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Understanding mosquito ecology and disease spread: Application for global health and vector control

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Abstract
Mosquitoes serve as key vectors for several major infectious diseases, including Malaria, Dengue, Zika and Chikungunya. Their ecological characteristics, life cycle patterns and behavioural traits play a crucial role in shaping mosquito borne disease transmission dynamic. Various environmental factors such as temperature, humidity and rapid urbanization, along with human habitat changes like deforestation and climate change, have facilitated the spread of mosquito population into new region, thereby increasing the risk of outbreak. A comprehensive understanding of mosquito ecology is fundamental for designing effective and sustainable vector control strategies. These may include innovative methods such as genetic interventions, biological control methods, Remote Sensing and Geographical Information System and the strategic use of insecticides. This review highlights the complex interactions between mosquito ecology and disease transmission and underscores the importance of integrated and adaptive control measures to reduce the global impact of mosquito-borne diseases.

Keywords: Mosquito ecology and vector borne diseases & control and global health

Introduction

Mosquitoes are recognized as one of the most important vectors of infectious diseases across the globe, responsible for the transmission of numerous pathogens that cause illnesses such as malaria, dengue fever, Zika virus infection, chikungunya, and yellow fever (Onen H *et al*., 2023) [22]. Despite their small size, these insects pose a major threat to public health, leading to high levels of illness and death, especially in tropical and subtropical regions. Their widespread distribution and ability to adapt to diverse environments further increase their impact on human populations. According to the World Health Organization (WHO), mosquito-borne diseases affect millions of people each year, creating a substantial burden on healthcare systems, national economies, and communities, particularly in low- and middle-income countries. The success of mosquitoes in a wide range of habitats is largely due to their remarkable ecological adaptability, feeding habits, and reproductive capacity (Zhang Y *et al*., 2024 & Yu Y *et al*., 2023) [29, 30].

Different mosquito species demonstrate varied breeding preferences, utilizing environments such as stagnant water bodies, artificial containers, and urban drainage systems for egg laying. In addition, their host-seeking behavior is strongly influenced by environmental signals, including carbon dioxide, body heat, and human odors (Tunon, R *et al*.,2025) [28]. These sensory cues enable mosquitoes to efficiently locate hosts, thereby enhancing their role in the transmission of infectious diseases.

Moreover, mosquitoes not only impact human health but also play an essential role in ecosystems, serving as pollinators for certain plants and as a crucial food source for various predators, including birds, fish, and amphibians (Brown, M.D *et al*., 2002) [4]. Despite their ecological significance, their role as disease vectors has made their control a top priority in global public health initiatives. Environmental and anthropogenic factors, including temperature, humidity, deforestation, urbanization, and climate change, have significantly influenced the geographic distribution and density of mosquito populations. Rising global temperatures and altered precipitation patterns have expanded the habitat ranges of many mosquito species, leading to the emergence and resurgence of vector-borne diseases in regions that were previously unaffected. Additionally, rapid urbanization and inadequate waste management have created new breeding sites for mosquitoes, further exacerbating disease transmission risks. Understanding mosquito ecology, behavior, and its role in disease transmission is crucial for developing sustainable and effective vector control strategies. Integrated approaches, including genetic modification, biological control, Remote Sensing and Geographical Information System and targeted insecticide applications, are being explored to combat mosquito-borne diseases (Ali & Majid, 2020). A comprehensive understanding of these factors is essential to mitigating the impact of mosquitoes on public health and reducing the global burden of vector-borne diseases (Gujju Gandhi *et al*., 2017) [18].

Result and Discussion

The present analysis highlights the diversity of mosquito vectors and their strong association with major vector-borne diseases across India. Species such as *Anopheles culicifacies*, *Anopheles stephensi*, *Anopheles fluviatilis*, and *Anopheles minimus* remain the principal vectors of malaria, particularly in states like Andhra Pradesh, Chhattisgarh, Gujarat, Madhya Pradesh, and Maharashtra (Amruthraj Radhakrishnan 2019) [1]. Their widespread distribution reflects ecological adaptability and the persistence of malaria transmission in both rural and peri-urban settings.

Similarly, *Culex quinquefasciatus* and *Mansonia* species play a dominant role in the transmission of lymphatic filariasis, especially in densely populated regions such as Bihar, Uttar Pradesh, Jharkhand, Maharashtra, and Karnataka. The prevalence of these vectors in areas with poor sanitation and stagnant water bodies indicates the strong link between environmental conditions and disease burden.

Japanese Encephalitis (JE), transmitted primarily by Culex and Mansonia species, is largely confined to states like Tamil Nadu, West Bengal, and Uttar Pradesh. These regions provide favorable ecological niches such as rice fields and wetlands, which enhance vector breeding and disease transmission. In contrast, *Aedes aegypti* and *Aedes albopictus*, the vectors of dengue, show a much broader geographical distribution, spanning both urban and semi-urban areas across multiple states including Andhra Pradesh, Maharashtra, Karnataka, Telangana, Kerala, and West Bengal. Their adaptability to artificial breeding habitats underscores the growing public health challenge posed by rapid urbanization.

Environmental variables play a critical role in shaping mosquito density and transmission dynamics. Temperature influences the life cycle of mosquitoes and pathogen development, with seasonal variations (summer, monsoon, and winter) affecting vector abundance. High humidity levels enhance mosquito survival and biting activity, thereby increasing disease transmission potential. Rainfall contributes to the creation of breeding habitats, particularly stagnant water collections, which significantly elevate mosquito populations. Urbanization further exacerbates the problem by introducing artificial breeding sites such as containers, drains, and construction areas, increasing human–vector contact. Additionally, deforestation facilitates the spread of vectors into new ecological zones, potentially introducing diseases into previously unaffected regions.

Table 1: Common Vectors associated with Diseases

Vector	Primary Diseases	Geographical Distribution (India)
An. Culicifacies, An. Stephensi, An. Fluviatilis, An. Minimus	Malaria	Andhra Pradesh, Chhattisgarh, Gujarat, MP and MH
Cx. Quinquefasciatus, Mansonia. Annulifera, Ma. Uniformis	Lymphatic Filariasis	Bihar, Jharkhand, UP, MH, Karnatak
Culex Spp and Mansonia Spp	Japanese Encephalitis	Tamil Nadu, West Bengal, UP etc
Aedes aegypti, Aedes albopctus	Dengue	AP, CH, MP, MH, WB, Karnataka, TS, kerala, Bihar, UP, et

Table 2: Role of Environmental Variable in mosquito density

Factor	Effect on mosquito density and disease transmission
Temperature	Seasonal and Regional Temperature Variations (summer, Monsoon, winter)
Humidity	Average / High humidity and regional variation (Increase the Mosquito activity and surveillance)
Rainfall	Average and regional Variation (Increase the breeding habitats)
Urbanization	Fast-growing (Increases artificial breeding habitats (e.g., containers, drains) and human-mosquito interactions.)
Deforestation	Spread of mosquitoes in to new areas

The evaluation of vector control methods reveals varying degrees of effectiveness. Biological control methods, such as lar*vivo*rous fish or microbial agents, provide moderate and environmentally sustainable solutions by targeting larval stages. Chemical control methods, including insecticides, offer rapid reduction in adult mosquito populations but are often limited by short-term effectiveness and the risk of resistance development. Genetic approaches, such as sterile insect techniques, show promise for long-term vector suppression but require further large-scale validation. Environmental management remains one of the most sustainable strategies, focusing on reducing breeding sites and minimizing both larval and adult populations over time.

Table-3: Vector Control Methods and effectiveness

Control method	Mechanism	Effectiveness
Biological	Reduce the larval surviaval	Moderate
Chemical	Kill the adult mosquitoes	High and short time
Genetical	Reduce the reproductive successes	Promising long-term Solution
Environmental	Reduce the larval and adult	Long term
RS & GIS	Find and mapping the vector and diseases	Accuracy

The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) has emerged as a powerful tool in vector surveillance and disease mapping (Gandhi G *et al*., 2013) [14]. These technologies enable accurate identification of high-risk areas, facilitate targeted interventions, and improve resource allocation. Their application is particularly valuable in a country like India, where environmental and climatic conditions vary widely across regions.

Material and Methods

Vector Biology and Behaviour

Mosquitoes, belonging to the order Diptera and family Culicidae, comprise more than 3,500 species distributed across diverse ecological regions worldwide. Despite this diversity, only a few genera, notably *Anopheles*, *Aedes*, and *Culex*, play a major role in transmitting pathogens that cause diseases in humans (Gandhi G *et al.*, 2024) [13]. The biological features of mosquitoes including their feeding behavior, reproductive capacity, and ecological adaptability are key determinants of disease transmission patterns and the success of vector control interventions. In recent decades, mosquito-borne diseases have shown patterns of emergence and re-emergence, largely driven by factors such as rapid urbanization, environmental changes, and climate variability. These factors have facilitated the expansion of mosquito habitats and increased human–vector interactions, thereby elevating the risk of disease outbreaks. Vector-borne diseases continue to represent a major global health challenge, contributing substantially to morbidity and mortality. It is estimated that more than half of the global population is at risk of such infections, which together account for a significant proportion of the worldwide infectious disease burden. (CDC.2014d).

Vector Life Cycle and Breeding Habitat

The mosquito life cycle is composed of four developmental stages: egg, larva, pupa, and adult. The initial three stages occur in aquatic environments, typically in standing or slow-moving water such as ponds, ditches, containers, and temporary pools. The mode of egg-laying varies among species; for example, *Anopheles* mosquitoes deposit eggs individually on the water surface, whereas *Culex* species lay eggs in grouped formations known as rafts. In contrast, *Aedes* mosquitoes prefer to lay their eggs on damp surfaces just above the water line, where they remain viable until submerged.

Once hatched, the larvae emerge and actively feed on microorganisms and organic debris present in the water (Souza RS *et al*., 2019) [26]. These larvae undergo multiple growth stages before transforming into pupae. The pupal stage is a transitional, non-feeding phase during which the organism undergoes significant internal changes to develop into an adult mosquito (Gandhi G *et al*., 2024) [13]. The total duration of the life cycle is influenced by environmental conditions such as temperature, humidity, and nutrient availability. Under favorable conditions, development from egg to adult can occur within a short period, often around one to two weeks. Higher temperatures generally speed up this process, enabling faster population growth and increasing the likelihood of disease transmission. The evolution of host preference, from nonhuman animals to humans, has not been homogeneous across the anopheline community (Rulli, M. C *et al*., 2025) [24].

Several mosquito species have quickly adapted to human dwellings, showing a strong preference for feeding on humans, whereas others remain primarily zoophilic, relying on animals as their main hosts (Carnevale, P., *et al.,* 2009) [5]. Host selection in mosquitoes is influenced by a combination of internal and external factors, such as the availability of hosts, the mosquito's physiological condition, and its genetic makeup (Takken & Verhulst, 2013) [27]. Malaria exists in every tropical and subtropical landscape across the globe, sometimes making seasonal excursions into temperate areas as well (Fikadu M *et al*., 2023) [11]. The protozoan parasites that cause it have more complex genomes, metabolisms and life cycles than almost any other vector-borne threat. This complexity makes them a difficult target for interventions such as drugs and vaccines because the parasite's shape-shifting ways allow it to evade chemical and immunological defenses (Gandhi.G *et al.,* 2017) [18].

Anopheles spp.-These are nocturnal feeders, primarily biting humans indoors or outdoors during the night. They are the primary vectors of malaria, transmitting Plasmodium parasites (Gandhi G *et al.,* 2023) [16, 17].

Aedes aegypti- his species is a diurnal feeder, active during the early morning and late afternoon. It is the primary vector of dengue, Zika virus, chikungunya, and yellow fever (Bhuvaneswari, R *et al*., 2016) [2].

Culex spp.-hese mosquitoes prefer birds as their primary hosts but also bite humans and other mammals. They are responsible for transmitting West Nile virus, filariasis, and Japanese encephalitis (Fernandes, R.S *et la*., 2020) [10]. In recent years, vector-borne diseases (VBD) have emerged as a serious public health problem in most of the countries including India. Health Information System (HIS) is one of the best preventive methods to control the vector borne diseases through RS and GIS (Gujju, G *et al*., 2013) [19]. Altho chemical insecticides will remain important in vector control programs some study include polio also (Chapla, J *et al.,* 2017) [7], problems they have caused, and the paucity of new types under development, have for some time chose the stimulated interest in alternative control agents like biology method (Gandhi, G *et al.,* 2016) [15].

Flight Activity and Resting Behavior

Mosquito flight patterns are strongly affected by environmental conditions, including temperature, humidity, and wind velocity (Bidlingmaye, 1971). In general, most mosquito species remain within a relatively limited flight range, typically between 1 and 5 km from their breeding sites. However, under favorable conditions or when searching for hosts and suitable habitats, some species are capable of dispersing over much longer distances (Christophers, 1960) [8].

Following a blood meal, mosquitoes display distinct resting behaviors that vary among species. *Anopheles* mosquitoes commonly rest on indoor surfaces such as walls and ceilings, as well as on nearby vegetation. In contrast, *Aedes* species prefer sheltered and shaded locations, often hiding in places like furniture, closets, and other indoor corners (Seang-arwut, *et al*.,2023) [25]. *Culex* mosquitoes are typically found resting in dark and humid environments, including drainage systems, basements, and areas with dense vegetation.

Control Methods

Various mosquito control methods have been developed to reduce vector populations and limit disease transmission, each operating through different mechanisms and offering varying levels of effectiveness (Renuka S. *et al*., 2025) [23]. Biological control involves the use of natural agents such as predators, parasites, or microorganisms to decrease larval survival in aquatic habitats, providing a moderately effective and environmentally sustainable approach (de Melo KR, *et al*., 2023) [9]. Chemical control relies on the application of insecticides and larvicides to eliminate adult mosquitoes or their immature stages, offering rapid and high effectiveness, although its impact is often short-lived and may lead to resistance over time. Genetic control strategies focus on reducing reproductive success through techniques such as sterile insect release or genetic modification, representing a promising long-term solution, though still under active development (Hacker I *et la.,* 2023 & Galizi R *et al*., 2016) [12, 21]. Environmental management emphasizes the elimination of breeding sites through measures such as removal of stagnant water, improved sanitation, and habitat modification, making it a highly effective and sustainable long-term strategy (Guo S, *et al*., 2025) [20]. Additionally, the integration of Remote Sensing (RS) and Geographic Information Systems (GIS) (Gujju, G.*et al*., 2013) [19] enables accurate mapping and monitoring and evaluation of mosquito population and disease distribution, supporting targeted and efficient vector control methods.

Conclussion

Mosquito-borne diseases continue to pose a major public health challenge, driven by the complex interplay between mosquito ecology, environmental conditions, and human activities. This study highlights that vector diversity, adaptive breeding behavior, and climatic factors such as temperature, humidity, and rainfall significantly influence mosquito population dynamics and disease transmission patterns across India. Rapid urbanization and environmental changes, including deforestation, have further expanded vector habitats and increased human mosquito interactions, elevating the risk of outbreaks. While various control strategies Biological, Chemical, Genetic, Environmental, and technological tools like Remote Sensing and GIS offer differing levels of effectiveness, no single method is sufficient on its own. Therefore, an integrated and region-specific approach to vector management, supported by continuous surveillance, environmental modification, and public health awareness, is essential for sustainable control. Strengthening these multidisciplinary strategies will be crucial in reducing the burden of mosquito-borne diseases and improving global health outcomes.

Table-4: Integrated Conclusion on Mosquito Ecology, Disease Transmission, and Control Strategies

Component	Key Findings	Implications for Disease Spread	Recommended Strategies
Mosquito Diversity & Vectors	Major genera include *Anopheles*, *Aedes*, and *Culex* with species-specific disease roles (Malaria, Dengue, Filariasis, JE)	Wide distribution and adaptability increase transmission across rural, urban, and peri-urban regions	Species-specific surveillance and targeted vector control programs
Life Cycle & Breeding Ecology	Aquatic stages (egg, larva, pupa) depend on stagnant water; rapid development under favorable conditions	Faster life cycle increases vector population and outbreak risk	Elimination of breeding habitats and water management practices
Environmental Factors	Temperature, humidity, rainfall, urbanization, and deforestation strongly influence mosquito density	Climate variability and human activities expand vector habitats and transmission zones	Climate-based forecasting and environmental management strategies
Host-Seeking & Behavior	Mosquitoes respond to CO_2, heat, and odors; feeding patterns vary (diurnal/nocturnal)	Increased human-vector contact enhances disease transmission efficiency	Personal protection measures and behavioral intervention strategies
Geographical Distribution (India)	Disease prevalence varies regionally based on ecological suitability	Local environmental conditions determine disease hotspots	Region-specific intervention and surveillance programs
Vector Control Methods	Biological (moderate), Chemical (high but short-term), Genetic (emerging), Environmental (sustainable), RS & GIS (accurate mapping)	No single method is sufficient; resistance and sustainability are major concerns	Integrated Vector Management (IVM) combining multiple approaches
Technological Integration (RS & GIS)	Enables mapping of vector habitats and prediction of outbreaks	Improves early warning systems and resource allocation	Adoption of spatial tools for real-time monitoring and decision-making
Public Health Impact	Mosquito-borne diseases remain a major burden in tropical countries like India	Increased morbidity, mortality, and economic strain	Strengthening public health infrastructure and awareness programs
Overall Conclusion	Mosquito ecology, environmental dynamics, and human behavior are interconnected	Disease transmission is complex and multifactorial	Integrated, adaptive, and sustainable vector control strategies are essential

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