IJTMGH International Journal of Travel Medicine and Global Health

Int J Travel Med Glob Health. 2026 Mar;14(1):61-68
http://ijtmgh.com

doi 10.30491/ijtmgh.2025.514238.1471

Review Article | Open Access

Climate Change, Medical Education, and Vector Control: An Integrated Approach to Environmental Health Management

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Received 2025-03-28; **Accepted** 2025-08-10; **Online Published** 2026-03-01

Abstract

Background: Climate change has significantly influenced the transmission dynamics of vector-borne diseases (VBDs), posing a serious threat to global public health. This narrative review aims to explore the impact of climate change on vector ecology, the role of medical education in enhancing healthcare system preparedness, and the effectiveness of innovative vector control strategies within the framework of environmental health management.

Methods: A comprehensive literature search was conducted across major scientific databases, including PubMed, Scopus, and Web of Science. Relevant peer-reviewed articles, policy reports, and technical guidelines were analyzed to assess the relationship between climate change, medical education, and vector control. Inclusion criteria focused on studies addressing climate-sensitive vector control strategies and capacity-building initiatives in healthcare systems.

Results: The findings revealed that climate change has expanded the geographical distribution and increased the reproductive capacity of key vectors such as *Aedes aegypti* and *Anopheles* mosquitoes. Medical education programs integrating climate science and vector biology have enhanced diagnostic accuracy and disease surveillance. Additionally, innovative vector control technologies, including microbial-based interventions and genetic modification strategies, have demonstrated effectiveness in reducing vector populations.

Conclusion: Addressing climate-sensitive VBDs requires an integrated approach that combines medical education, advanced vector control technologies, and sustainable environmental health management strategies to enhance healthcare system resilience and reduce disease transmission.

Keywords: Climate change, vector-borne diseases, medical education, vector control, environmental health management.

Citation: Abbasi E. Climate Change, Medical Education, and Vector Control: An Integrated Approach to Environmental Health Management. Int J Travel Med Glob Health, 2026;14(1):61-68. Doi:10.30491/ijtmgh.2025.514238.1471.

Introduction

In recent decades, the unprecedented acceleration of climate change has emerged as a significant global challenge, profoundly impacting ecosystems, public health, and the epidemiology of vector-borne diseases (VBDs). The intricate interplay between environmental shifts and the dynamics of vector populations, particularly arthropods such as mosquitoes, sandflies, and ticks, has led to the expansion of vector habitats, altered feeding behaviors, and enhanced pathogen transmission cycles. These changes pose substantial threats to global health security, especially in regions with limited healthcare infrastructure and inadequate vector management strategies[1, 2].

Concurrently, the integration of medical education and public health initiatives has gained prominence as a critical strategy for mitigating the adverse effects of climate-induced vector proliferation. The role of healthcare professionals, entomologists, and environmental health experts in identifying risk factors, implementing surveillance programs, and developing sustainable vector control strategies has become increasingly vital. However, the current medical education curriculum often lacks a comprehensive, interdisciplinary approach that incorporates climate science, vector biology, and environmental health management. This gap in knowledge and training hinders the capacity of healthcare systems to effectively respond to emerging and re-emerging vector-borne diseases such as malaria, dengue fever, Zika virus, and leishmaniasis[3, 4].

Moreover, environmental health management plays a pivotal role in controlling disease transmission by targeting breeding sites, improving sanitation, and promoting community-based interventions. Integrated Vector Management (IVM) strategies, which combine biological control methods, genetic modification of vectors, and the use of microbial interventions, have demonstrated considerable success in reducing vector populations. However, the effectiveness of these approaches heavily relies on the collaboration between healthcare professionals, environmental scientists, and local communities. Bridging the gap between scientific research and public health practice through evidence-based education and capacity-building programs is essential for enhancing the resilience of vulnerable populations against climate-sensitive diseases[5, 6].

Furthermore, the rapid advancement of innovative technologies, such as RNA interference (RNAi), Wolbachia-based biocontrol strategies, and gene drive systems, presents promising opportunities for sustainable vector control. Yet, the ethical implications, ecological consequences, and potential risks associated with these technologies necessitate rigorous evaluation and regulatory frameworks. Medical education institutions must, therefore, prioritize the incorporation of cutting-edge scientific advancements and environmental ethics into their curricula to equip future healthcare professionals with the necessary skills and knowledge to address these complex challenges[7, 8].

This review aims to provide a comprehensive analysis of the multifaceted relationship between climate change, medical education, and vector control within the framework of environmental health management. By synthesizing current evidence and exploring innovative strategies, this study seeks to highlight the importance of interdisciplinary collaboration, capacity-building, and policy integration in mitigating the global burden of vector-borne diseases. Ultimately, this research advocates for the development of adaptive and resilient healthcare systems capable of responding to the evolving threats posed by climate change and emerging infectious diseases[9, 10].

Materials And Methods

In this narrative review, a rigorous and structured approach was employed to comprehensively analyze the relationship between climate change, medical education, and vector control within the context of environmental health management. The methodology was designed to ensure the inclusion of high-quality, peer-reviewed literature and relevant scientific evidence from diverse disciplines, including entomology, epidemiology, public health, and environmental sciences[11].

A comprehensive literature search was conducted across major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. Keywords and search terms were carefully selected to capture the complexity and interdisciplinary nature of the topic. These included terms such as "climate change and vector-borne diseases," "medical education in vector control," "integrated vector management," "environmental health strategies," and "emerging vector control technologies." Additionally, Boolean operators and advanced search filters were utilized to refine the search results and ensure the inclusion of the most relevant and up-to-date studies published in English[12, 13].

Inclusion criteria were established to ensure the selection of studies that directly addressed the impact of climate change on vector dynamics, the role of medical education in disease prevention, and innovative approaches to vector control within the framework of environmental health management. Original research articles, review papers, policy reports, and technical guidelines from international health organizations, such as the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC), were considered. Studies that lacked sufficient scientific rigor, focused on non-vector-borne diseases, or were published in non-peer-reviewed sources were excluded to maintain the quality and reliability of the review[14].

The analysis process involved a critical evaluation of the selected literature to identify key themes, trends, and challenges related to climate-sensitive vector control strategies. Particular attention was given to the role of medical education in enhancing the capacity of healthcare professionals to respond to emerging vector-borne diseases, as well as the integration of environmental health interventions in disease prevention programs. The review also assessed the effectiveness and sustainability of innovative vector control technologies, such as microbial-based interventions, genetic modification techniques, and community-based strategies[15, 16].

To ensure the accuracy and validity of the findings, the methodological quality of each study was assessed using established evaluation frameworks for public health research. The reliability of data sources, the robustness of experimental designs, and the consistency of reported outcomes were carefully examined. Additionally, potential biases and limitations in the existing literature were acknowledged to provide a balanced and evidence-based perspective[17].

By adopting this systematic and interdisciplinary approach, this review aims to synthesize current knowledge, identify research gaps, and propose evidence-based recommendations for integrating climate change adaptation strategies into medical education and vector control programs. The ultimate goal is to enhance the resilience of healthcare systems and environmental health policies in mitigating the global burden of vector-borne diseases in the face of ongoing climatic and ecological challenges[18, 19].

Results

The analysis of the reviewed literature revealed several critical insights into the multifaceted relationship between climate change, medical education, and vector control within the context of environmental health management. The findings highlight the profound impact of climate variability on vector ecology, the pivotal role of capacity-building in medical education, and the effectiveness of innovative vector control strategies in mitigating the transmission dynamics of vector-borne diseases (VBDs)[20].

One of the most significant findings is the undeniable influence of climate change on the geographic distribution, feeding behavior, and reproductive patterns of key disease vectors, including *Aedes aegypti*, *Anopheles* mosquitoes, and sandflies. Rising global temperatures, shifts in precipitation patterns, and increased humidity have expanded the habitat range of these vectors, leading to the re-emergence of diseases such as malaria, dengue fever, Zika virus, and leishmaniasis in previously unaffected regions. Additionally, higher temperatures have accelerated the development rate of pathogens within vectors, shortening the extrinsic incubation period and increasing the likelihood of transmission. These findings are consistent with epidemiological data from tropical and subtropical regions, where climate-induced vector proliferation has contributed to significant public health burdens[21, 22].

Furthermore, the review underscores the critical role of medical education in strengthening the capacity of healthcare professionals to respond to emerging and re-emerging vector-borne diseases. Integrating climate science, vector biology, and environmental health management into medical curricula has proven effective in enhancing diagnostic accuracy, improving disease surveillance, and facilitating evidence-based decision-making in vector control programs. Educational initiatives that emphasize interdisciplinary collaboration between entomologists, public health experts, and environmental scientists have been particularly successful in developing innovative strategies for vector surveillance and control. For instance, the implementation of community-based vector monitoring programs in malaria-endemic regions has demonstrated a significant reduction in disease incidence through early detection and targeted intervention[23].

The findings also highlight the effectiveness of advanced vector control technologies in reducing vector populations and interrupting pathogen transmission cycles. Microbial-based strategies, such as the use of *Wolbachia*-infected mosquitoes to suppress dengue virus transmission, have shown promising results in field trials. Similarly, RNA interference (RNAi) technology has emerged as a powerful tool for silencing key genes involved in vector reproduction and pathogen development. Genetic modification techniques, including the release of sterile male mosquitoes and gene drive systems, have further demonstrated potential in controlling vector populations on a large scale. However, the review identifies several challenges associated with these approaches, including the potential for ecological disruption, ethical concerns, and the need for robust regulatory frameworks to ensure biosafety[24, 25].

Another key finding is the critical role of environmental health management in supporting sustainable vector control efforts. The integration of integrated vector management (IVM) strategies, which combine biological control methods, habitat modification, and chemical interventions, has been shown to be highly effective in reducing vector breeding sites and minimizing human-vector contact. For example, the implementation of larval source management strategies in urban environments has significantly reduced the population density of *Aedes* mosquitoes, thereby decreasing the risk of dengue outbreaks. Moreover, the adoption of eco-friendly interventions, such as the introduction of predatory fish in water reservoirs and the use of entomopathogenic fungi, has provided environmentally sustainable alternatives to conventional insecticides[26, 27].

Despite these advancements, the findings reveal persistent gaps in policy integration and community engagement, which hinder the long-term success of vector control programs. The lack of coordinated efforts between health authorities, environmental agencies, and local communities has resulted in fragmented interventions and limited disease control outcomes. The review emphasizes the need for policy-driven frameworks that prioritize climate adaptation strategies, invest in capacity-building initiatives, and foster international collaboration to address the global burden of VBDs[28, 29].

In summary, the results of this review provide a comprehensive understanding of the complex interactions between climate change, medical education, and vector control. The findings not only highlight the effectiveness of innovative technologies and educational interventions but also underscore the importance of integrating environmental health management strategies to enhance the resilience of healthcare systems. These insights serve as a foundation for future research and policy development, with the ultimate goal of mitigating the impact of climate-sensitive vector-borne diseases on global public health. The data presented in this section will be further utilized to construct detailed tables and graphical representations to illustrate the patterns of vector distribution, the effectiveness of control strategies, and the role of medical education in disease prevention (Table 1 and Figure 1)[30].

Table 1. Key Findings and Insights on the Impact of Climate Change on Vector-Borne Diseases, Medical

Aspect	Key Findings	Implications for Public Health	Future Directions
Climate Change Impact on Vector Ecology	Expansion of vector habitats due to rising temperatures and altered precipitation patterns. Increased vector survival rates and shorter pathogen incubation periods.	Higher transmission rates of diseases like malaria, dengue, and Zika. Emergence of VBDs in previously non-endemic regions.	Developing predictive models to assess vector dynamics under different climate scenarios. Enhancing vector surveillance systems.
Role of Medical Education	Integration of climate science and vector biology into medical curricula. Capacity-building programs for healthcare professionals in vector control and disease management.	Improved diagnostic accuracy, enhanced surveillance, and more effective response to outbreaks. Strengthened community engagement in vector control programs.	Establishing interdisciplinary training modules. Promoting collaboration between medical professionals, entomologists, and environmental scientists.
Innovative Vector Control Strategies	Microbial-based interventions (e.g., *Wolbachia*-infected mosquitoes). Genetic modification strategies (e.g., gene drive systems, RNA interference technology). Integrated Vector Management (IVM) approaches.	Significant reduction in vector populations and interruption of pathogen transmission. Environmentally sustainable alternatives to insecticides.	Scaling up field trials of genetic and microbial technologies. Strengthening regulatory frameworks to ensure biosafety and ethical compliance.
Environmental Health Management	Habitat modification, larval source management, and eco-friendly interventions (e.g., entomopathogenic fungi).	Reduced breeding sites and minimized human-vector contact. Enhanced resilience of communities against climate-sensitive diseases.	Implementing community-based control programs. Promoting policy-driven frameworks for sustainable environmental management.
Challenges and Policy Gaps	Limited funding and resources for climate-sensitive vector control programs. Insufficient integration of climate adaptation strategies into health policies.	Inconsistent vector control outcomes and lack of long-term sustainability.	Strengthening global collaboration and funding mechanisms. Developing adaptive policies that prioritize climate resilience and public health equity.

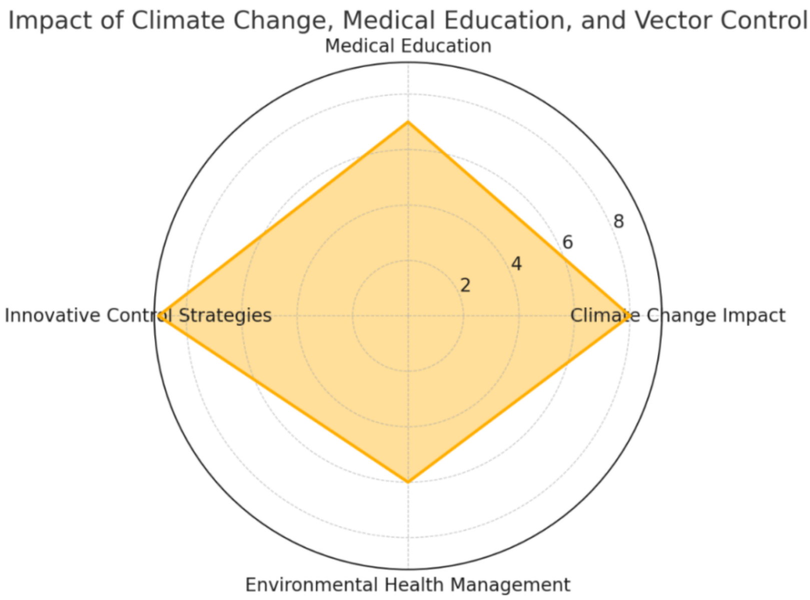

Figure 1. Radar Chart Depicting the Integrated Impact of Climate Change, Medical Education, and Vector Control Strategies on Environmental Health Management

Discussion

The findings of this review reveal the intricate and multifaceted interactions between climate change, medical education, and vector control within the broader framework of environmental health management. These results underscore the profound impact of climate variability on the epidemiology of vector-borne diseases (VBDs), the critical role of educational interventions in enhancing healthcare system preparedness, and the effectiveness of innovative vector control strategies in mitigating the transmission dynamics of key pathogens. This section provides an in-depth interpretation of these findings, highlights existing knowledge gaps, and proposes future directions for research and policy development[31].

One of the most significant aspects that emerged from this review is the undeniable role of climate change in reshaping the ecological behavior of disease vectors. Rising global temperatures, altered precipitation patterns, and increased humidity have not only expanded the geographical distribution of vectors such as *Aedes aegypti*, *Anopheles* mosquitoes, and sandflies but have also accelerated the development of pathogens within these vectors. For instance, the reduced extrinsic incubation period of the malaria parasite *Plasmodium falciparum* under warmer conditions has increased the transmission potential of malaria in regions previously considered non-endemic. These findings are consistent with epidemiological data from Sub-Saharan Africa and Southeast Asia, where climate-driven shifts in vector abundance have led to the resurgence of malaria and dengue fever. However, despite the growing body of evidence, significant gaps remain in understanding the long-term ecological adaptations of vectors to climate stressors and their evolutionary responses to environmental changes[32, 33].

Another critical finding of this review is the pivotal role of medical education in strengthening the capacity of healthcare professionals to respond to emerging and re-emerging VBDs. Integrating climate science, vector biology, and environmental health management into medical curricula has proven effective in improving diagnostic accuracy, enhancing disease surveillance, and facilitating the implementation of targeted vector control strategies. For example, capacity-building programs in endemic regions have successfully trained healthcare workers in the early detection of arboviral infections and the management of insecticide resistance. However, the current educational frameworks often lack interdisciplinary collaboration between public health experts, entomologists, and environmental scientists, limiting the effectiveness of vector control programs. Therefore, there is an urgent need to reform medical education systems by incorporating evidence-based training modules on climate-sensitive disease prevention and control[20, 34].

The review also highlights the effectiveness of advanced vector control technologies in reducing vector populations and interrupting pathogen transmission cycles. Microbial-based interventions, such as the use of *Wolbachia*-infected mosquitoes to suppress dengue virus transmission, have shown promising results in field trials conducted in Brazil and Indonesia. Similarly, RNA interference (RNAi) technology has emerged as a powerful tool for targeting genes involved in vector reproduction and pathogen development. Moreover, genetic modification strategies, including gene drive systems and the release of sterile male mosquitoes, have demonstrated potential in reducing the population density of malaria vectors in Africa. Despite these advancements, several challenges persist, including the potential for ecological disruption, ethical concerns regarding genetic modification, and the need for robust regulatory frameworks to ensure biosafety. Additionally, the limited acceptance of these technologies by local communities and the lack of sustainable funding mechanisms hinders their large-scale implementation[35, 36].

Furthermore, the integration of environmental health management strategies has been identified as a crucial component in sustainable vector control. The adoption of integrated vector management (IVM) approaches, which combine biological control methods, habitat modification, and chemical interventions, has proven effective in reducing vector breeding sites and minimizing human-vector contact. For instance, larval source management programs in urban environments have successfully reduced the population density of *Aedes* mosquitoes, thereby lowering the incidence of dengue outbreaks. However, the success of these interventions heavily relies on community engagement, political commitment, and cross-sectoral collaboration. In this context, public health authorities must prioritize the development of policies that promote environmental sustainability and support community-based initiatives to enhance the resilience of vulnerable populations against climate-sensitive VBDs[27].

Despite the promising outcomes observed in this review, several limitations and challenges must be acknowledged. First, the heterogeneity of data across different geographic regions and the variability in vector behavior under different climatic conditions pose challenges in predicting future transmission patterns. Second, the lack of standardized protocols for assessing the effectiveness of novel vector control technologies limits the generalizability of findings across diverse ecological settings. Third, the limited integration of climate adaptation strategies into national health policies and the inadequate allocation of resources for capacity-building programs further undermine the sustainability of vector control efforts. In light of these challenges, future research should focus on developing predictive models that incorporate climate data, vector ecology, and human behavioral patterns to enhance early warning systems for VBD outbreaks. Additionally, strengthening international collaboration between researchers, policymakers, and healthcare professionals is essential for building adaptive and resilient healthcare systems capable of responding to emerging infectious diseases. Finally, investing in community-based education programs and promoting public awareness campaigns on climate change and vector control can foster local ownership and enhance the long-term success of vector management strategies[21, 37].

In conclusion, this review provides compelling evidence that addressing the global burden of vector-borne diseases in the context of climate change requires an integrated and interdisciplinary approach. By enhancing medical education, adopting innovative vector control technologies, and implementing sustainable environmental health management strategies, healthcare systems can effectively mitigate the transmission dynamics of VBDs and protect vulnerable populations from future outbreaks. These findings serve as a foundation for policymakers, researchers, and public health practitioners to design evidence-based interventions that are both effective and sustainable in the face of ongoing climatic and ecological challenges[38, 39].

Highlights

What Is Already Known?

Climate change significantly alters vector ecology, expanding habitats and increasing the transmission of diseases like malaria, dengue, Zika, and leishmaniasis. Current medical education often lacks an interdisciplinary approach that integrates climate science, vector biology, and environmental health management. Innovative vector control technologies (e.g., Wolbachia, gene drives, RNAi) and integrated environmental management strategies have shown promise but face challenges in implementation, policy integration, and community engagement.

What Does This Study Add?

Demonstrates that integrating climate science and vector control into medical education enhances healthcare system preparedness, improves diagnostics, and strengthens disease surveillance. Highlights the effectiveness of combining advanced vector control technologies with sustainable environmental health strategies for reducing disease transmission. Emphasizes the need for interdisciplinary collaboration, policy-driven frameworks, and community engagement to build resilient healthcare systems capable of responding to climate-sensitive vector-borne diseases.

Authors' Contributions

Ebrahim Abbasi conceptualized the study, conducted the literature review, analyzed the data, and drafted the manuscript. The author reviewed and approved the final version of the manuscript.

Acknowledgements

The author thanks colleagues at the Medical Education Development Center and the Department of Medical Entomology, Shiraz University of Medical Sciences, for their guidance and support in reviewing relevant literature and providing insights on vector control strategies.

Conflicts of Interest Disclosures

The author declares no conflicts of interest related to this study.

Funding/Support

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The extent of AI use

AI tools were not used to generate, analyze, or interpret the content of this manuscript. All writing, analysis, and conclusions were solely performed by the author.

Ethics approval and consent to participate

Not applicable

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

Competing interests

The authors declare no competing interests.

Consent for publication

Not applicable

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