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ENVIRONMENTAL DETERMINANTS AND CONTROL STRATEGIES OF VECTOR-BORNE DISEASES: A SYSTEMATIC REVIEW

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Abstract

Background of the study: Vector-borne diseases (VBDs) represent a persistent global health threat increasingly exacerbated by climate change, unplanned urbanization, and accelerating environmental degradation across tropical and subtropical regions. Purpose: This study aims to systematically identify the primary environmental determinants of VBDs and comparatively evaluate the effectiveness of existing vector control strategies through a rigorous literature synthesis. Method: A Systematic Literature Review (SLR) was conducted following PRISMA guidelines, with searches performed across PubMed, Scopus, Web of Science, and Google Scholar databases. From 309 initially identified records, 20 articles satisfied all inclusion criteria and were comprehensively synthesized. Findings: Temperature, rainfall variability, land use change, inadequate sanitation, and socioeconomic disparities emerged as dominant ecological determinants of VBD transmission. Integrated Vector Management (IVM) demonstrated superior effectiveness compared to single-component interventions. GIS-based technologies and digital surveillance innovations significantly enhanced outbreak early-warning capacities. Conclusion: Sustainable VBD control necessitates an integrated paradigm shift combining real-time environmental monitoring, biotechnological innovation, geospatial modeling, and equitable multisectoral collaboration within a comprehensive.

Keywords: Environmental Determinants, Integrated Vector Management, Vector-Borne Diseases

Introduction

Vector-borne diseases (VBDs) remain one of the most complex and life-threatening global health challenges. Diseases such as malaria, dengue hemorrhagic fever, chikungunya, filariasis, and leishmaniasis are recorded as contributing to more than 700,000 deaths annually worldwide, with the greatest burden borne by developing countries in tropical and subtropical regions [1]. Massive global climate change has significantly altered the geographic distribution patterns of disease vectors, expanding the range of Aedes aegypti, Anopheles gambiae, and other arthropod mosquito species into previously non-endemic areas. This phenomenon emphasizes the urgency of a deeper understanding of the environmental determinants that influence the survival, reproduction, and transmission capacity of disease vectors [2]. Ecologically, the presence and density of vector populations are strongly influenced by a series of dynamically interacting environmental factors. Air temperature, rainfall, relative humidity, and land use characteristics have been shown to directly and indirectly influence the vector life cycle. Recent research shows that a consistent increase in average temperature of 1–2°C can accelerate pathogen replication within the vector (extrinsic incubation period) while expanding potential habitats for disease-carrying mosquitoes. On the other hand, unplanned urbanization creates environmental conditions conducive to vector proliferation, such as stagnant water, poor waste management, and

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minimal sanitation in residential areas [3]. These factors collectively create a constantly changing epidemiological landscape that requires adaptive, evidence-based control responses [4].

The literature on VBD control strategies has grown rapidly in the past decade. Various approaches have been explored, ranging from chemical control using new-generation insecticides, biological control through the use of Bacillus thuringiensis israelensis (Bti) and larva-eating fish, to biotechnological innovations such as the release of sterile male mosquitoes (sterile insect technique) and Wolbachia-infected mosquitoes, which have been shown to significantly suppress dengue virus transmission [5]. Furthermore, the application of geographic information systems (GIS) and machine learning-based spatial modeling is increasingly being used to map transmission risks and optimize vector control resource allocation [6]. However, there is a substantial research gap in the existing literature. Most studies have been partial, examining only one environmental determinant or one control strategy in isolation, without integrating the two within a comprehensive and systematic analytical framework. Few systematic reviews explicitly examine the causal relationship between specific environmental determinants and the effectiveness of specific control strategies across different geographic and epidemiological contexts. This knowledge gap often results in VBD control policy recommendations being contextually detached and less responsive to local environmental conditions (Rocklöv & Dubrow, 2023). The novelty of this research lies in its systematic synthesis, which explicitly links environmental determinants and the comparative effectiveness of various vector control strategies, resulting in an integrated conceptual framework that can serve as a reference for evidence-based policymaking.

Based on the description above, the research problem formulation in this study is: what environmental factors are significantly the main determinants of the spread of vector-borne diseases, and how effective are various vector control strategies in the context of these environmental determinants? This study aims to identify and synthesize scientific evidence regarding the main environmental determinants of VBDs and evaluate the comparative effectiveness of control strategies that have been implemented globally through a systematic review approach. The benefits of this research include two main dimensions: theoretically, the results of the study are expected to enrich the treasury of environmental health science and vector epidemiology; practically, the research findings are expected to be a strategic reference for policymakers, public health practitioners, and international institutions in designing more effective, efficient, and sustainable VBD control programs.

Method

This study used a Systematic Literature Review (SLR) approach, implemented in a structured and transparent manner, referring to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The SLR method was chosen because of its ability to synthesize scientific evidence comprehensively, objectively, and reproducibly from various primary literature sources relevant to the topic of environmental determinants and vector-borne disease control strategies [8]. A systematic literature search was conducted in internationally reputable electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar. The keywords used included structured combinations of: "vector-borne diseases," "environmental determinants," "climate change," "vector control strategies," "disease ecology," and "systematic review," with Boolean AND/OR operators to maximize the scope of search results [8]. Inclusion criteria included articles published between 2019 and 2024, in English or Indonesian, in the form of primary research or systematic reviews, discussing environmental determinants of VBDs and vector control strategies, and available in full-text format. Articles containing opinion pieces, editorials, or thematically irrelevant articles were excluded. The literature selection process was carried out through four systematic stages, as visualized in the following PRISMA diagram:

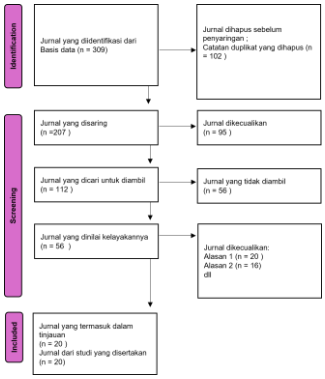


Figure 1. Prisma Flow Diagram

The identification stage yielded 309 articles from all databases. Subsequently, 102 duplicate records were removed, leaving 207 articles for screening. During the screening phase, 95 articles were excluded based on irrelevant titles and abstracts, resulting in 112 articles eligible for full-text review. From these, 56 articles were not accessible in full text, leaving 56 articles for eligibility assessment. After further evaluation, 36 articles were excluded—20 due to methodological limitations (Reason 1) and 16 due to topic irrelevance (Reason 2). Finally, 20 articles met all inclusion criteria and were included in the systematic review synthesis.

Results

The synthesis of 20 articles that met the inclusion criteria was conducted systematically to identify patterns, relationships, and the depth of scientific evidence related to environmental determinants and vector-borne disease (VBD) control strategies. Each study was reviewed based on its methodology, study subject, main findings, and relevance to the present research, as summarized in the following table

Table 1. Synthesis of Literature Review Findings

No	Author & Year	Title	Method	Subject	Key Findings	Relevance
1	Zhao & Liu (2022)	Dynamical Behavior and Optimal Control of a Vector-Borne Diseases Model on Bipartite Networks	Mathematical modeling, optimal control theory, numerical simulation	Bipartite network model of VBDs	Basic reproduction number identified; vaccination and quarantine strategies proven optimal in reducing disease spread	Provides a mathematical foundation for network-based VBD control strategies
2	Velde et al. (2024)	An Integrated Human Behavioral Model for Mosquito-Borne Disease Control	Scoping review, behavioral theory synthesis	28 studies on MBD control behavior	Knowledge, perceived susceptibility, and self-efficacy are key determinants of protective behavior	Strengthens the role of human behavior in VBD control
3	Pley et al. (2021)	Digital and Technological Innovation in Vector-Borne Disease Surveillance	Viewpoint review, technological innovation analysis	Climate-based VBD surveillance systems	Digital innovation and climate data integration improve outbreak prediction and early detection	Relevant to technology- and climate-based control strategies
4	Carvalho et al. (2025)	Unpacking the Risks of Zoonotic and	Narrative review, hazard-exposure-	Zoonotic and VBDs in	Climate change and land-use change	Links environmental

No	Author & Year	Title	Method	Subject	Key Findings	Relevance
		Vector-Borne Pathogen Transmission	vulnerability analysis	environmental change context	increase transmission risk; preventive approaches outperform curative ones	determinants with VBD transmission risks
5	Knudsen & Slooff (2025)	Vector-Borne Disease Problems in Rapid Urbanization	Policy analysis, urban control program review	VBDs in rapidly urbanizing areas of developing countries	Poor sanitation and dense settlements increase vector proliferation; integrated approaches outperform single pesticides	Highly relevant to urban environmental determinants and IVM strategies
6	Kalitsilo et al. (2025)	Vector-Borne Disease Control Interventions in Agricultural and Irrigation Areas in Sub-Saharan Africa	Systematic review, intervention analysis	16 VBD intervention studies in Sub-Saharan Africa	IRS, ITN, LSM, MDA, and IVM are effective; IVM most successful due to complementarity	Directly relevant to agricultural-based VBD control strategies
7	Masimalai (2024)	Vector Borne Disease Ecology and Environment: Remote Sensing and GIS	Spatial analysis, remote sensing, GIS mapping	Ecology and distribution of tropical and subtropical VBDs	Remote sensing and GIS effectively map VBD hotspots; land-use and climate changes influence vector distribution	Highly relevant for spatial-environmental determinants and GIS-based control
8	Ojayli et al. (2022)	Vector Control Strategies in Public Health – Challenges and Innovative Solutions	Systematic review, innovation analysis	Global VBD control strategies (malaria, dengue, Zika)	Insecticide resistance, urbanization, and climate change are major challenges; biotechnology and GIS are key innovations	Relevant to challenges and innovations in VBD control
9	Velde et al. (2024)	Integrated Human Behavioral Model for Mosquito-Borne Disease Control	Scoping review, behavioral theory	KAP studies on MBD	Strong theoretical behavioral frameworks are needed; KAP alone often insufficient	Relevant to behavioral determinants in VBD control
10	Wilson et al. (2020)	The Importance of Vector Control for the Control and Elimination of VBDs	Historical review, global program analysis	Global vector control programs since 1800s	Ecological-based control is more effective and sustainable than insecticide-only approaches	Strong historical foundation for ecological vector control
11	Batheja et al. (2026)	Socioeconomic and Household Water Management Determinants of Malaria and VBD Prevention	Household survey, logistic regression	4,074 households in Gujarat, India	Socioeconomic status and water management affect VBD incidence; vulnerable groups need targeted interventions	Relevant to socio-environmental determinants and community-based control
12	Okumu et al. (2025)	Elevating Larval Source Management as a Key Strategy for Controlling Malaria	Narrative review, modeling, expert discussion	Malaria LSM programs in Africa	LSM effectively reduces mosquito populations long-term; alternative evaluation approaches needed	Relevant to larval source-based control within IVM
13	Nunes et al. (2025)	Multisectoral Approaches to the Prevention and Control of VBDs	Case study, multisectoral workshop, collaborative review	Cross-sector VBD programs	Multisectoral collaboration improves effectiveness of VBD control	Relevant to holistic, multisectoral control strategies

No	Author & Year	Title	Method	Subject	Key Findings	Relevance
14	Choolayil et al. (2026)	Spatial Justice and Health (In)equity: The Case of VBDs	Mixed methods, geospatial mapping, survey & interviews	650 recovered VBD individuals in Puducherry, India	Socio-spatial configurations exacerbate health inequities; vulnerable groups remain in high-risk environments	Relevant to spatial determinants and health equity
15	Poudyal et al. (2025)	Contrasting and Comparing the Efficacy of Mobility-Targeted Interventions on VBDs	Mathematical modeling, urban mobility analysis, spatial data	Urban mobility and VBD transmission in Cali, Colombia	Mobility interventions for airborne diseases may worsen VBDs; integrated strategies required	Relevant to mobility-based control strategies
16	Robbiati et al. (2024)	One Health Prevention and Preparedness to VBDs	Rapid literature review, stakeholder consultation	13 One Health VBD studies	Multisectoral and multilevel synergy improves effectiveness and sustainability	Relevant to holistic governance via One Health
17	Yadav et al. (2025)	Environmental and Socio-Demographic Factors Associated with VBDs in India	NSSO data analysis, probit model	National survey data (76th round, India)	Age, education, wealth index, sanitation, and animal housing significantly affect VBD incidence	Relevant to socio-demographic and micro-environmental determinants
18	Alqassim (2024)	Social, Behavioral and Environmental Determinants of VBDs: A Narrative Review	Narrative review, multidimensional synthesis	Studies over the past two decades	Poverty, unplanned urbanization, climate change, and poor water management are key determinants	Highly relevant as a synthesis of VBD determinants
19	Hu et al. (2026)	Health Needs Assessment for Tropical VBD Prevention among Chinese Expatriate Workers in Africa	Cross-sectional survey, multivariate logistic regression	303 Chinese expatriate workers in Africa	Age, assignment duration, primate exposure, and limited medical support increase infection risk	Relevant to environmental exposure and mobile populations
20	Molina-Guzmán et al. (2022)	Models of Spatial Analysis for Vector-Borne Diseases Studies	Systematic review, spatial model analysis	Spatial VBD studies (2010–2020)	Climate and abiotic variables interact complexly; spatial modeling is critical for surveillance and control planning	Relevant for spatial analysis in VBD surveillance and control

The overall synthesis of the 20 articles reflects a wide diversity of scientific perspectives, ranging from mathematical modeling, geospatial spatial analysis, systematic reviews, to community-based field studies. This methodological diversity actually strengthens the validity of the synthesis, as it enables triangulation of findings from multiple scientific viewpoints in a comprehensive and complementary manner

Discussion

Key Environmental Determinants of Vector-Borne Diseases

The synthesis of 20 studies consistently confirms that environmental determinants are the most fundamental drivers in the dynamics of VBD transmission. Climatic factors—particularly temperature, rainfall, and humidity—interact synergistically in shaping vector habitats and accelerating pathogen replication. The acceleration of global climate change significantly exacerbates the emergence and spread of VBDs through the expansion of vector distribution zones into previously non-endemic areas [2],[3],[7],[12]. This finding is consistent with spatial analyses demonstrating that land-use changes and the dynamics of water bodies—such as dams, irrigation systems, and urban water stagnation—directly expand ecosystems that support vector proliferation in tropical and subtropical regions [6],[15].

Beyond climatic factors, unplanned urbanization has proven to be a significant ecological amplifier. High-density slum settlements lacking adequate drainage systems and waste management consistently increase vector abundance and the intensity of human–vector contact [13]. Evidence further shows that poverty, gender inequality, and poor water management form a cluster of socio-environmental determinants that reinforce each other, creating highly conducive conditions for VBD transmission in marginalized communities [25]. Meanwhile, micro-environmental factors—such as stagnant water, the presence of animal shelters, and poor household ventilation—have been shown to significantly influence the probability of VBD occurrence at the household level [24],[18].

The dimension of spatial justice also emerges as an often-overlooked determinant. Unequal socio-spatial configurations place vulnerable populations in environments that structurally increase exposure to vectors, while more affluent groups have the resources to modify or mitigate these risks [21]. This indicates that VBD determinants are not purely ecological but are also products of socially structured inequalities manifested spatially.

Effectiveness of Vector Control Strategies

A review of various vector control strategies shows that no single approach can provide a comprehensive and sustainable solution. Integrated Vector Management (IVM)—which combines indoor residual spraying (IRS), insecticide-treated nets (ITNs), larval source management (LSM), and mass drug administration (MDA)—produces significantly superior effectiveness compared to single interventions [14],[17]. The complementarity among interventions is key to IVM success, as each component targets different stages of the vector life cycle simultaneously.

Larval source management (LSM) has been highlighted as a priority strategy, as suppressing mosquito populations at the larval stage provides more sustainable long-term impacts compared to focusing exclusively on adult mosquito control using insecticides [19]. This approach is particularly relevant given the increasing global spread of insecticide resistance among malaria vectors, which remains one of the most critical barriers to successful VBD control programs [16].

Technological innovation is also playing an increasingly strategic role. The integration of climate data into real-time digital surveillance systems substantially enhances early detection capacity and enables proactive responses to VBD outbreak threats [11]. In addition, spatial modeling that incorporates climatic, biotic, and abiotic variables has been identified as a critical tool for surveillance planning and the targeted allocation of control resources [27],[6].

Multisectoral Approaches and One Health as an Integrative Framework

Evidence consistently shows that effective and sustainable VBD control requires approaches that go beyond the health sector alone. Cross-sector collaboration involving health, education, agriculture, environment, as well as water and sanitation significantly improves the coverage and sustainability of VBD control programs [20]. The One Health framework further emphasizes multisectoral and multilevel synergy as the foundation for comprehensive VBD governance [23] Human behavior also represents a

critical dimension. A deep understanding of the determinants of protective behaviors is essential for the success of sustainable, community-based VBD control interventions [10],[18].

Conclusion

This systematic review brings new insights that vector-borne disease control can no longer be viewed solely as an entomological issue, but rather as a multidimensional socio-ecological challenge. The most important implication of this research is the urgency of a paradigm shift from a reactive, single-insecticide-based approach to an adaptive control system that integrates real-time monitoring of environmental determinants, biotechnological innovation, spatial modeling, and cross-sectoral collaboration within a One Health framework. These findings emphasize that investment in climate and geospatial data-based surveillance systems is not merely a technical option but a strategic imperative in addressing the threat of vector-borne diseases (VBDs) exacerbated by global climate change and massive urbanization. Furthermore, this study underscores that spatial equity and reducing socioeconomic disparities are integral structural prerequisites for the success of sustainable and equitable VBD control programs.

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