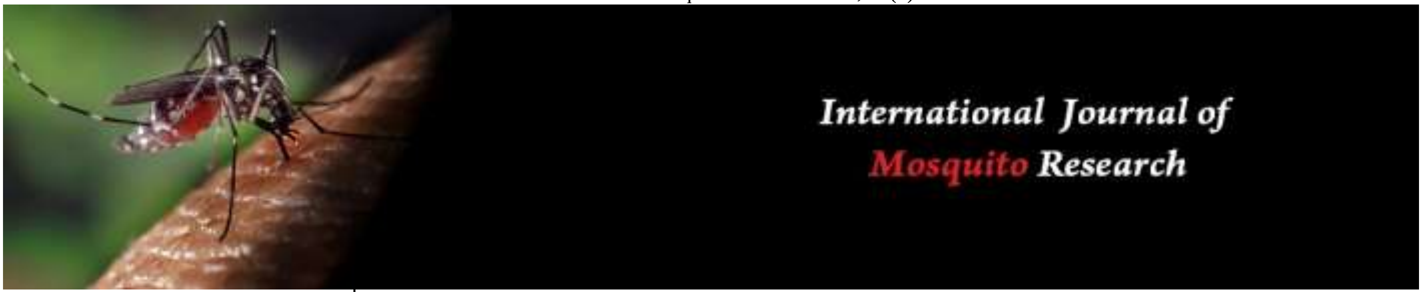

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Prevalence of vector species of mosquitoes (Diptera: Culicidae) and their habitat drivers in District Fatehgarh Sahib, Punjab (India) and its surrounding areas

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Abstract
Mosquito-borne diseases continue to be a public health concern in many parts of India, particularly in regions where agriculture and peri-urban development create diverse mosquito habitats. This study examines the incidence and abundance of vector mosquito species in District Fatehgarh Sahib and adjoining areas over four years (2021–2024). A total of 23 mosquito species were recorded, of which ten were medically important vectors. *Culex quinquefasciatus* was the most dominant species, accounting for more than two-thirds of all the specimens, followed by species belonging to the *Culex vishnui* subgroup and genus *Aedes*. Seasonal analysis revealed that the monsoon and post-monsoon periods supported the highest mosquito densities, primarily due to the increased availability of stagnant and temporary water bodies. The study also identifies key ecological drivers responsible for vector buildup, including agricultural irrigation, polluted wastewater, domestic water storage, rainfall, and peri-domestic containers. These findings underscore the importance of habitat-based vector control and continuous surveillance in reducing disease risk in the region.

Keywords: Vector mosquitoes, abundance, incidence, Fatehgarh Sahib, breeding habitats

Introduction

Mosquito-borne diseases remain one of the most persistent public health challenges across tropical and subtropical regions. Mosquitoes belonging to the family Culicidae can transmit a wide range of pathogens, including viruses, protozoa, and nematodes, which contribute to illnesses such as dengue, chikungunya, malaria, Japanese encephalitis, West Nile fever, and lymphatic filariasis. Their ability to occupy varied ecological niches and adapt to changing environments has made them extremely successful vectors in both rural and urban landscapes (Khan *et al*., 2018) [19]. In many parts of India, these environmental and ecological conditions strongly influence the distribution and seasonal buildup of vector species, shaping the pattern of disease risk throughout the year.

The epidemiological relevance of different mosquito genera varies widely. *Aedes aegypti* and *Aedes albopictus* act as primary or secondary vectors of dengue, chikungunya, Zika, and yellow fever, and are well known for their close association with human dwellings and artificial containers (Kraemer *et al*., 2015; Christophers, 1960) [20, 10]. Their rapid breeding cycles, day-biting habits, and ability to exploit containers such as tyres, tanks, and pots make them particularly difficult to control (Morin *et al*., 2013) [24]. *Culex quinquefasciatus*, the dominant species in many urban and peri-urban settings, is responsible for transmitting Bancroftian filariasis and thrives in polluted water bodies, such as drains and sewage channels (Curtis & Feachem, 1981) [11]. Species belonging to the *Culex vishnui* subgroup, including *Cx. tritaeniorhynchus*, *Cx. vishnui*, and *Cx. gelidus*, are important vectors of Japanese encephalitis, especially in rice-growing regions where flooded fields create extensive larval habitats (Kanojia, 2007; Mwandawiro *et al*., 2000) [17, 23].

Anopheles species, though less abundant in some northern regions, remain important vectors of malaria. Their distribution is closely linked to agricultural irrigation, rainfall patterns, and the availability of clean or semi-clean water bodies suitable for larval development (Das *et al*., 2013; Dharmamuthuraja *et al*., 2023) [12, 14].

In many agricultural districts of India, changes in cultivation practices, canal irrigation, and groundwater extraction have altered mosquito habitats, contributing to shifts in species composition and abundance (Mutero *et al*., 2004) [25]. These ecological transformations highlight the importance of district-level entomological surveillance in understanding how local environments influence vector populations.

Punjab presents a unique ecological setting where agriculture dominates the landscape. Extensive paddy cultivation, canal systems, peri-urban expansion, and inconsistent waste management together create diverse and often overlapping habitats for *Culex*, *Aedes*, and *Anopheles* species. Earlier studies from northern India highlight that mosquito abundance is strongly influenced by local rainfall, temperature, and organic pollution, especially in districts with mixed rural-urban characteristics (Ghosh & Chandra, 2006; Banerjee *et al*., 2020) [4, 15]. Despite this, systematic documentation of vector species distribution at the district level remains limited for many parts of Punjab.

Fatehgarh Sahib district, with its mixture of agricultural fields, stagnant drainage channels, water storage systems, and domestic containers, provides favourable breeding conditions throughout much of the year. Vector species frequently respond to these habitats in different ways: *Aedes* species proliferate in artificial containers following monsoon rains; *Culex* species thrive in polluted and semi-polluted perennial water bodies; and *Anopheles* species increase in number where irrigation networks and temporary pools form after rain (Aminuwa *et al*., 2018; Alto & Juliano, 2001) [3,]. Understanding these habitat–vector relationships is essential for predicting seasonal peaks, identifying high-risk areas, and improving control strategies.

Given these conditions, the present study focuses on the diversity and abundance of vector mosquito species in the study area and ecological factors contribute to their population buildup. By analysing four years of entomological data (2021–2024), this study aims to offer a detailed and locally grounded understanding of vector dynamics in Fatehgarh Sahib. Such insights are vital for strengthening targeted, evidence-based vector management strategies in Punjab and can support health authorities in planning timely and effective interventions.

2. Review of Literature

Mosquito-borne diseases continue to be a major concern in many tropical and subtropical regions, and a considerable body of research has examined mosquito ecology, species distribution, and environmental drivers of vector abundance. Much of the existing literature highlights that mosquito populations respond strongly to local climatic and ecological conditions, especially rainfall, temperature, and the availability of suitable breeding habitats. These environmental factors not only influence the presence of vector species but also shape disease transmission patterns across seasons.

Several studies have emphasized the ecological diversity within mosquito genera and their different vectorial roles. For instance, *Aedes aegypti* and *Aedes albopictus* have been closely studied because of their increasing involvement in dengue, chikungunya, and Zika outbreaks. Their dependence on artificial containers and their tendency to breed in close association with human dwellings make them particularly successful in urban and peri-urban environments (Christophers, 1960; Kraemer *et al*., 2015) [10, 20]. Research from various regions of India and Asia suggests that these species exhibit strong seasonal peaks following monsoon rainfall, when water-filled containers, tyres, and domestic storage units become abundant (Kumari *et al*., 2013; Chakraborty *et al*., 2012) [21, 6]. Temperature fluctuations also impact their development and survival, as observed in laboratory studies, which show increased larval growth rates at higher temperatures (Alto & Juliano, 2001).

The genus *Culex* has received considerable attention for its association with polluted or organically enriched water bodies. *Culex quinquefasciatus*, a primary vector of lymphatic filariasis, is known to breed abundantly in urban drains, septic tanks, and sewage-contaminated habitats (Curtis & Feachem, 1981; Ghosh & Chandra, 2006) [11, 15]. Studies from various parts of India indicate that this species remains active year-round, with densities increasing sharply during the monsoon and post-monsoon months (Khan *et al*., 2018) [19]. Temperature, organic load, and stagnant wastewater tend to favour its continuous presence, making it difficult to control in rapidly urbanising regions (Mutero *et al*., 2004) [25]. Another important group within the genus, the *Culex vishnui* subgroup, particularly *Cx. tritaeniorhynchus, Cx. vishnui, Cx. pseudovishnui,* and *Cx. gelidus* is well documented for its role in the transmission of Japanese encephalitis. These species prefer flooded paddy fields, irrigation channels, and natural pools associated with rice cultivation (Kanojia, 2007; Mwandawiro *et al*., 2000) [17, 23]. Agricultural intensification and the expansion of rice farming have been associated with increased proliferation of JE vectors in several regions (Dharmamuthuraja *et al*., 2023) [14].

The *Anopheles* genus, responsible for transmitting malaria, has also been extensively studied in relation to environmental conditions and human-altered landscapes. Research in India has demonstrated that species diversity and seasonal abundance vary across regions, depending on factors such as irrigation, land use, and rainfall (Das *et al*., 2013) [12]. Malaria vectors such as *An. annularis*, *An. maculatus*, and *An. stephensi* tend to favour cleaner, sunlit water bodies, often formed in agricultural fields, seepage pools, or domestic storage structures (Aminuwa *et al*., 2018) [3]. Ecological studies have demonstrated that irrigation development projects and the spread of agricultural canals can create new larval habitats, thereby altering the spatial distribution of Anopheles populations (Amerasinghe & Ariyasena, 1990) [2]. Conversely, high organic pollution may limit their breeding, giving a competitive advantage to *Culex* species in such habitats.

A significant theme across recent literature is the strong influence of climate on mosquito dynamics. Studies from various Indian states indicate that rainfall and temperature are significant predictors of mosquito abundance and seasonal disease outbreaks. Banerjee *et al*. (2020) [4] observed that dengue vector densities in West Bengal increased sharply during months with higher rainfall and humidity, while Morin *et al*. (2013) [24] demonstrated similar relationships across global climatic models. Climatic anomalies such as delayed monsoons or extended warm seasons may extend breeding periods and delay population declines, thereby widening transmission windows for diseases like dengue and malaria.

Human activities also play an important role in shaping mosquito ecology. Urban expansion, unplanned construction, poor drainage, and improper waste disposal create countless artificial breeding sites for *Aedes* and *Culex* species (Kaur *et al*., 2020) [18]. Meanwhile, agricultural practices such as paddy cultivation, canal irrigation, and livestock farming support the growth of JE vectors and rural malaria vectors (Mutero *et al*., 2004; Mwandawiro *et al*., 2000) [25, 23]. The interaction between human behaviour, land use, and environmental change adds complexity to mosquito population dynamics and highlights the need for region-specific vector control approaches.

Overall, the existing literature suggests that the composition and abundance of mosquito species are highly sensitive to ecological and climatic conditions, and that the presence of vector species often reflects broader environmental patterns. While many studies have focused on specific regions or vector species, there remains a need for localized and continuous surveillance, especially in districts such as Fatehgarh Sahib, where agricultural and peri-urban ecosystems coexist closely. Understanding how these local factors shape mosquito populations can provide essential insights for targeted vector management and disease prevention strategies.

3. Materials and Methods

3.1 Study Area

The study was conducted in District Fatehgarh Sahib, Punjab, along with its adjoining areas. The region lies within the Indo-Gangetic plains and is dominated by intensive agriculture, particularly the wheat–paddy cropping cycle. The district experiences a subtropical climate characterised by hot summers, a humid monsoon season, and cool winters. The average annual rainfall is approximately 700–800 mm, with most of it occurring between July and September. These climatic and agricultural conditions create a range of habitats suitable for mosquito breeding, including paddy fields, irrigation channels, domestic water storage containers, open drains, abandoned tyres, and peri-domestic animal shelters. Both urban and rural sites were included to capture the full ecological diversity of mosquito habitats.

3.2 Study Duration and Design

The study was conducted over a four-year period, from 2021 to 2024. A descriptive entomological survey design was adopted to record the incidence and abundance of vector species across different seasons. The survey tours were planned in such a way that every site is covered at least twice a month, and around 40 sites were selected throughout the district. Sampling sites were categorised into different habitats, including urban and rural areas, farms, cattle sheds, near water tanks, gardens and slums. The collection was made mainly during the morning and evening times when maximum number of insects can be collected.

3.3 Selection of Sampling Sites

Sampling sites were selected to represent all major habitat types found in the district:

- **Urban sites:** Residential areas, construction sites, rooftop tanks, drains, and domestic containers.
- **Rural sites:** Villages, cattle sheds, wells, irrigation channels, and natural water bodies.
- **Agricultural landscapes:** Paddy fields, tube-well run-offs, seepage pools, and temporary rainwater collections.
- **Peri-domestic habitats:** Courtyards, cement troughs, discarded plastic items, and small containers.

This stratified approach ensured that both natural and man-made breeding habitats were thoroughly examined.

3.4 Sampling Frequency

Mosquito collections were carried out **fortnightly** at each site during most months of the year. During monsoon and immediate post-monsoon months (July–November), when mosquito proliferation is typically highest, sampling was intensified to weekly intervals. This strategy helped in capturing short-term population surges that may otherwise be missed.

3.5 Mosquito Collection Methods

3.5.1 Larval and Pupal Collection

Larvae and pupae were collected using the standard dipping method (Service, 1993) [27]. A 350 ml dipper was used for large habitats such as ponds, ditches, and paddy fields, while pipettes or ladles were used for smaller domestic containers. At least ten dips were taken from each site to minimise sampling bias. Collected immature stages were transferred to labelled containers and transported to the laboratory for rearing and identification.

3.5.2 Adult Mosquito Collection

Multiple approaches were used to obtain adult specimens:

- **Indoor Resting Collection (IRC):** From inside resting areas, like housed and cattle sheds, mosquitoes were collected with the help of tubes and aspirators.
- **Outdoor Aspirator Sampling:** Hand-held aspirators and sweep nets were used to collect adults resting on vegetation, walls, and shaded structures.

3.6 Preservation and Laboratory Rearing

Immature mosquitoes were reared under controlled laboratory conditions (27 ± 2°C temperature and 70–80% relative humidity). Upon emergence, adults were fed on a glucose solution and euthanized using chloroform vapours for identification. Specimens were pinned and kept in boxes for morphological study.

3.7 Species Identification

Species identification was performed using established morphological keys, including those of Christophers (1933) [9], Barraud (1934) [5], Nagpal and Sharma (1995) [26], and WHO (2016) [31]. Diagnostic features, including wing patterns, leg banding, bands on proboscis, palpal length, and thoracic markings, along with the male genitalia, were used to differentiate among genera and species. Care was taken to identify medically important vector species belonging to *Aedes*, *Culex*, and *Anopheles*.

4. Results and Discussion

4.1 Incidence of Vector Species

A total of 23 mosquito species were recorded from District Fatehgarh Sahib and adjoining areas during the four-year period (2021–2024) (Table 1). Out of these, ten species were medically important vectors. These species belonged to three major genera: *Aedes*, *Anopheles*, and *Culex*, along with one *Mansonia* species. Table 2. summarises all vector species and their associated diseases.

Table 1: Comprehensive List of Mosquito Species Recorded in Fatehgarh Sahib

Genus	Species
Aedes	*Aedes aegypti*
	Aedes albopictus
Anopheles	*Anopheles annularis*
	Anopheles maculatus
	Anopheles splendidus
	Anopheles stephensi
Armigeres	*Armigeres aureolineatus*
	Armigeres kesseli
	Armigeres subalbatus
Culex	*Culex barraudi*
	Culex edwarsi
	Culex epidesmus
	Culex gelidus
	Culex quinquefasciatus
	Culex selangorensis
	Culex theleri
	Culex tritaeniorhynchus
	Culex univittatus
	Culex vagans
	Culex vishnui
	Culex whitemorei
Lutzia	*Lutzia fuscanus*
Mansonia	*Mansonia indiana*

Table 2: Vector Mosquito Species Recorded in Fatehgarh Sahib (2021–2024)

S. No.	Vector Species	Disease(s) Transmitted
1	*Aedes aegypti*	Dengue, Chikungunya, Zika, Yellow Fever
2	*Aedes albopictus*	Dengue, Chikungunya, Zika
3	*Anopheles annularis*	Malaria (secondary vector)
4	*Anopheles maculatus*	Malaria (regional vector)
5	*Anopheles stephensi*	Urban Malaria (primary vector)
6	*Culex gelidus*	Japanese Encephalitis
7	*Culex quinquefasciatus*	Lymphatic Filariasis
8	*Culex tritaeniorhynchus*	Japanese Encephalitis
9	*Culex vishnui*	Japanese Encephalitis
10	*Mansonia indiana*	Filariasis (secondary vector)

These findings show that the district supports multiple species capable of transmitting different vector-borne diseases. Their coexistence reflects the ecological diversity of the region, which includes polluted drains, agricultural fields, domestic breeding sites, and peri-domestic habitats.

4.2 Abundance of Vector Species

Based on the four-year dataset, *Culex quinquefasciatus* was the most abundant vector species, forming more than 66.7% of all vector specimens collected. The *Aedes aegypti* occupied second position, followed by *Cx. vishnui*. *Anopheles* vectors were found in comparatively much smaller numbers (Table 2).

Table 2: Annual Abundance of Vector Species in Fatehgarh Sahib (2021–2024)

S. No.	Name of the Species	2021	2022	2023	2024	Total	Percentage (%)
1	*Ae. aegypti*	386	325	295	274	1280	13.8
2	*Ae. albopictus*	59	53	65	58	235	2.54
3	*An. annularis*	2	2	0	1	5	0.05
4	*An. maculatus*	32	0	0	0	32	0.34
5	*An. stephensi*	0	1	1	1	3	0.03
6	*Cx. gelidus*	3	3	2	3	11	0.11
7	*Cx. quinquefasciatus*	2284	1194	1242	1449	6169	66.7
8	*Cx. tritaeniorhynchus*	124	153	112	125	514	5.55
9	*Cx. vishnui*	147	285	235	271	938	10.1
10	*Ma. indiana*	6	22	7	23	58	0.62

The striking dominance of *Culex quinquefasciatus* indicates that polluted, organically rich water bodies, particularly drains, sewage channels, and poorly managed wastewater, are widespread across the district. This species' continuous presence throughout the year is consistent with earlier studies reporting its persistence in urban environments with inadequate sanitation (Khan *et al*., 2018; Curtis & Feachem, 1981) [19, 11]. The significant numbers of *Culex vishnui* and *Cx. tritaeniorhynchus* reflects the agricultural landscape of Fatehgarh Sahib, particularly paddy cultivation. As reported in JE-endemic areas of India, these species prefer flooded fields and irrigation channels (Kanojia, 2007; Mwandawiro *et al*., 2000) [17, 23]. *Ae. aegypti* and *Ae. albopictus* showed moderate and consistent abundance. Their presence across seasons highlights the widespread availability of artificial containers and domestic water storage structures, conditions commonly associated with dengue outbreaks (Kumari *et al*., 2013; Kaur *et al*., 2020) [21, 18]. The low abundance of *Anopheles* species may indicate effective indoor residual spraying or ecological constraints limiting malaria vector breeding in this region.

4.3 Seasonal Patterns of Vector Species

The seasonal analysis shows a clear increase in mosquito abundance during the monsoon and post-monsoon periods (Table 3). These months recorded the highest species richness and density.

Table 3: Seasonal Dominant Vector Species (2021–2024)

Season	Dominant Vector Species	Key Observations
Pre-Monsoon	*Cx. quinquefasciatus*	Present year-round; thrives in drains and wastewater.
Monsoon	*Cx. quinquefasciatus, Aedes aegypti, Cx. vishnui*	Monsoon rains create abundant breeding sites; surge in Aedes and JE vectors.
Post-Monsoon	*Cx. quinquefasciatus, Aedes aegypti*	Residual water from monsoon sustains breeding; *Aedes* peaks in domestic containers.
Winter	*Cx. quinquefasciatus*	Persists due to adaptability; other species decline due to lower temperatures.

The seasonal trends observed in this study align with findings from earlier research. Rainfall and humidity during the monsoon create temporary pools, flooded paddy fields, and water-filled containers, which serve as ideal breeding habitats for several vector species (Banerjee *et al*., 2020; Dharmamuthuraja *et al*., 2023) [4, 14]. The rapid post-monsoon rise in *Aedes* is consistent with patterns observed in urban dengue-prone regions (Chakraborty *et al*., 2012) [6]. The consistent presence of *Cx. quinquefasciatus* across all seasons suggests that wastewater habitats remain stable year-round. Such habitats are typically unaffected by climatic variations, explaining the species' dominance.

4.4 Ecological Drivers behind Population Buildup

Data from field observations and species distribution suggest that the following ecological factors strongly influenced mosquito abundance (Table 4):

1. Paddy fields and irrigation canals supported the members of the *Culex vishnui* subgroup.
2. Overhead tanks, pots, coolers, and discarded tyres contributed to stable *Aedes* breeding.
3. Open drains, open ponds and septic tanks provided year-round breeding sites for *Cx. quinquefasciatus*.

Table 4: Comparative Distribution of *Ae. aegypti, Cx. quinquefasciatus, Cx. vishnui* and *Cx. tritaeniorhynchus* Larvae Across Different Aquatic Habitats in Fatehgarh Sahib

Species	*Aedes aegypti*	*Culex quinquefasciatus*	*Culex vishnui*
Drains/Wastewater	Absent	Present	Present
Household Pots/Containers	Present	Absent	Absent
Open Ponds/Permanent Water	Present	Present	Present
Tyres/Discarded Containers	Present	Absent	Absent
Water Tanks/Overhead Storage	Present	Absent	Absent

5. Conclusion and Recommendations

The present study provides an extensive account of the incidence and abundance of vector mosquito species in District Fatehgarh Sahib and its adjoining areas over a four-year period. The findings reveal that the region supports a diverse mosquito fauna comprising 23 species, of which ten are medically important vectors. The study clearly demonstrates that *Culex quinquefasciatus* is the most dominant vector species in the district, thriving throughout the year and forming more than two-thirds of all vector specimens collected. This dominance reflects the widespread presence of organically rich wastewater habitats across both urban and semi-urban areas. The study also highlights the significant presence of *Aedes aegypti* and *Aedes albopictus*, which were consistently found in domestic and peri-domestic containers. Their steady abundance across seasons indicates a continuous risk of dengue and chikungunya transmission, especially during the post-monsoon months. Meanwhile, the *Culex vishnui* subgroup, including *Cx. tritaeniorhynchus* and *Cx. Gelidus* was closely associated with agricultural landscapes, particularly flooded paddy fields, suggesting a favourable setting for Japanese encephalitis vectors in the region. Seasonal analysis confirmed that monsoon and post-monsoon months support the highest mosquito densities. The combination of rainfall, stagnant water, irrigation patterns, and domestic water storage practices strongly influenced the spatial and temporal buildup of vector populations. The low abundance of *Anopheles* species indicates limited malaria vector activity, although the presence of *An. annularis*, *An. maculatus*, and *An. stephensi* suggests that the risk cannot be entirely dismissed.

The findings of this study suggest several important measures for strengthening vector control in Fatehgarh Sahib and similar regions. First, wastewater management must be improved, as the continuous dominance of *Culex quinquefasciatus* reflects the persistent accumulation of stagnant wastewater in drains and open channels; regular cleaning, proper sewage disposal, and covering of drains can greatly reduce breeding sites. Control of *Aedes* mosquitoes requires strong community participation, particularly in reducing artificial containers, discarded tyres, and overhead tank leakages, as well as promoting weekly checks to eliminate stagnant water during monsoon and post-monsoon periods. Agricultural water bodies also need targeted intervention, especially in paddy-growing areas where JE vectors proliferate; measures such as intermittent irrigation, proper field leveling, and the use of biological control agents like larvivorous fish can help limit larval development. Season-specific planning is essential, with intensified action before and during the monsoon months and focused cleanup campaigns afterward to prevent Aedes outbreaks. Integrating entomological and epidemiological surveillance, linking larval indices, adult mosquito densities, and disease case trends, can strengthen early-warning systems and improve public health preparedness. Community awareness should be enhanced through schools, local bodies, and village committees to encourage behaviour change and promote personal protection. Environmentally safe larval control, including bacterial larvicides such as *Bacillus thuringiensis israelensis* and *Bacillus sphaericus*, should be prioritized to reduce chemical overuse and slow resistance development. Lastly, regular monitoring of insecticide resistance in mosquito populations is necessary to guide rational insecticide use and maintain long-term effectiveness of control programmes. Future studies may focus on molecular identification of vector species, insecticide resistance profiling, and predictive modelling to understand how climate change and land-use patterns may alter mosquito distribution in the region.

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