woodhead Publishing (an imprint of Elsevier); 2015. p. 23–47. Available online at: https://www.sciencedirect.com/science/article/pii/B9781782423324000035
25. Papanikolaou EA, Baka A. Policy strategies for managing food safety risks associated with climate change and agriculture. Int J Sci Res Rev 2024; 13(2):178–190.
26. Utaaker KS, Robertson LJ. Climate change and foodborne transmission of parasites: A consideration of possible interactions and impacts for selected parasites. Food Res Int 2015; 68:16–23.
27. Kim S, Nam K, Heo S, Lee S, Choi J, Park J, *et al*. Spatio-temporal incidence modeling and prediction of vector-borne disease using an ecological model and deep neural network for climate change adaptation. Korean Chem Eng Res 2020; 58:197–208.
28. Caminade C, Van Dijk J, Baylis M, Williams D. Modelling recent and future climatic suitability for fasciolosis in Europe. Geospat Health 2015; 9:301–308.
29. Haydock LAJ, Pomroy WE, Stevenson MA, Lawrence KE. A growing degree-day model for determination of Fasciola hepatica infection risk in New Zealand with future predictions using climate change models. Vet Parasitol 2016; 228:52–59.
30. Rupasinghe R, Chomel BB, Martínez-López B. Climate change and zoonoses: A review of the status, knowledge gaps, and future trends. Acta Trop 2022; 226:106225.
31. McCreesh N, Nikulin G, Booth M. Predicting the effects of climate change on *Schistosoma mansoni* transmission in eastern Africa. Parasit Vectors 2015; 8:4.
32. Elwakil R, Elsahhar M, Fouad T. Impact of climate change on parasitic liver diseases in Africa. Microbiol Infect Dis 2021; 5(4):1–8.
33. Paz S. Climate change: A driver of increasing vector-borne disease transmission in non-endemic areas. PLoS Med 2024; 21(4):e1004382.
34. Lynch VD, Shaman J. Waterborne infectious diseases associated with exposure to tropical cyclonic storms, United States, 1996–2018. Emerg Infect Dis 2023; 29(8):1548–1558.
35. Chhetri BK, Galanis E, Sobie S, Brubacher J, Balshaw R, Otterstatter M, *et al*. Projected local rain events due to climate change and the impacts on waterborne diseases in Vancouver, British Columbia, Canada. Environ Health 2019; 18:116.
36. Zhu S, VanWormer E, Shapiro K. More people, more cats, more parasites: Human population density and temperature variation predict prevalence of *Toxoplasma gondii* oocyst shedding in free-ranging domestic and wild felids. PLoS One 2023; 18(6):e0286808.
37. Nordling K, Fahrenbach NLS, Samset BH. Climate variability can outweigh the influence of climate mean changes for extreme precipitation under global warming. Atmos Chem Phys 2025; 25(3):1659–1674.
38. Nayar N, Vasseur DA. Temperature fluctuations in a warmer environment: Impacts on microbial plankton. F1000Res 2021; 10:9.
39. Rocklöv J, Dubrow R. Climate change: An enduring challenge for vector-borne disease prevention and control. Nat Immunol 2020; 21(5):479–483.
40. Carlson CJ, Albery GF, Merow C, Trisos CH, Zipfel CM, Eskew EA, *et al*. Climate change increases cross-species viral transmission risk. Nature 2022; 607(7919):555–562.
41. Zhang W, Wang Y, Huang R, Zhao Z. Innovative strategies and challenges mosquito-borne disease control amidst climate change. Front Microbiol 2024; 15:1488106.
42. Medlock JM, Hansford KM, Versteirt V, Cull B, Kampen H, Fontenille D, *et al*. An entomological review of invasive mosquitoes in Europe. Bull Entomol Res 2015; 105:637–663.
43. Khan SU, Ogden NH, Fazil AA, Gachon PH, Dueymes GU, Greer AL. Current and projected distributions of Aedes aegypti and Aedes albopictus in Canada and the U.S. Environ Health Perspect 2020; 128:57007.
44. Chitnis N, Giorgi A, Capinha C, Fischer D. Evolution of the recent habitat suitability area of *Aedes albopictus* in the extended Mediterranean area due to land-use and climate change. Sci Total Environ 2025; 974:179202.
45. European Centre for Disease Prevention and Control (ECDC). Climate change in Europe: Vector-borne diseases. 2019. Available online at: https://www.google.com/search?q=https://www.ecdc.europa.eu/en/publications-data/climate-change-europe-vector-borne-diseases-0
46. World Health Organization. World malaria report 2024: Addressing inequity in the global malaria response. WHO, 2024. Available online at: https://www.who.int/publications/i/item/9789240104440
47. Kripa PK, Thanzeen PS, Jaganathasamy N. Impact of climate change on temperature variations and extrinsic incubation period of malaria parasites in Chennai, India: Implications for its disease transmission potential. Parasit Vectors 2024; 17:134.
48. Pokharel S, Raut S, Rijal S, Ostbye T, Punam B. The ongoing risk of Leishmania donovani transmission in eastern Nepal: an entomological investigation during the elimination era. PLoS Negl Trop Dis 2023; 17(11):e0011746.
49. Poudyal N, Adhikari M, Sherchan D, Pandey B, Khan AA, Rijal S, *et al*. Distribution and Seasonal Variation of Phlebotomus and Sergentomyia Sand Fly Populations in Bhutan. J Trop Med 2023; 2023:1–9.
50. Couper LI, MacDonald AJ, Mordecai EA. Impact of prior and projected climate change on US Lyme disease incidence. Glob Chang Biol 2021; 27(4):738–754.
51. Robinson SJ, Neitzel DF, Moen RA. Disease risk in a dynamic environment: The spread of tick-borne pathogens in Minnesota, USA. Ecohealth 2015; 12:152–163.
52. Ostfeld RS, Brunner JL. Climate change and Ixodes tick-borne diseases of humans. Philos Trans R Soc Lond B Biol Sci 2015; 370:20140051.
53. Cheke RA, Basáñez M-G, Perry M, White MT, Garms R, Obuobie E, *et al*. Potential effects of warmer worms and

vectors on onchocerciasis transmission in West Africa. Philos Trans R Soc Lond B Biol Sci 2015; 370(1665):20130559.
54. Nnko HJ, Gwakisa PS, Ngonyoka A, Sindato C, Estes AB. Potential impacts of climate change on geographical distribution of three primary vectors of African Trypanosomiasis in Tanzania's Maasai Steppe: G. m. morsitans, G. pallidipes and G. swynnertoni. PLoS Negl Trop Dis 2021; 15:e0009081.
55. Mweempwa C, Marcotty T, De Pus C. Impact of habitat fragmentation on tsetse populations and trypanosomosis risk in Eastern Zambia. Parasit Vectors 2015; 8:406.
56. Elliott I, Pearson I, Dahal P, Thomas NV, Roberts T, Newton PN. Scrub typhus ecology: A systematic review of Orientia in vectors and hosts. Parasit Vectors 2019; 12:513.
57. Pankao V, Chantree P, Martviset P. Global warming and parasitic infection in urban communities: A systematic review. Vajira Med J 2024; 68(2):e267469.
58. Delong JP, Lyon S. Temperature alters the shape of predator–prey cycles through effects on underlying mechanisms. PeerJ 2020; 8:e9377.
59. Martin G, Yanez-Arenas C, Chen C. Climate change could increase the geographic extent of Hendra virus spillover risk. Ecohealth 2018; 15(3):509–525.
60. Ma C, Jiang W, Wei S. Environmental fluctuations drive rapid evolution of phenotypic plasticity in invasive plant populations. Ecol Evol 2023; 13(7):e10166.
61. Li M, Guo MC, Peng Y. High proportion of tuberculosis transmission among social contacts in rural China: A 12-year prospective population-based genomic epidemiological study. Emerg Microbes Infect 2022; 11(1):2102–2111.
62. Daniloski Z, Jordan TX, Wessels HH, Hoagland DA, Abedalthagafi M, Almontarri F, *et al*. Identification of required host factors for SARS-CoV-2 infection in human cells. Cell 2021; 184(1):92–105.
63. Piscitelli P, Miani A. Climate change and infectious diseases: Navigating the intersection through innovation and interdisciplinary approaches. Int J Environ Res Public Health 2024; 21:314.
64. Islam MT, Dominguez A, Turley RS, Kim H, Sultana KA, Shuvo MAI, *et al*. Development of photocatalytic paint based on TiO2 and photopolymer resin for the degradation of organic pollutants in water. Sci Total Environ 2020; 704:135406.
65. Pozio E. How globalization and climate change could affect foodborne parasites. Exp Parasitol 2020; 208:107807.