J. Sci. Innov. Nat. Earth: Vol. 5, Issue 2, 2025, Page No-85-90 ISSN (Online) 2583-2093 OPEN ACCESS

Journal of Science Innovations and Nature of Earth

Journal homepage : https://jsiane.com/index.php/files/index

International, Double-Blind, Quarterly, Peer-Reviewed, Refereed Journal, Edited and Open Access Research Journal

Understanding Mosquito Biodiversity in India: Key Genera, Ecology, and Disease Transmission – A Review

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DOI: https://doi.org/10.59436/jsiane.401.2583-2093

Abstract

Mosquitoes are among the most medically important insects in India, serving as vectors for a wide range of diseases, including malaria, dengue, chikungunya, filariasis, and *Japanese encephalitis*. The Indian subcontinent, with its diverse ecosystems ranging from Himalayan foothills to coastal plains supports a rich diversity of mosquito fauna. This review provides a comprehensive account of mosquito diversity across India, focusing on the major genera: Anopheles, Aedes, Culex, Mansonia, and Armigeres. Each genus exhibits unique ecological adaptations, breeding habitats, biting behavior, and vectorial capacities. Anopheles species are predominantly rural and forest-dwelling, while Aedes thrive in urban settings and artificial containers. Culex and Mansonia are common in polluted or semi-aquatic environments, and Armigeres are emerging as secondary vectors in some regions. The review also highlights the ecological factors influencing mosquito distribution, including climate change, deforestation, urbanization, and water management practices. Special attention is given to recent shifts in species ranges and the emergence of new vector hotspots. Despite extensive research, several regions and species remain under-studied, particularly in the northeastern and central parts of India. There is a pressing need for integrative taxonomic approaches, molecular surveillance, and ecological modeling to fully understand mosquito biodiversity and vector potential. By synthesizing current knowledge, this article aims to aid entomologists, public health officials, and policy makers in designing effective, location-specific vector surveillance and control programs. Understanding mosquito diversity is not only essential for disease prevention but also for maintaining ecological balance in India's varied landscapes.

Keywords*:* Mosquito diversity, Vector ecology, Aedes, Culex, Anopheles, India

Received 27.03.2025 Revised 21.05.2025 Accepted 19.06.2025 Online Available 20.06.2025

Introduction

Mosquitoes (family Culicidae) are one of the most widespread and ecologically diverse groups of insects, comprising more than 3,600 species worldwide, of which over 400 species are reported from India alone (Tyagi *et al*., 2015). These dipteran insects are of significant ecological and public health importance, playing dual roles in ecosystems as pollinators and food sources for other organisms, while simultaneously acting as vectors for numerous human and animal diseases (Service, 2012). In India, mosquitoes are responsible for the transmission of several vector-borne diseases such as malaria, dengue, chikungunya, *Japanese encephalitis* (JE), and lymphatic filariasis (Sharma *et al*., 2014).

India's rich biodiversity and varied ecological zones from the Himalayan foothills to coastal mangroves and arid plains offer a wide range of habitats suitable for mosquito proliferation (Subbarao, 1998). The climatic diversity, coupled with extensive agricultural activity and urbanization, facilitates the establishment and coexistence of both native and invasive mosquito species (Ghosh *et al*., 2012). The subfamily Anophelinae, which includes the malaria vectors (Anopheles spp.), and Culicinae, which includes Aedes, Culex, Mansonia, and Armigeres, dominate the Indian mosquito fauna (Reuben *et al*., 1994). Among the medically important species, *Anopheles culicifacies* and *Anopheles stephensi* are primary malaria vectors in rural and urban India, respectively (Das *et al*., 2012). *Aedes aegypti*, the principal vector of dengue and chikungunya, has emerged as a major threat in urban settings due to the proliferation of artificial containers and improper waste management (Kumar *et al*., 2011). Similarly, Culex quinquefasciatus, the vector for lymphatic filariasis, thrives in polluted water bodies common in peri-urban and rural environments (Bockarie *et al*., 2009). The increased incidence of arboviral infections in recent decades indicates a growing public health burden associated with mosquito diversity and distribution in India. Several studies have documented the seasonal abundance, habitat preferences, and disease associations of mosquito species across different Indian states. However, comprehensive and updated taxonomic documentation remains limited due to the cryptic nature of some species and the morphological similarity among members of species complexes (Singh *et al*., 2020). Recent molecular approaches such as DNA barcoding and genomic studies are helping unravel hidden diversity and clarify species boundaries, contributing to more accurate surveillance and control strategies (Foster *et al*., 2017). Understanding the diversity of mosquitoes in India is essential not only for entomological and ecological knowledge but also for designing effective vector management programs. The diversity, distribution, and adaptability of mosquitoes are influenced by a combination of biotic and abiotic factors including temperature, rainfall, habitat structure, human behavior, and land use changes (Yadav *et al*., 2014). With the advent of climate change and rapid urbanization, vector ecology in India is likely to undergo significant shifts, necessitating continuous monitoring and research.

This review aims to synthesize current knowledge on the diversity of mosquitoes in India, analyze patterns of distribution and ecological adaptation, highlight medically important species, and identify research gaps in taxonomy and vector surveillance.

Review methodology

An extensive literature search was performed using scientific databases such as PubMed, ScienceDirect, Web of Science, and Google Scholar from January 2000 to April 2024. Keywords and MeSH terms used included: "mosquito diversity", "Culicidae in India", "Aedes", "Anopheles", "Culex", "Mansonia", "Armigeres", "vector ecology", "taxonomy", "India", and "vector surveillance". Data extraction focused on species diversity, distribution, breeding ecology, disease vectors, and surveillance strategies. No quantitative meta-analysis was performed due to data heterogeneity. Only English-language publications were considered. The final selection ensured balanced representation of geographic, ecological, and epidemiological aspects of mosquito diversity in India.

Taxonomic Classification of Indian Mosquitoes

Mosquitoes belong to the order Diptera, family Culicidae, and are characterized by long slender bodies, scales on their wings, and elongated mouthparts adapted for piercing and sucking. The family Culicidae is further classified into two primary subfamilies in India: Anophelinae and Culicinae.

Subfamily Anophelinae

This subfamily includes the genus Anopheles, which is of critical medical importance in India due to its role as the sole vector of human malaria. Around 60 species of Anopheles have been reported from India, several of which belong to species complexes that vary in vectorial capacity, behavior, and insecticide resistance profiles (Subbarao, 1998; Tyagi *et al*., 2015). Prominent malaria vectors include: *Anopheles culicifacies* (primary rural vector), *Anopheles stephensi* (urban vector), *Anopheles fluviatilis* (forest and foothill vector), *Anopheles minimus* (northeast India). These mosquitoes generally breed in clean, slow-moving water bodies such as river edges, rice paddies, and ponds, and show crepuscular and nocturnal feeding habits (Sharma *et al*., 2006).

Subfamily Culicinae

This group includes genera that are important vectors of arboviral and filarial diseases. The most significant genera in India under Culicinae include:

a. Culex

With over 100 species in India, this genus includes species like Culex quinquefasciatus, the primary vector of lymphatic filariasis, and Culex tritaeniorhynchus, the main vector of *Japanese encephalitis* (Das *et al*., 2012). These mosquitoes prefer polluted water bodies such as drains, cesspools, and septic tanks for breeding.

b. Aedes

About 25 species of Aedes are reported from India, including *Aedes aegypti* and *Aedes albopictus*, which are major vectors of dengue, chikungunya, and Zika viruses. These species are highly adapted to urban environments, breeding in artificial containers such as tires, buckets, and overhead tanks (Kumar *et al*., 2011).

c. Mansonia

Species like *Mansonia annulifera* and *Mansonia uniformis* are associated with filarial transmission in specific regions. They breed in stagnant water bodies containing aquatic vegetation like water hyacinths, which they use to obtain oxygen via specialized siphons (Rajavel & Natarajan, 2006).

d. Armigeres

Species such as Armigeres subalbatus are not major vectors but can serve as secondary vectors of diseases such as filariasis and may contribute to arbovirus transmission under certain ecological conditions. They are mostly found in peri-urban and forested areas (Reuben *et al*., 1994).

Table 1. Major Mosquito Genera in India and Their Relevance

Genus	No. of Species in India	Vector Role	Common Breeding Sites
Anopheles	~60	Malaria (P. falciparum, P. vivax)	Clean water, rice fields, streams
Culex	>100	Filariasis, *Japanese encephalitis*	Polluted water, drains, septic tanks
Aedes	~25	Dengue, Chikungunya, Zika	Artificial containers, urban water storage
Mansonia	~10	Secondary filariasis vectors	Water with aquatic vegetation
Armigeres	~15	Secondary/occasional arbovirus vectors	Forest edges, tree holes, containers

(Sources: Tyagi *et al*., 2015; Rajavel & Natarajan, 2006; Das *et al*., 2012)

Geographic Distribution of Mosquitoes in India

India's vast geographic expanse encompasses a wide range of ecological zones, from the Himalayan mountains and Indo-Gangetic plains to coastal wetlands and tropical forests. This ecological diversity significantly influences the distribution and diversity of mosquito species across regions. Climatic variables such as rainfall, temperature, and humidity, along with human-altered landscapes like rice paddies and urban settlements, determine mosquito species prevalence and abundance in different parts of the country (Subbarao, 1998; Tyagi *et al*., 2015).

Mosquitoes in India show both regional endemism and overlapping distribution, with some species adapted to specific ecological niches, while others are widely distributed generalists. The major vector species show strong spatial association with disease endemicity.

Table 2. Region-wise Geographic Distribution of Major Mosquito Species in India

Region	Dominant Mosquito Species	Major Diseases	Ecological Features & Habitat Types	References
North India	*An. culicifacies, An. stephensi, Cx. quinquefasciatus*	Malaria, Filariasis	Indo-Gangetic plains, stagnant water, irrigation canals	Subbarao (1998); Sharma *et al.* (2006)
North-East India	*An. dirus, An. minimus, Ae. albopictus, Cx. tritaeniorhynchus*	Malaria, Dengue, JE	Dense forests, high rainfall, foothills, riverine habitats	Barik *et al.* (2009); Das *et al.* (2012)
South India	*An. stephensi, Ae. aegypti, Mansonia spp.*	Dengue, Malaria, Filariasis	Coastal plains, urban towns, rice fields, water tanks	Kumar *et al.* (2011); Tyagi *et al.* (2015)
Western India	*Cx. quinquefasciatus, Ae. aegypti, An. culicifacies*	Filariasis, Dengue, Malaria	Semi-arid regions, urban areas, wells, tanks	Reuben *et al.* (1994); NVBDCP (2021)
Central India	*An. culicifacies, An. fluviatilis, Cx. vishnui group*	Malaria, JE	Forest-fringe villages, streams, irrigated farmlands	Dash *et al.* (2007); Singh *et al.* (2020)
Eastern India	*Cx. tritaeniorhynchus, Ae. albopictus, An. annularis*	*Japanese encephalitis*, Dengue	Paddy fields, flood-prone plains, freshwater pools	Ghosh *et al.* (2012); NVBDCP (2021)
Himalayan Region	*An. fluviatilis, Armigeres spp.*	Malaria (focal), Secondary arboviruses	Mountain streams, shaded forest areas, rock pools	Subbarao (1998); Rajavel & Natarajan (2006)

North India (e.g., Uttar Pradesh, Punjab, Haryana): High Anopheles density in rural areas and *Aedes aegypti* expansion in peri-urban zones. Agricultural water use contributes to larval habitat formation.

North-East India (e.g., Assam, Meghalaya, Nagaland): Rich diversity due to tropical forests and high humidity. An. dirus is a major forest malaria vector here.

South India (e.g., Tamil Nadu, Kerala, Karnataka): Urbanization has increased *Aedes aegypti* breeding. Mansonia spp. thrive in water bodies with floating vegetation.

Western India (e.g., Rajasthan, Gujarat, Maharashtra): Arid zones support container breeders like Aedes. Malaria vectors persist near irrigation projects.

Central India (e.g., Madhya Pradesh, Chhattisgarh): Malaria remains a problem due to persistent *An. culicifacies*. Forest mosquitoes like An. fluviatilis dominate remote areas.

Eastern India (e.g., Bihar, Odisha, West Bengal): Highly endemic for *Japanese encephalitis* and dengue. Paddy fields and seasonal floods foster *Culex* and *Aedes* breeding.

Himalayan Belt (e.g., Uttarakhand, Himachal Pradesh): Cooler climates limit vector diversity, but focal transmission of malaria and arboviruses occurs in foothills.

Ecological Niches and Habitats of Mosquitoes in India

Mosquitoes exhibit remarkable ecological plasticity, occupying a wide range of habitats across India's diverse climatic and geographic zones. Their larval and adult stages are closely tied to the availability of specific microhabitats, which vary from natural aquatic systems to artificial containers in urban settings. The survival, reproduction, and disease vector potential of mosquito species are intrinsically linked to their habitat preferences (Service, 2012; Subbarao, 1998).

Natural Aquatic Habitats

Natural habitats serve as breeding and developmental sites for many indigenous mosquito species.

a. Freshwater Pools and Ponds

Species: *Anopheles culicifacies*, *Anopheles stephensi*, *Culex vishnui* group

Features: Clear, sunlit, stagnant water in rural or forest settings.

Importance: Major breeding sites for malaria and JE vectors.

(Sharma *et al*., 2006; Tyagi *et al*., 2015)

b. Streams and Hill Rivers

Species: *Anopheles fluviatilis*, *An. minimus*

Features: Shaded, slow-moving water in forested hilly areas.

Ecological Role: Vectors of malaria in Himalayan and forested regions.

(Subbarao, 1998; Singh *et al*., 2020)

c. Marshes and Wetlands

Species: *Mansonia uniformis*, *Mansonia annulifera*

Features: Stagnant, vegetation-covered water bodies with aquatic plants.

Ecology: Attach to plant roots to extract oxygen unique larval adaptation.

(Rajavel & Natarajan, 2006)

d. Tree Holes and Bamboo Stumps

Species: *Armigeres subalbatus*, *Aedes albopictus*

Features: Rain-filled natural containers in forests and rural backyards.

Ecology: Ideal for sylvatic dengue and zoonotic arboviruses.

(Reuben *et al*., 1994)

Artificial and Urban Habitats

India's rapid urbanization has created abundant artificial breeding habitats, facilitating the spread of Aedes and Culex mosquitoes.

a. Artificial Water Containers

Species: *Aedes aegypti*, *Aedes albopictus*

Features: Buckets, water tanks, flower pots, discarded tires.

Disease Risk: Dengue, chikungunya, Zika virus epidemics.

(Kumar *et al*., 2011; WHO India, 2021)

b. Sewage Drains and Septic Tanks

Species: *Culex quinquefasciatus*

Features: Highly polluted and organically rich stagnant water.

Significance: Primary vector of lymphatic filariasis.

(Bockarie *et al*., 2009)

c. Irrigated Agricultural Fields

Species: *Anopheles culicifacies*, *Culex vishnui*

Features: Rice paddies, sugarcane fields with periodic flooding.

Role: Support seasonal malaria and JE transmission.

(Dash *et al*., 2012)

d. Construction Sites and Urban Infrastructure

Species: *Aedes aegypti*, *An. stephensi*

Features: Rainwater collection on rooftops, basements, and construction debris.

Risk: Explains rapid rise of dengue in metropolitan cities.

(Ghosh *et al*., 2012)

Forest and Peri-urban Interfaces

The forest edges and human settlements near wildlife habitats provide mixed breeding conditions for zoonotic vectors.

Species: An. dirus, *Armigeres* spp., *Ae. albopictus*

Conditions: Mixed ecosystems of forest undergrowth and human intrusion.

Threats: Spillover of vector-borne zoonoses (Barik *et al*., 2009).

Table 3. Ecological Niches of Major Indian Mosquito Genera

Habitat Type	Key Genera/Species	Disease Association	Reference
Freshwater ponds, rivers	*An. culicifacies*, *An. fluviatilis*	Malaria	Subbarao (1998), Sharma *et al.* (2006)
Tree holes, bamboo	*Ae. albopictus*, *Armigeres spp.*	Dengue (sylvatic), Zoonoses	Reuben *et al.* (1994)
Rice paddies, irrigated fields	*An. culicifacies*, *Cx. tritaeniorhynchus*	Malaria, JE	Dash *et al.* (2012)
Vegetation-rich wetlands	*Mansonia annulifera*, *M. uniformis*	Filariasis	Rajavel & Natarajan (2006)
Urban water containers	*Ae. aegypti*, *Ae. albopictus*	Dengue, Zika	Kumar *et al.* (2011), WHO India (2021)
Polluted drains, sewage	*Cx. quinquefasciatus*	Lymphatic filariasis	Bockarie *et al.* (2009)
Construction sites	*Ae. aegypti*, *An. stephensi*	Dengue, Urban malaria	Ghosh *et al.* (2012)

Public Health Significance

Anopheles spp.

Table 4. Important Anopheles Species of India and Their Characteristics

Anopheles Species	Species Complex	Distribution in India	Preferred Habitat	Vectorial Role	Disease Association	References
Anopheles culicifacies	Culicifacies complex (A–E)	Rural India (north, central, west)	Wells, irrigation channels, rice fields	Primary malaria vector	Malaria (*P. falciparum*, *P. vivax*)	Subbarao (1998); Sharma *et al.* (2014)
Anopheles stephensi	-	Urban and peri-urban India	Overhead tanks, containers, construction sites	Urban malaria vector	Malaria (*P. vivax*, *P. falciparum*)	Singh *et al.* (2020); WHO India (2021)
Anopheles fluviatilis	Fluviatilis complex (S, T, U)	Himalayan foothills, Odisha, tribal areas	Forest streams, hill rivers	Forest malaria vector	Malaria (*P. falciparum*)	Dash *et al.* (2007); Subbarao (1998)
Anopheles minimus	Minimus complex	North-eastern India (Assam, Arunachal)	Slow-moving shaded streams	Highly efficient vector	Malaria (*P. falciparum*)	Tyagi *et al.* (2015); Das *et al.* (2012)
Anopheles dirus	Dirus complex	Forests of NE states (Arunachal, Mizoram)	Jungle pools, forest streams	Highly anthropophilic	Malaria (*P. falciparum*)	Barik *et al.* (2009); Subbarao (1998)
Anopheles annularis	Annularis complex	Eastern & central India	Margins of ponds, rice fields	Secondary malaria vector	Malaria (*P. vivax*, *P. falciparum*)	Das *et al.* (2012); Sharma *et al.* (2006)
Anopheles subpictus	Subpictus complex (A–D)	Coastal & inland India	Brackish and freshwater pools	Secondary/occasional vector	Malaria (low transmission)	Tyagi *et al.* (2015); Reuben *et al.* (1994)
Anopheles jeyporiensis	-	North-east and eastern India	Rice fields, flood plains	JE vector (experimental)	*Japanese encephalitis* (suspected)	Rajavel & Natarajan (2006); NVBDCP (2021)
Anopheles aconitus	-	North-east India, Himalayan belt	Clean, flowing water	Secondary vector	Malaria	Dash *et al.* (2007); WHO India (2021)
Anopheles maculatus	Maculatus group	NE hills, Himalayan foothills	Shaded forest streams	Vector potential (localized)	Malaria (*P. falciparum*)	Subbarao (1998); Singh *et al.* (2020)

Species complexes (e.g., culicifacies, fluviatilis, dirus) consist of morphologically identical sibling species with different vector competencies and insecticide susceptibilities. *An. culicifacies* is responsible for nearly 60–70% of malaria transmission in rural India (Sharma *et al*., 2014). An. stephensi is now expanding into rural areas, posing new challenges for malaria elimination (Singh *et al*., 2020). North-eastern states harbor highly efficient vectors (An. minimus, An. dirus) due to forested and high-rainfall ecologies.

Aedes spp.

The genus Aedes comprises several species in India, among which two are of paramount medical importance *Aedes aegypti* and *Aedes albopictus*. These species are highly anthropophilic and are the primary vectors of arboviral diseases such as dengue, chikungunya, Zika, and yellow fever (imported cases). Their breeding habitats are closely associated with human dwellings and peridomestic areas.

Table 5. Major Aedes Species in India

Species Name	Common Name	Distribution in India	Breeding Habitats	Vectorial Role	Disease(s) Transmitted	References
Aedes aegypti	Yellow fever mosquito	Widespread in urban and semi-urban areas	Artificial containers, overhead tanks, tires, pots	Primary vector of arboviruses	Dengue, Chikungunya, Zika	Kumar *et al.* (2011); WHO India (2021)
Aedes albopictus	Asian tiger mosquito	Rural, peri-urban, forest-edge zones	Tree holes, coconut shells, flower bracts, containers	Secondary vector, zoonotic bridge host	Dengue, Chikungunya, Zika	Reuben *et al.* (1994); Tyagi *et al.* (2015)
Aedes vittatus	-	Forests and rocky terrains, especially south India	Rock pools, tree holes, artificial containers	Experimental vector	Dengue, Yellow fever (outside India)	Das *et al.* (2012); Rajavel & Natarajan (2006)
Aedes niveus	-	North-East India (Assam, Meghalaya)	Bamboo stumps, tree holes	Sylvatic vector (Zika potential)	Zoonotic arboviruses (potential)	Barik *et al.* (2009); Tyagi *et al.* (2015)
Aedes w-albus	-	Western Ghats and central India	Forest ground pools, temporary puddles	Poorly studied, secondary vector	Possibly chikungunya	Rajavel & Natarajan (2006)
Aedes simplex	-	Coastal south India, Andaman Islands	Brackish water containers	Unknown/under investigation	-	Tyagi *et al.* (2015)
Aedes scutellaris	-	Andaman & Nicobar Islands	Coconut shells, bracts, peridomestic sites	Arbovirus vector (historical outbreaks)	Dengue (limited evidence)	NVBDCP (2021); WHO India (2021)

Aedes aegypti is the dominant urban vector in India and is responsible for the recurring dengue and chikungunya outbreaks across metros and towns. *Aedes albopictus* is more ecologically versatile and found in rural and forested regions, often acting as a bridge vector between wildlife reservoirs and humans. Other species such as Aedes vittatus and Aedes niveus are less understood but may serve as potential vectors in sylvatic and emerging arboviral scenarios. The breeding habitats of Aedes spp. are mostly artificial water-holding containers, making them difficult to control without community participation.

Culex spp.

The genus Culex is ecologically widespread in India and includes several species that are important vectors of lymphatic filariasis, *Japanese encephalitis* (JE), and other arboviruses. Culex mosquitoes typically prefer organically polluted water sources and are prolific breeders in both urban and rural environments.

Table 6. Major Culex Species in India

Species Name	Distribution in India	Preferred Breeding Sites	Vectorial Role	Disease(s) Transmitted	References

Culex quinquefasciatus	Pan-India, urban and peri-urban zones	Polluted drains, septic tanks, latrines, sullage pits	Primary vector	Lymphatic filariasis (*W. bancrofti*)	Bockarie *et al*. (2009); WHO India (2021)
Culex tritaeniorhynchus	Eastern, southern, northeastern India	Paddy fields, ponds, ditches, irrigation channels	Primary vector	*Japanese encephalitis*	Das *et al*. (2012); NVBDCP (2021)
Culex vishnui complex	NE India, Eastern plains, central India	Rice fields, freshwater marshes	Major JE vector complex	*Japanese encephalitis*	Tyagi *et al*. (2015); Rajavel & Natarajan (2006)
Culex pseudovishnui	NE and eastern India	Paddy fields, shallow water collections	Part of vishnui complex	*Japanese encephalitis*	Das *et al*. (2012)
Culex gelidus	Eastern India, Andaman & Nicobar Islands	Ditches, temporary pools, marshes	Potential JE vector	*Japanese encephalitis* (secondary vector)	Reuben *et al*. (1994); WHO India (2021)
Culex fuscocephala	North-East India, forests	Forest swamps, shaded pools	Minor role in arbovirus transmission	JE (experimental)	Rajavel & Natarajan (2006)
Culex sitiens	Coastal regions of south and east India	Brackish water, mangrove swamps	Vector in coastal settings	Arboviruses (potential)	Rajavel & Natarajan (2006); Reuben *et al*. (1994)
Culex bitaeniorhynchus	Widespread in India	Clean, slow-moving water in shaded areas	Poorly understood role	Suspected in arbovirus cycles	Tyagi *et al*. (2015)
Culex whitmorei	NE India, forest edges	Rainwater pools, swamps	Potential arbovirus vector	Under investigation	Barik *et al*. (2009)

Culex quinquefasciatus is a major urban vector, breeding prolifically in polluted water and driving the transmission of lymphatic filariasis in slum and peri-urban areas (Bockarie *et al*., 2009). Culex tritaeniorhynchus and the *Cx. vishnui* complex are key vectors of *Japanese encephalitis* and breed abundantly in rice fields and waterlogged areas during monsoons. *Culex gelidus* and *Cx. sitiens* are important secondary vectors, especially in coastal and island regions. Many Culex species are nuisance mosquitoes due to their biting activity at night, though not all are competent disease vectors.

Mansonia spp.

The genus Mansonia consists of mosquitoes known for their specialized larval adaptation they attach to aquatic plants to extract oxygen. Though less abundant than *Anopheles*, *Culex*, or *Aedes*, certain Mansonia species play a significant role in lymphatic filariasis transmission, particularly in coastal and wetland regions of India.

Table 7. Major Mansonia Species in India

Species Name	Distribution in India	Larval Habitat Type	Adult Behavior & Ecology	Vectorial Role	Disease Association	References
Mansonia annulifera	Kerala, Assam, Tamil Nadu, coastal Odisha	Stagnant water with aquatic plants (*Pistia*, *Eichhornia*)	Endophilic, aggressive night biter	Secondary vector of filariasis	Lymphatic filariasis (*W. bancrofti*)	Rajavel & Natarajan (2006); NVBDCP (2021)
Mansonia uniformis	Kerala, Assam, Tripura, Maharashtra, NE states	Marshes, swamps, ponds with floating vegetation	Zoophilic/anthropophilic, rural settings	Secondary vector of filariasis	Lymphatic filariasis	Reuben *et al*. (1994); Tyagi *et al*. (2015)
Mansonia indiana	West Bengal, NE states, central wetlands	Water hyacinth-rich ponds	Lesser known species	Suspected role (low transmission)	Possibly filariasis	Das *et al*. (2012); Barik *et al*. (2009)
Mansonia africana	Occasional (reported in NE India, Assam)	Temporary vegetated pools, shallow lakes	Poorly studied	No major role	Arbovirus reservoir (theoretical)	WHO India (2021); Rajavel & Natarajan (2006)

Unique adaptation: Unlike other mosquitoes, Mansonia larvae attach to aquatic plants such as Pistia stratiotes (water lettuce) and Eichhornia crassipes (water hyacinth) using modified siphons to draw oxygen from plant tissues (Tyagi *et al*., 2015). These mosquitoes prefer stagnant, vegetation-rich environments such as swamps, backwaters, wetlands, and rice paddies. Adult Mansonia species are nocturnal biters, often found indoors and outdoors, with varying host preferences. While not the primary vectors of lymphatic filariasis in India (that role belongs to Culex quinquefasciatus), *Mansonia annulifera* and M. uniformis are important secondary vectors in coastal and northeastern India. Filariasis control programs must target Mansonia habitats to prevent residual transmission (NVBDCP, 2021). Their unique larval ecology makes source reduction more challenging than for other mosquito genera.

Armigeres Spp.

The genus Armigeres (Subgenus Leicesteria) comprises medium-to-large, robust mosquitoes, often recognized by their distinctive curved proboscis and aggressive biting behavior. Although less studied than Anopheles, *Aedes*, or *Culex*, some species of Armigeres are increasingly being recognized for their nuisance biting and potential roles in arbovirus transmission. They breed predominantly in decaying organic-rich water found in tree holes, bamboo stumps, and artificial containers.

Table 8. Major Armigeres Species Reported in India

Species Name	Distribution in India	Breeding Habitat	Adult Behavior	Medical Importance	References
Armigeres subalbatus	Widespread: South India, NE states, Central India	Tree holes, bamboo stumps, artificial containers	Aggressive night biter, peridomestic	Suspected vector of *Japanese encephalitis*, filariasis (*Brugia malayi*)	Reuben *et al*. (1994); Tyagi *et al*. (2015)
Armigeres kesseli	Assam, Meghalaya, Andaman Islands	Tree holes, coconut shells	Nocturnal, forest-associated	Poorly studied, possible vector role	Rajavel & Natarajan (2006); Das *et al*. (2012)
Armigeres obturbans	Western Ghats, Odisha, NE India	Tree holes, shaded pools	Sylvatic species, low anthropophily	Experimental vector of filariasis	Subbarao (1998); Barik *et al*. (2009)
Armigeres magnus	Assam, West Bengal, Arunachal Pradesh	Natural containers, bamboo internodes	Zoophilic, forested habitats	Not yet associated with disease	Reuben *et al*. (1994)

Armigeres spp. are primarily zoophilic, but *Ar. subalbatus* is anthropophilic in peri-urban and forest fringe areas. They prefer shaded, humid environments and breed in organic-rich stagnant water, including in artificial containers in rural areas. Their eggs are laid individually and hatch into larvae that are filter feeders, often found alongside *Aedes spp*. Armigeres subalbatus is the most medically important species, implicated in the transmission of Brugia malayi in parts of Kerala and NE India (Reuben *et al*., 1994). It is also experimentally competent to transmit *Japanese encephalitis* virus (JEV) in some laboratory studies (Das *et al*., 2012). Their aggressive biting behavior makes them significant nuisance vectors, especially in monsoon and post-monsoon seasons.

Factors Influencing Mosquito Diversity in India

The diversity of mosquito species in India is shaped by a complex interplay of climatic, ecological, anthropogenic, and biological factors. Understanding these drivers is crucial for predicting mosquito-borne disease risks and implementing targeted vector control strategies. India's varied geography—from the Himalayas to coastal plains, deserts to mangroves—provides unique ecological niches that sustain more than 400 mosquito species (Tyagi *et al*., 2015).

Climate and Weather Patterns

Temperature, rainfall, and humidity are primary abiotic determinants of mosquito abundance and diversity. Warm temperatures accelerate the gonotrophic cycle and larval development of mosquitoes, while humidity influences adult survival. Monsoonal rainfall leads to breeding site proliferation, particularly for species like *Anopheles culicifacies* and *Culex tritaeniorhynchus.* Altitudinal gradients (e.g., Himalayas vs. Indo-Gangetic plain) create microclimates that support distinct mosquito assemblages (Ghosh *et al*., 2012; Dash *et al*., 2007; Reuben *et al*., 1994).

Ecological Habitat Diversity

The presence of varied ecosystems such as wetlands, forests, mangroves, urban slums, and agricultural fields provides a mosaic of habitats. Forested ecosystems favor *Anopheles fluviatilis* and *Aedes albopictus*, while wetlands and marshes favor *Mansonia* and *Culex* spp. Anthropogenic habitats (e.g., water storage containers, construction sites) are exploited by *Aedes aegypti* and An. stephensi (Rajavel & Natarajan, 2006; Subbarao, 1998; Tyagi *et al*., 2015).

Urbanization and Land Use Changes

Urban expansion leads to habitat fragmentation and creates artificial breeding habitats. Unplanned development results in poor sanitation and water stagnation, aiding *Culex quinquefasciatus* and *Aedes aegypti*. Changes in land use, such as deforestation and irrigation, alter local mosquito fauna and allow invasion by adaptable species (Kumar *et al*., 2011; Barik *et al*., 2009; WHO India, 2021).

Water Availability and Storage Practices

Domestic water storage without covering containers is a major factor in Aedes proliferation. Agricultural practices (e.g., paddy cultivation) contribute to mosquito diversity by supporting *Anopheles* and *Culex* breeding. Seasonal floods and monsoon rains temporarily increase the diversity and density of mosquitoes (Das *et al*., 2012; NVBDCP, 2021; Singh *et al*., 2020).

Biotic Interactions and Insecticide Resistance

Competition and predation among mosquito larvae and other aquatic organisms affect population structures. Insecticide pressure has led to shifts in species composition and dominance (e.g., replacement of susceptible vectors by resistant ones). Emergence of insecticide-resistant forms of An. culicifacies and An. stephensi alters diversity dynamics (Raghavendra *et al*., 2011; WHO, 2012; Subbarao, 1998).

Human Behavior and Socioeconomic Factors

Improper waste disposal, poor drainage, and lack of mosquito-proofing in homes significantly increase mosquito-human contact. Migration and urban crowding introduce new mosquito species to non-endemic areas (Ghosh *et al*., 2012; Bockarie *et al*., 2009)

Table 10. Factors Influencing Mosquito Diversity in India.

Factor	Impact on Mosquito Diversity	Examples in India	References
Climate (temperature, rainfall, humidity)	Influences mosquito lifecycle, breeding, biting behavior, and species distribution	High diversity in monsoonal zones like Kerala and NE India	Ghosh *et al.* (2012); Dash *et al.* (2007)
Habitat/Ecosystem Diversity	Varied landscapes support diverse mosquito species due to availability of different ecological niches	*Anopheles fluviatilis* in forests, *Mansonia* in wetlands	Rajavel & Natarajan (2006); Tyagi *et al.* (2015)
Urbanization and Land Use Change	Alters natural habitats and creates artificial breeding grounds, leading to shifts in species composition	Urban expansion favors *Aedes aegypti*, *Culex quinquefasciatus*	Kumar *et al.* (2011); Barik *et al.* (2009)
Water Availability and Storage	Breeding site abundance is directly linked to water availability from rain, irrigation, or storage	Paddy fields promote *Anopheles*, containers promote *Aedes*	Das *et al.* (2012); NVBDCP (2021)
Vegetation and Aquatic Flora	Floating plants provide habitats for certain mosquitoes, especially *Mansonia* spp.	*Pistia* and *Eichhornia* support *Mansonia uniformis* larvae	Tyagi *et al.* (2015); Reuben *et al.* (1994)
Altitude and Topography	Affects temperature and humidity gradients, influencing species richness	*An. minimus* and *An. dirus* in NE hills, lowland *An. culicifacies*	Subbarao (1998); Singh *et al.* (2020)
Human Behavior and Sanitation	Poor waste management increases breeding habitats; water storage habits influence *Aedes* proliferation	Slums with open drains harbor *Culex*, uncovered tanks favor *Aedes*	Ghosh *et al.* (2012); WHO India (2021)
Insecticide Usage and Resistance	Long-term insecticide use affects species composition and behavior, possibly leading to reduced diversity or shifts	Insecticide-resistant *An. culicifacies* dominate in treated zones	Raghavendra *et al.* (2011); WHO (2012)
Seasonality and Monsoon	Determines mosquito breeding intensity and population cycles	Peak diversity in July–September during southwest monsoon	Das *et al.* (2012); Tyagi *et al.* (2015)
Host Availability and Density	Affects survival and reproductive success; influences host-seeking behavior	High human density areas support *Aedes aegypti*, livestock areas support *Culex* spp.	Barik *et al.* (2009); Reuben *et al.* (1994)

Surveillance and Monitoring

Effective surveillance and monitoring are fundamental to understanding mosquito population dynamics, species distribution, and vector-borne disease risk in India. The country employs both entomological and epidemiological surveillance through the National Centre for Vector Borne Diseases Control (NCVBDC), formerly NVBDCP. Entomological surveillance includes larval and adult mosquito collection, vector density estimation, species identification, and insecticide resistance testing (NVBDCP, 2021). Surveillance is particularly focused on Anopheles, Aedes, and Culex mosquitoes due to their roles in malaria, dengue, chikungunya, and filariasis transmission. Urban areas emphasize container surveys for *Aedes aegypti*, while rural zones monitor Anopheles breeding in water bodies. Molecular techniques such as PCR-based vector identification, blood meal analysis, and detection of Plasmodium or arbovirus pathogens in mosquitoes are increasingly used for precise monitoring (Singh *et al*., 2020).

GIS mapping, remote sensing, and digital surveillance tools are being integrated for real-time prediction of outbreaks and targeted control efforts. However, challenges remain in rural coverage, data integration, and capacity-building. Strengthening community-based and cross-sectoral surveillance will be key to achieving India's vector-borne disease elimination goals.

Knowledge Gaps and Research Priorities

Despite significant advances in mosquito taxonomy, surveillance, and control, key knowledge gaps persist in understanding the diversity, ecology, and vectorial capacity of mosquitoes in India. Many non-vector species remain under-researched, especially those in forested, high-altitude, and coastal ecosystems, where cryptic species or species complexes may exist undetected (Tyagi *et al*., 2015). There is limited genomic data available for indigenous mosquito populations, hindering precise species identification and vector competence assessment (Singh *et al*., 2020).

Research on behavioral adaptations, such as changing feeding patterns, exophily, and resting preferences due to insecticide pressure, is also limited. Insecticide resistance mechanisms, particularly metabolic and kdr mutations, require deeper molecular investigation across vector genera (Raghavendra *et al*., 2011). Moreover, climate change impacts on mosquito seasonality and distribution have yet to be fully mapped using long-term ecological datasets.

To bridge these gaps, priorities include: (1) expanding molecular taxonomy and DNA barcoding for Indian mosquitoes, (2) conducting longitudinal ecological studies in underrepresented regions, (3) enhancing resistance monitoring and genomic surveillance, and (4) integrating One Health approaches to study zoonotic vector dynamics. Increased funding, intersectoral collaboration, and technological innovation will be essential to fill these critical research voids.

Future Directions

Future mosquito research in India must prioritize integrated vector management (IVM) using ecological, genetic, and community-based tools. Emphasis should be placed on molecular surveillance, climate-resilient vector modeling, and next-generation control strategies such as Wolbachia-based biocontrol and sterile insect techniques. Expansion of digital entomological mapping, public health data integration, and citizen science will enhance real-time response. Strengthening intersectoral collaboration through the One Health approach and investing in capacity-building at regional research centers will be essential. Ultimately, aligning vector control strategies with climate adaptation and urban planning policies will be vital for sustained mosquito-borne disease reduction in India.

Conclusion

Mosquitoes in India exhibit vast taxonomic and ecological diversity, comprising multiple genera such as *Anopheles, Aedes, Culex*, Mansonia, and *Armigeres*, each with distinct breeding habits, biting patterns, and vectorial roles. This diversity underpins the wide range of mosquito-borne diseases prevalent in the country, including malaria, dengue, chikungunya, filariasis, and *Japanese encephalitis*. While substantial progress has been made in surveillance, taxonomy, and vector control strategies, challenges such as insecticide resistance, climate-driven habitat shifts, and inadequate monitoring persist. Strengthening integrated vector management, molecular surveillance, and ecological studies is vital for informed public health action and sustainable mosquito control in India.

Acknowledgement-The authors sincerely acknowledge the support and guidance of the Department of Zoology, NREC College, Khurja, for providing academic resources and research facilities essential for completing this review. We are grateful to our colleagues and mentors who contributed valuable insights during the preparation of this manuscript.

Conflict of Interest- The authors declare that there is no conflict of interest regarding the publication of this review article.

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