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Oviposition ecology of *Aedes* mosquitoes in relation to indoor-outdoor light intensity and dengue endemicity in Aceh Besar, Indonesia

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Abstract. *Yulianti A, Rizki A, Suwarno, Arahman N, Gani BA, Husnurrizal, Harapan, Mudatsir. 2025. Oviposition ecology of* Aedes *mosquitoes in relation to indoor-outdoor light intensity and dengue endemicity in Aceh Besar, Indonesia. Biodiversitas 26: 5803-5813.* Dengue fever continues to pose a major public health problem in tropical regions, with *Aedes aegypti* and *Aedes albopictus* as the main vectors. While the effects of temperature, humidity, and rainfall on mosquito ecology are well documented, the influence of light intensity on oviposition behavior across areas with different dengue endemicity levels remains less understood. This study aimed to assess the influence of indoor-outdoor light intensity and dengue endemicity on oviposition activity of *Aedes* mosquitoes in Aceh Besar District, Indonesia. A cross-sectional ecological survey was conducted in two sub-districts classified as high and low endemicity, with three villages randomly selected from each. In total, 240 ovitraps (120 indoor and 120 outdoor) were deployed over two five-day sampling periods, accompanied by concurrent light intensity measurements using a lux meter. Ovitrap positivity and egg density were analyzed using logistic regression and the Mann-Whitney U test. Of all traps, 62.92% were positive for *Aedes* eggs. No significant differences in Ovitrap Index (OI) or oviposition activity were observed between locations or endemicity levels (both had $p>0.05$). Indoor light intensity had a significant effect on oviposition activity: dimly lit households in high-endemicity areas recorded higher oviposition (1.67%, p: 0.01 and 3.33%, p: 0.02, respectively). Outdoor oviposition showed no significant variation by light intensity. These results indicate that low indoor lighting favors *Aedes* oviposition regardless of endemicity level. Improving household illumination may reduce suitable oviposition habitats and serve as a practical addition to existing vector control strategies.

Keywords: *Aedes* surveillance, habitat characteristics, light environment, mosquito oviposition, vector ecology

INTRODUCTION

Dengue fever is one of the most major mosquito-borne viral diseases in tropical and subtropical regions, transmitted primarily by *Aedes aegypti* and *Aedes albopictus*, species that thrive near human dwellings (Krishna et al. 2024). Globally, dengue incidence has increased sharply in recent decades, causing recurrent epidemics and significant pressure on health systems. The World Health Organization recognizes dengue as a major public health challenge due to its expanding range, high transmission potential, and severe clinical outcomes such as dengue hemorrhagic fever and dengue shock syndrome (World Health Organization 2024).

Dengue remains endemic across nearly all provinces in Indonesia, with tens of thousands of cases reported annually despite long-standing vector control programs. In 2024, more than 60,000 cases and 455 deaths were recorded nationwide (Kertapati and Aminah 2024). Aceh Province is among the consistently affected regions, showing fluctuating yet recurrent outbreaks. In 2019, 2,386 cases were reported, followed by a decline in 2020, but the numbers increased again in subsequent years (Aceh Provincial Health Office 2021). In Aceh Besar District, 296 cases were documented in 2022, with Lhoknga Sub-district identified as an area of high endemicity (Aceh Provincial Health Office 2023). These figures highlight the persistence of dengue transmission and underscore the need for targeted local investigations. Such localized studies are essential for identifying the ecological drivers that sustain vector populations and contribute to ongoing transmission, thereby supporting more effective and context-specific dengue control strategies.

Microclimatic and environmental factors shape the ecology of *Aedes* mosquitoes. Well-documented determinants include temperature, humidity, rainfall, and availability of artificial containers that provide larval habitats (Dom et al. 2025). Warm and humid conditions enhance mosquito survival and reproduction, while rainfall creates water-filled receptacles suitable for oviposition (Reinhold et al. 2018; Westby et al. 2021; Liu et al. 2023; Souza et al. 2024). Consequently, climate-based surveillance has become a core element of vector control strategies (Leandro and Maciel-de-Freitas 2024).

Light intensity has received comparatively little attention as a microclimatic factor in dengue vector ecology. Although *Aedes* mosquitoes are often reported to prefer dim and shaded habitats for oviposition (Facchinelli et al. 2023; Akollo 2024; Yani 2024), evidence regarding its role remains inconsistent, with some studies showing significant associations between illumination and egg density (Sari et al. 2017; Romiti et al. 2025), while others report no clear relationship (Cui et al. 2021). This inconsistency underscores the need for further investigation to clarify the ecological function of light in sustaining mosquito breeding.

The distinction between indoor and outdoor lighting is particularly relevant in rural or resource-limited communities, where household illumination often falls below recommended standards. Such conditions may encourage gravid females to oviposit indoors, while brighter outdoor environments may be less conducive (Rund et al. 2020; Wijewardana et al. 2025). This suggests that inadequate household lighting could represent an overlooked but modifiable risk factor in dengue transmission dynamics.

In Aceh Besar District, the persistence of dengue cases despite routine larval source reduction and chemical interventions highlights the need to investigate additional ecological drivers persistent (Ipa et al. 2017; Harapan et al. 2018). While temperature, humidity, and rainfall have been extensively documented, the contribution of light intensity to oviposition ecology remains poorly understood. Addressing this knowledge gap is critical to developing more comprehensive and context-specific vector management strategies.

Therefore, this study aimed to examine the effect of indoor-outdoor light intensity and dengue endemicity on the oviposition behavior of *Aedes* mosquitoes in Aceh Besar District, Indonesia. By comparing oviposition indices across different lighting conditions and endemicity levels, this research sought to determine whether inadequate lighting promotes vector breeding. The results are expected to add to the evidence supporting environment-based interventions, highlighting household lighting improvements as a potential low-cost addition to integrated dengue control programs.

MATERIALS AND METHODS

Study design and setting

A short-term cross-sectional ecological study was carried out in August 2023 in Aceh Besar District, Aceh Province, Indonesia, to examine the association between indoor-outdoor light intensity and *Aedes* oviposition activity during the observation period. Two sub-districts were selected based on dengue incidence from 2020-2022 to represent both high and low endemicity settings. Households served as sampling units, and oviposition was assessed using oviposition traps (ovitraps) to calculate the Ovitrap Index (OI), which represents the proportion of positive ovitraps containing *Aedes* eggs relative to the total number of traps deployed, expressed as a percentage (Sasmita et al. 2021). The sampling was conducted in two periods separated by one week. To better characterize the breeding environment, microclimatic conditions including indoor-outdoor light intensity, temperature, and relative humidity were measured across the study sites. These parameters provide important ecological context for understanding the relationship between environmental factors and *Aedes* oviposition dynamics. It should be noted that the study represents a short-term snapshot limited to August 2023 due to logistical and funding constraints. Therefore, the findings primarily reflect the oviposition pattern during the study period and may not capture potential seasonal variations across different months.

Study area

The study was conducted in two sub-districts of Aceh Besar, Indonesia, representing different dengue endemicity levels determined based on dengue case data reported in Aceh Besar in 2022 (Aceh Provincial Health Office 2023), namely the high endemicity area (Lhoknga) and the low endemicity area (Indrapuri). These locations were selected to represent ecological variations influencing *Aedes* oviposition. In each sub-district, three villages were randomly selected to represent residential and peri-domestic environments: Aneuk Paya, Lamcok, and Lampaya for the high endemicity area, and Aneuk Glee, Mon Alue, and Reukih Dayah for the low endemicity area (Figure 1). Each village was mapped using Global Positioning System (GPS), and the coordinates were plotted to visualize spatial distribution.

Sampling and oviposition traps (ovitraps) placement

In each village, 20 ovitraps (10 indoors and 10 outdoors) were deployed across 10 households, resulting in 60 traps for each sub-district for each sampling period. Ovitraps consisted of a 350 mL black plastic container filled to two-thirds with clean water and lined with filter paper as an oviposition substrate. Sampling was conducted over two periods separated by a one-week interval following the previous recommendation (de Almeida et al. 2025), with each period lasting five days in accordance with the Standard Operating Procedure for Assembly and Deployment of Ovitraps (Protocol Integer ID: 64751) (Russell et al. 2022). This yielded a total of 240 ovitrap observations (120 in high-endemic areas and 120 in low-endemic areas). Each ovitrap was treated as an independent replicate for analysis. After five days of exposure, traps were retrieved, and filter papers were air-dried and examined under a stereomicroscope. Eggs were manually counted by a single trained observer to ensure consistency. The OI was calculated as the proportion of traps containing *Aedes* eggs or immature stages relative to the total number of traps examined (Djiappi-Tchamen et al. 2022).

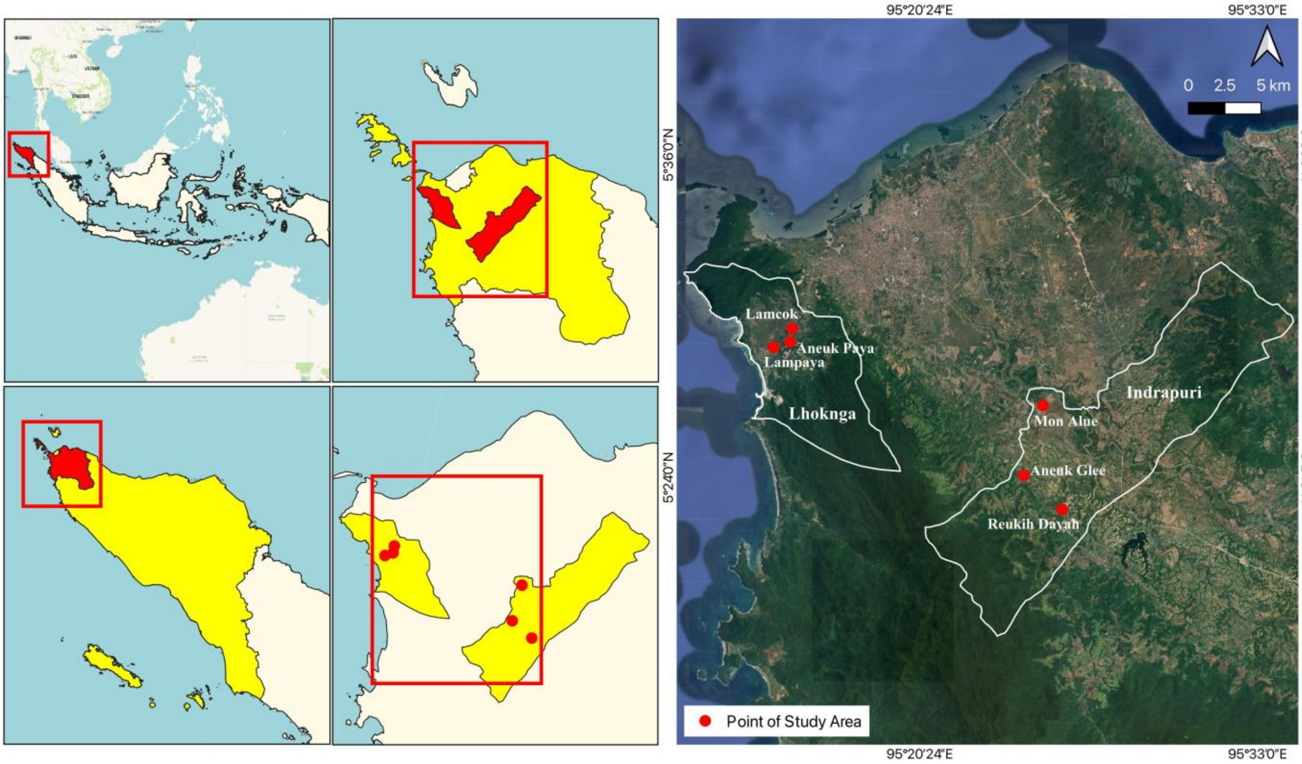

Figure 1. Map of study sites in Aceh Besar District, Indonesia, indicating the high endemicity status area ((Lhoknga; Aneuk Paya (5°29'02.5"N 95°15'33.9"E), Lamcok (5°29'32.7"N 95°15'39.0"E)) and the low endemicity status area ((Indrapuri; Aneuk Glee (5°24'04.7"N 95°24'17.6"E), Mon Alue (5°26'40.9"N 95°25'00.4"E), Reukih Dayah (5°22'48.8"N 95°25'43.3"E), Lampaya (5°28'50.9"N 95°14'57.7"E)), where the oviposition ecology of *Aedes* mosquitoes was investigated

Light intensity measurement

Light intensity at each ovitrap site was assessed using a calibrated lux meter (LX-1010B) positioned approximately 0.8 m above the floor surface. Measurements were conducted both indoors (living areas) and outdoors (shaded yards). Based on the recommended threshold values described by Lustiyati and Astuti (2018), Duffield et al. (2019), and Fitria (2021), lighting conditions were categorized as Compliant Lighting (CL) when the measured intensity was ≥60 lux, and non-Compliant Lighting (nCL) when it was <60 lux. In this study, compliant lighting denotes illumination levels that conform to the minimum standard for adequate residential lighting required to maintain proper visibility and environmental comfort. Light intensity was measured once per site during daylight hours to represent typical exposure conditions.

Data analysis

Statistical analyses were conducted using SPSS Statistics version 26 (IBM, New York, USA). Light intensity and oviposition activity were analyzed descriptively. Logistic regression was applied to assess the association between ovitrap positivity (egg status: 0: negative, 1: positive) and three predictors: trap location (indoor vs. outdoor), light intensity (expressed in lux), and endemicity status (high vs. low), with each ovitrap serving as one observation. Logistic regression was conducted as an exploratory analysis, treating each ovitrap as an independent unit due to the limited sample size. The Mann-Whitney U test was used to compare differences across light intensity categories and endemicity levels. Statistical significance was set at $p<0.05$.

RESULTS AND DISCUSSION

Microclimatic variables shaping *Aedes* oviposition ecology

The variation of microclimatic conditions (temperature, humidity, rainfall, wind speed, and air pressure) across dengue endemicity levels in Aceh Besar District during the study period (August 2023) is presented in Figure 2. Meteorological data during 2023 August showed mean temperatures ranging from 22.9-23.5°C (minimum) to 31.7-33.0°C (maximum) and relative humidity between 76-85%, both conditions known to enhance *Aedes* survival and oviposition. Rainfall varied considerably (92.6-312.7 mm), increasing the availability of water-holding containers that serve as breeding habitats. Moderate wind speeds (2.0-2.4 m/s) and stable atmospheric pressure (~1009-1010 mb) provided additional environmental stability. These microclimatic conditions were consistent with ovitrap results, which demonstrated higher egg positivity in outdoor and shaded habitats, confirming that warm, humid, and rain-enriched environments strongly favor *Aedes* oviposition.

A. High endemicity

	Min Temp. (°C)	Max Temp. (°C)	Mean Temp. (°C)	Rainy Days (days)	Rainfall (mm)	Mean Sunshine (h/day)	Wind Speed(m/s)	Mean RH (%)	Air Pressure (mb)
July	23.20	32.80	27.50	10	116.40	6.80	2.50	78	1010.30
August	23.40	33.00	27.60	9	92.60	7.10	2.40	77	1010.10
September	23.50	32.90	27.50	14	172.80	6.40	2.30	79	1010.00
October	23.40	32.70	27.40	18	221.70	6.10	2.20	81	1009.80
November	23.30	32.40	27.30	20	267.20	5.90	2.10	82	1009.70
December	23.20	32.20	27.20	22	289.50	5.70	2.00	83	1009.60

B. Low Endemicity

	Min Temp. (°C)	Max Temp. (°C)	Mean Temp. (°C)	Rainy Days (days)	Rainfall (mm)	Mean Sunshine (h/day)	Wind Speed(m/s)	Mean RH (%)	Air Pressure (mb)
July	22.90	32.30	27.10	11	124.00	6.60	2.30	80	1010.50
August	23.10	32.50	27.30	10	99.90	6.90	2.20	79	1010.30
September	23.20	32.40	27.20	15	186.50	6.20	2.10	81	1010.20
October	23.10	32.20	27.10	19	239.40	5.90	2.00	83	1010.00
November	23.00	31.90	27.00	21	288.60	5.70	1.90	84	1009.90
December	22.90	31.70	26.90	23	312.70	5.50	1.80	85	1009.80

Figure 2. Microclimatic conditions across dengue endemicity levels in Aceh Besar District, Indonesia, during the study period and beyond. Source: BPS Kabupaten Aceh (2024). Note: The color gradient represents the relative magnitude of each climatic parameter, where warmer tones (red-orange) indicate higher values, and cooler tones (green-blue) indicate lower values. This visual scheme facilitates comparison of monthly variations in temperature, rainfall, and other microclimatic factors between high- and low-endemic areas

Influence of light intensity on oviposition behavior in high- and low-endemicity areas

Light intensity plays a crucial role in shaping *Aedes* oviposition activities. Inadequate indoor illumination may mimic shaded habitats favorable for egg laying, and evaluating household compliance with lighting standards across endemicity levels highlights how microenvironmental light variations support mosquito breeding.

Figure 3 illustrates distinct spatial patterns of light intensity compliance between indoor and outdoor environments across dengue-endemic areas. Indoor areas predominantly exhibited suboptimal light intensity, particularly within high-endemic zones, where a substantial proportion of households failed to meet the recommended light intensity thresholds (36.67-48.33%), while compliance rates remained relatively low (1.67-13.33%). In contrast, outdoor lighting generally conformed to standard levels, demonstrating more consistent compliance across endemicity categories (46.67-50.00%). These results suggest that inadequate indoor illumination, especially in highly endemic areas, may create shaded microhabitats conducive to *Aedes* oviposition and persistence within households.

Our results indicated that indoor light intensity had a significant influence on oviposition activity during the first trapping period, suggesting that variations in illumination directly affect mosquito breeding preferences. The change in oviposition significance observed during the second trapping period suggests that *Aedes* mosquitoes may exhibit dynamic behavioral plasticity, allowing them to adapt to short-term microenvironmental fluctuations in light intensity rapidly. The findings highlight that inadequate indoor illumination represents an often-overlooked ecological factor that contributes to sustaining *Aedes* breeding potential in dengue-endemic areas.

Table 1 presents the results of the logistic regression analysis identifying trap location and light intensity as significant predictors of ovitrap positivity. Ovitraps placed outdoors were approximately eight times more likely to contain *Aedes* eggs compared to indoor traps (OR: 8.02; p: 0.002). Conversely, higher light intensity significantly reduced the likelihood of oviposition (OR: 0.11; p: 0.001), indicating a clear preference of mosquitoes for shaded environments. However, endemicity status, showed no significant association (p: 0.187).

Table 1. Logistic regression analysis of ovitrap positivity (egg status) with location, light intensity, and endemicity status as predictors

	Regression coefficient	SE	χ^2 (Chi-squared)	*p*-value	Odds ratio	95% confidence interval
Trap location (indoor-outdoor)	2.08	0.67	9.60	0.002	8.02	2.14-29.93
Light Intensity	-2.19	0.67	10.50	0.001	0.11	0.03-0.42
Endemicity status (low-high endemicity)	0.36	0.27	1.73	0.187	1.44	0.83-2.49

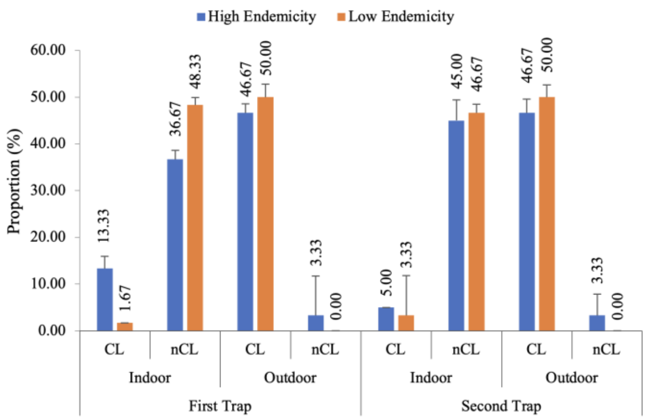

Figure 3. Proportion of ovitraps with indoor and outdoor light intensity compliance across two measurement periods by dengue endemicity level in Aceh Besar District, Indonesia. Bar chart showing households with Compliant Lighting (CL) and non-Compliant Lighting (nCL) relative to the recommended threshold. Indoor settings exhibited higher non-compliance, particularly in high-endemic areas, whereas outdoor lighting generally met the compliance standard (>60 lux)

The results demonstrate that *Aedes* oviposition patterns are predominantly influenced by localized microenvironmental conditions rather than regional endemicity. The elevated oviposition rates in outdoor traps support previous observations that peridomestic containers provide more stable and favorable breeding habitats. Similarly, the inverse relationship with light intensity underscores the adaptive preference of *Aedes* females for shaded, low-light environments that enhance egg survival. Collectively, these findings highlight the need for vector control measures focusing on the removal or modification of shaded outdoor water-holding containers to suppress *Aedes* breeding sites effectively.

Oviposition dynamics across endemicity status and habitat settings

The spatial distribution of *Aedes* oviposition activity was analyzed to determine differences in breeding patterns across endemicity levels and habitat types in Aceh Besar District. Table 2 summarizes the OI of *Aedes* mosquitoes across areas with different dengue endemicity levels in Aceh Besar District. High-endemic areas showed slightly higher mean OI values (13.17±1.94; 8.72±1.29%) than low-endemic areas (12.00±1.79; 7.95±1.18%). Of the 240 ovitraps installed, 151 (62.92%) were positive for *Aedes* eggs. Statistical analysis revealed no significant differences in OI values between high- and low-endemicity zones (p value 0.110) or between indoor and outdoor habitats (p value 0.349; p>0.05), suggesting that *Aedes* oviposition activity was relatively consistent across different environmental contexts.

While outdoor traps recorded marginally higher OI values, these variations were not statistically significant. The comparable OI values observed across endemicity gradients indicate that local microenvironmental conditions, rather than endemicity status, exert a greater influence on oviposition behavior. This finding reflects the ecological plasticity of *Aedes* mosquitoes and reinforces the need for integrated vector management strategies that simultaneously address both indoor and outdoor breeding habitats.

Table 3 presents the oviposition activity of *Aedes* spp. across indoor and outdoor ovitraps in high- and low-endemicity areas of Aceh Besar District. The oviposition activity of *Aedes* spp. varied across clusters and trap locations but showed no significant statistical differences between indoor and outdoor ovitraps (p-value 0.110; p>0.05). In high-endemicity areas, such as Aneuk Paya, indoor traps tended to yield higher mean oviposition activity during both trapping events compared to outdoor traps, although the differences were not consistent or statistically significant. Similar temporal fluctuations were observed in Lamcok and Lampaya, suggesting that oviposition activity may shift dynamically across time without a clear preference for indoor or outdoor habitats.

Impact of environmental light and dengue endemicity levels on oviposition dynamics of *Aedes* mosquitoes

The results indicate that indoor light intensity influenced *Aedes* oviposition activity during both the first and second trapping periods. The relationship between light intensity and dengue endemicity levels in shaping the oviposition dynamics of *Aedes* mosquitoes is presented in Figure 4.

Figure 4 illustrates the influence of light intensity on *Aedes* oviposition activity. The Mann-Whitney U test revealed a significant effect of indoor light intensity during the first trapping event (p: 0.01, Z: -2.51), indicating that differences in indoor lighting were associated with variation in oviposition activity. However, this effect was not observed in the second trapping event (p: 0.64, Z: -0.46). In contrast, indoor oviposition activity showed a significant difference only in the second trap (p: 0.02, Z: -2.26), suggesting temporal variation in oviposition dynamics. Neither outdoor light intensity nor outdoor oviposition activity demonstrated significant differences in either trapping event (all p>0.05), implying that outdoor oviposition may be less influenced by light variation or endemicity status under the conditions studied.

Table 2. Distribution of Ovitrap Index (OI) of *Aedes* spp. by endemicity level in Aceh Besar District, Indonesia

Cluster area	Trap location	Ovitrap Index				
		n	F	Proportion by endemicity status (%)	% total	p-value
High endemicity						
Aneuk Paya	Indoor	20	15	18.99	9.93	0.490
	Outdoor	20	13	16.46	8.61	
Lamcok	Indoor	20	14	17.72	9.27	0.197
	Outdoor	20	10	12.66	6.62	
Lampaya	Indoor	20	12	15.19	7.95	0.311
	Outdoor	20	15	18.99	9.93	
Mean±SD			13.17±1.94	16.67±2.46	8.72±1.29	
Low endemicity						
Aneuk Glee	Indoor	20	9	12.50	5.96	0.110
	Outdoor	20	14	19.44	9.27	
Mon Alue	Indoor	20	12	16.67	7.95	0.744
	Outdoor	20	13	18.06	8.61	
Reukih Dayah	Indoor	20	11	15.28	7.28	0.519
	Outdoor	20	13	18.06	8.61	
Mean±SD			12.00±1.79	16.67±2.48	7.95±1.18	
Total positive trap		240	151		62.92	

Note: n: Total number of ovitraps installed, F: Number of positive ovitraps containing *Aedes* eggs. Proportion by endemicity status (%): Percentage of positive traps within each endemicity category. % total: Percentage of positive traps relative to the total number of traps

Table 3. Oviposition activity of *Aedes* spp. in indoor and outdoor ovitraps by endemicity status in Aceh Besar District, Indonesia

Cluster area	Trap times	Oviposition activity								p-value
		Indoor				Outdoor				
		Min	Max	Mean	SE	Min	Max	Mean	SE	
High endemicity										
Aneuk Paya	1st	0	80	30.10*	9.66	0	55	14.70*	5.84	0.110
	2nd	0	98	27.60*	10.81	0	78	16.40*	7.94	
Lamcok	1st	0	12	3.50	1.24	0	37	6.10	3.64	
	2nd	0	84	23.70	10.39	0	17	4.90	2.22	
Lampaya	1st	0	15	2.30	6.10	0	56	13.40	5.93	
	2nd	0	22	1.53	2.42	0	41	12.80	4.59	
Low endemicity										
Aneuk Glee	1st	0	36	7.40	3.94	0	41	10.70	4.44	
	2nd	0	14	3.20	1.53	0	33	14.30	4.34	
Reukih Dayah	1st	0	68	13.60	7.02	0	35	7.10	3.85	
	2nd	0	137	16.50	13.55	0	83	20.40	8.32	
Mon Alue	1st	0	8	2.40*	1.00	0	15	2.50*	1.48	
	2nd	0	35	5.90*	3.41	0	15	4.80*	1.48	

Note: *: Mann-Whitney U test. Significant difference at the 0.05 level

Discussion

Microclimatic variables shaping Aedes oviposition ecology

Microclimatic conditions strongly influence *Aedes* ecology, yet their impact on oviposition is best understood in interaction with indoor-outdoor light intensity. In Aceh Besar District (August 2023), mean temperatures of 22.9-33.0°C and relative humidity of 76-85% aligned with optimal ranges for *Ae. aegypti* survival, larval development, and egg viability (Reinhold et al. 2018; Liu et al. 2023). Rainfall levels (92.6-312.7 mm) sustained container habitats, the primary breeding sites in urban and peri-urban settings (Westby et al. 2021). However, variation in dengue endemicity across villages could not be explained by climate alone. Poor indoor lighting, more common in high-endemicity areas, mimicked shaded habitats and enhanced mosquito attraction, particularly when combined with high humidity and rainfall-driven water availability. In contrast, better-lit households in low-endemicity areas provided less suitable oviposition conditions despite experiencing similar climatic profiles.

Wind speeds of 2.0-2.4 m/s and stable atmospheric pressure (~1009-1010 mb) reflected ecological stability conducive to mosquito dispersal (Liu et al. 2023). Nevertheless, flight and oviposition decline at speeds above 0.83 m/s, with constraints reported for *Ae. albopictus* near 3.12 m/s (Adeleke et al. 2022; Ouattara et al. 2022; Atieli et al. 2023; Akorli et al. 2025). These results highlight that while favorable microclimatic ranges create baseline suitability, oviposition patterns are most strongly shaped by the interplay of indoor light intensity with humidity and rainfall. While temperature and humidity were recorded to provide ecological context, these parameters were not statistically controlled in the regression analysis. Future research should incorporate them into multivariate or mixed-effects models to better account for potential confounding effects and to more accurately characterize the ecological relationship between light intensity and oviposition activity.

Influence of light intensity on oviposition behavior in high- and low-endemicity areas

Indoor light intensity showed a significant negative association with oviposition index, indicating that darker environments may promote egg-laying activity in *Aedes* mosquitoes. Although statistically significant, these results should be interpreted with caution due to potential pseudo-replication and the absence of mixed-model adjustment. The odds ratio suggests a moderate effect, implying that illumination contributes to, but does not solely determine, oviposition preference. Considering effect sizes provides an ecological perspective, emphasizing that *Aedes* oviposition is shaped by interacting environmental factors rather than a single variable. This aligns with previous studies showing that shaded habitats favor oviposition by reducing desiccation risk and predator exposure. The negative association between indoor light intensity and oviposition suggests a potential ecological link, rather than a direct causal relationship. Further experimental studies are needed to determine whether improving illumination genuinely influences oviposition behavior.

Our results indicate that indoor light intensity significantly influenced *Aedes* oviposition during the first trapping, consistent with previous studies showing that dim indoor environments can affect mosquito behavior and breeding site selection (Rund et al. 2020; Wijewardana et al. 2025). This results suggests that oviposition is not solely dependent on water availability but also shaped by microclimatic and visual cues, particularly in dengue-endemic settings (Aroonasyaka 2025). The absence of this association during the second trapping likely reflects behavioral flexibility, as gravid females adjust their oviposition strategies based on prior site use or environmental saturation (Costa-da-Silva et al. 2024). The comparison between the two trapping periods was conducted within a short interval and should therefore be interpreted as short-term variability rather than true behavioral plasticity. Temporal independence between the periods may not have been fully achieved. Future longitudinal studies are recommended to incorporate repeated-measures or time-series models to better assess temporal trends in oviposition behavior under varying environmental conditions.

In contrast, outdoor light intensity showed no significant association with oviposition in either trapping, possibly due to broader ecological opportunities, container diversity, and abundant olfactory cues that dominate outdoor breeding behavior (David et al. 2023; Dharmamuthuraja et al. 2023). These temporal variations highlight the adaptive and dynamic nature of *Aedes* oviposition, emphasizing the need for repeated sampling to better capture mosquito-environment interactions (Mondal et al. 2025).

The preference of *Ae. aegypti* and *Ae. albopictus* for shaded, low-light habitats, as observed in laboratory studies (Mozūraitis et al. 2020; Wynne 2023), is reinforced by our field data. Light intensity likely influences oviposition indirectly through changes in temperature, humidity, and predation risk, with low-light environments offering more favorable conditions for egg survival and reproductive success (David et al. 2023; Farnesi et al. 2025).

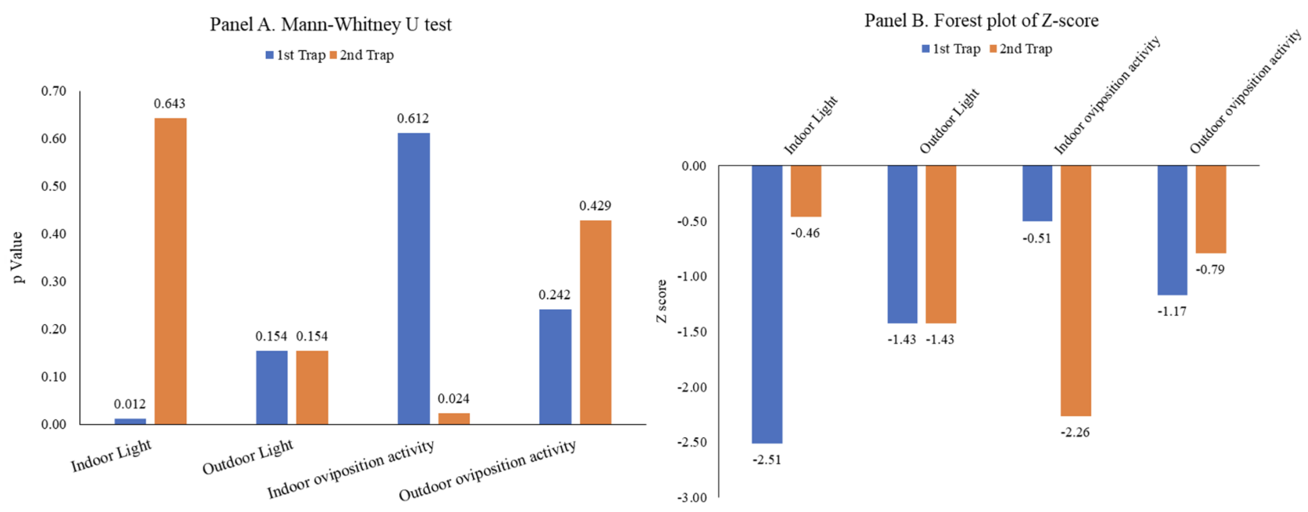

Figure 4. Influence of indoor-outdoor light intensity on egg density index of *Aedes*. Panel A: *p*-values from Mann-Whitney U test illustrating the association between indoor and outdoor light intensity and oviposition outcomes across the first and second trapping events. Panel B: Z-scores across first and second trapping events illustrating the comparative oviposition activity under different light intensity conditions by trapping period

Oviposition dynamics across endemicity status and habitat settings

Oviposition activity in low-endemicity areas exhibited greater heterogeneity, with Reukih Dayah showing increased outdoor oviposition during the second trapping period, while Mon Alue consistently recorded the lowest activity across both habitats. Both indoor and outdoor ovitraps provided comparable breeding opportunities for *Aedes* mosquitoes, with subtle spatial and temporal variations that may influence local transmission dynamics.

In Aceh Besar District, *Aedes* spp. maintained high oviposition activity across both high- and low-endemicity areas, indicated by an OI of 62.92%. The absence of statistically significant differences between endemicity levels or habitat types demonstrates the strong ecological adaptability of *Aedes*, allowing them to exploit diverse breeding environments. These findings are consistent with research conducted in Brazil, Malaysia, and Thailand, which reported that the distribution of *Ae. aegypti* and *Ae. albopictus* is determined more by microhabitat availability than by endemicity status (Ratnasari et al. 2020; Tedjou et al. 2020; Rahman et al. 2021; Wiyata et al. 2023; Knoblauch et al. 2024; Fikri et al. 2025).

Site-specific variations, such as higher indoor oviposition in Aneuk Paya and fluctuating outdoor activity in Reukih Dayah, likely reflect localized influences of microclimatic conditions, container availability, and household water management. The similarity in OI values between indoor and outdoor settings highlights the dual ecological niche of *Aedes* vectors. While *Ae. aegypti* typically dominates indoor habitats, *Ae. albopictus* increasingly thrives in peridomestic environments (Dharmamuthuraja et al. 2023; Adjobi et al. 2024; Akollo 2024; Fikri et al. 2025). These patterns reinforce the importance of Integrated Vector Management (IVM) strategies that address both indoor and outdoor breeding habitats through complementary interventions (Herath et al. 2024).

Improving household lighting may represent a novel, low-cost intervention to reduce oviposition in dimly lit indoor environments, which this study identified as more common in high-endemicity areas. Enhancing natural or artificial lighting could disrupt shaded microhabitats favored by *Ae. aegypti*, thereby complementing traditional vector control measures in resource-limited communities. Such an approach is consistent with community-based environmental modifications reported in Malaysia, Thailand, and Brazil, where structural and household-level changes reduced oviposition activity by limiting habitat suitability (Rahman et al. 2021; Westby et al. 2021; Souza et al. 2024). Integrating lighting improvements into IVM may therefore strengthen control programs by addressing both microclimatic and behavioral drivers of vector ecology.

Finally, the uniformity of oviposition indices across endemicity strata raises important considerations for dengue surveillance. While OI and oviposition activity remain practical entomological tools, their predictive value for dengue outbreaks is limited and should be complemented with additional indicators such as pupal indices, adult vector density, and viral infection rates in mosquitoes (Sasmita et al. 2021; Adjobi et al. 2024; Alipitchay et al. 2025). Moreover, the observed temporal fluctuations in egg density highlight the importance of longitudinal surveillance to capture dynamic breeding behaviors influenced by rainfall, temperature, and human water storage practices. Collectively, these findings emphasize the need for continuous, comprehensive entomological monitoring and integrated interventions, including household lighting improvements, across all endemic settings to mitigate dengue transmission risk effectively.

Impact of environmental light and dengue endemicity levels on oviposition dynamics of Aedes *mosquitoes*

The result highlights that the influence of environmental light on *Aedes* oviposition is both context- and time-dependent, with indoor conditions showing stronger associations than outdoor environments. The temporal shift in statistical significance between the first and second trap suggests that oviposition responses may be shaped by short-term ecological or behavioral adaptations within the mosquito population.

Our findings are consistent with earlier reports that *Ae. aegypti* preferentially deposits eggs in shaded or dim environments, where immature stages face reduced risk of desiccation and predation, enhancing reproductive success and population persistence (Walker 2021; Musunzaji et al. 2023; Meyerhof et al. 2025). The lack of consistent effects across both trapping periods, however, highlights that oviposition is not solely governed by light but also by other microclimatic and ecological drivers such as humidity, rainfall, and container availability (Gimenez et al. 2020; Andreo et al. 2021).

Notably, outdoor light intensity and oviposition activity showed no significant associations, suggesting that peridomestic oviposition is less dependent on light variation. This may reflect the ecological plasticity of *Ae. albopictus*, which is more common in outdoor habitats and capable of breeding across a wider range of environmental conditions (Kramer et al. 2021). Such flexibility underscores the challenge of targeting outdoor oviposition sites through light-related interventions alone.

The stronger association observed indoors highlights households as key points for surveillance and control. Targeted interventions like removing containers in shaded indoor areas, combined with ongoing monitoring through ovitraps, could help reduce vector growth. At the same time, the temporal variability in oviposition underlines the need for long-term surveillance to better understand ecological patterns and guide adaptive, integrated vector management strategies.

In conclusion, the oviposition activity of *Aedes* in Aceh Besar, Indonesia, is primarily influenced by local microclimatic conditions and light intensity, with low indoor lighting significantly increasing oviposition. *Aedes* adjusts its egg-laying behavior based on light, humidity, and the availability of water-holding containers in both dim indoor habitats and peridomestic outdoor environments. Improving household lighting offers a simple, low-cost intervention that could reduce oviposition in dimly lit environments and support integrated vector management efforts. Environmental modification, when combined with community-based participation and routine surveillance, could strengthen dengue prevention programs in endemic and semi-endemic regions.

Limitations

This study has some limitations that should be acknowledged. First, the sampling period was relatively short (August 2023), which may not have fully captured seasonal variations in oviposition dynamics. Second, molecular methods were not applied to confirm species identity, and thus interpretations rely on morphological identification, which may overlook cryptic species or mixed populations of *Ae. aegypti* and *Ae. albopictus*. Third, the study was conducted in only two sub-districts (Lhoknga and Indrapuri) representing high and low dengue endemicity areas. While this purposive selection allowed an initial ecological comparison, the limited spatial coverage may not capture the full heterogeneity of environmental conditions across Aceh Besar District. In addition, it is acknowledged that ovitraps deployed within the same household or village may share similar environmental conditions, which could introduce pseudo-replication. Although logistic regression was applied to provide exploratory interpretation, future studies with broader sampling should employ hierarchical or mixed-effects models to account for nested data structures and improve statistical robustness. Temperature and humidity were not statistically adjusted in the analysis, which may have influenced the observed associations. Several potential confounding factors, including house construction, surrounding vegetation, and household water management practices were not controlled for in this study. These variables could influence both lighting conditions and mosquito breeding activity, thereby limiting causal inference. Lastly, entomological risk assessment relied exclusively on the OI and oviposition activity, without integrating other indicators such as pupal indices, adult mosquito abundance, or viral infection status. Despite these constraints, the findings provide valuable preliminary insights into the ecological adaptability of *Aedes* mosquitoes across different endemicity contexts.

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REFERENCES

Aceh Provincial Health Office. 2021. Aceh Health Profile 2020. Aceh Provincial Health Office (Dinas Kesehatan Provinsi Aceh), Banda Aceh, Indonesia. https://dinkes.acehprov.go.id/detailpost/profil-kesehatan-aceh-tahun-2020. [Indonesian]

Aceh Provincial Health Office. 2023. Aceh Health Profile 2022. Aceh Provincial Health Office (Dinas Kesehatan Provinsi Aceh), Banda Aceh, Indonesia. https://dinkes.acehprov.go.id/detailpost/profil-kesehatan-aceh-tahun-2022. [Indonesian]

Adeleke ED, Shittu RA, Beierkuhnlein C, Thomas SM. 2022. High wind speed prevents the establishment of the disease vector mosquito *Aedes albopictus* in its climatic niche in Europe. Front Environ Sci 10: 846243. DOI: 10.3389/fenvs.2022.846243.

Adjobi CN, Zahouli JZB, Guindo-Coulibaly N, Ouattara AF, Vavassori L, Adja MA. 2024. Assessing the ecological patterns of *Aedes aegypti* in areas with high arboviral risks in the large city of Abidjan, Côte d'Ivoire. Plos Negl Trop Dis 18 (11): e0012647. DOI: 10.1371/journal.pntd.0012647.

Akollo R. 2024. Preferences for breeding places for *Aedes* spp. mosquitoes on materials and location of containers in the working area of Lateri Health Center, Ambon City. J Med Lab Infect Degener Dis 2 (1): 1-7. DOI: 10.36858/jmid.v2i1.16.

Akorli J, Oware SKD, Sackitey DB, Pul RM, Akyea-Bobi NE, Akporh SS, Amlalo GK, Osei JHN, Boakye HA, Abudu M, Akorli EA, Frempong KK, Pi-Bansa S, Opoku M, Dadzie SK. 2025. Climate-driven models reveal temporal trends in *Aedes* breeding: Implications for outbreak preparedness and control interventions. BMC Publ Health 25: 2735. DOI: 10.1186/s12889-025-24060-w.

Alipitchay S, Alias MA, Hamid SNSSA, Hamzah R, Mansor N, Hamid NA, Othman H. 2025. Temporal and interaction dynamics of dengue cases, entomological and meteorological variables in Melaka, Malaysia: A multivariate time series analysis. Plos One 20 (4): e0321273. DOI: 10.1371/journal.pone.0321273.

Andreo V, Porcasi X, Guzman C, Lopez L, Scavuzzo CM. 2021. Spatial distribution of *Aedes aegypti* oviposition temporal patterns and their relationship with environment and dengue incidence. Insects 12 (10): 919. DOI: 10.3390/insects12100919.

Aroonasyaka R. 2025. Literature review: The effect of water type on the growth of *Aedes aegypti* mosquito larvae in Indonesia. Tropis 2 (1): 27-31. DOI: 10.37304/tropis.v2i1.18245.

Atieli HE, Zhou G, Zhong D, Wang X, Lee MC, Yaro AS, Diallo M, Githure J, Kazura J, Lehmann T, Yan G. 2023. Wind-assisted high-altitude dispersal of mosquitoes and other insects in East Africa. J Med Entomol 60 (4): 698-707. DOI: 10.1093/jme/tjad033.

Badan Pusat Statistik (BPS) Kabupaten Aceh. 2024. Kabupaten Aceh Besar Dalam Angka 2024. BPS Kabupaten Aceh, Aceh. [Indonesian]

Costa-da-Silva AL, Cabal S, Lopez K, Boloix J, Rodriguez BG, Marrero KM, Bellantuono AJ, DeGennaro M. 2024. Female *Aedes aegypti* mosquitoes use communal cues to manage population density at breeding sites. Commun Biol 7: 143. DOI: 10.1038/s42003-024-05830-5.

Cui G, Zhong S, Zheng T, Li Z, Zhang X, Li C, Hemming-Schroeder E, Zhou G, Li Y. 2021. *Aedes albopictus* life table: Environment, food, and age dependence survivorship and reproduction in a tropical area. Parasit Vectors 14: 568. DOI: 10.1186/s13071-021-05081-x.

David MR, Maciel-de-Freitas R, Petersen MT, Bray D, Hawkes FM, Fernández-Grandon GM, Young S, Gibson G, Hopkins RJ. 2023. *Aedes aegypti* oviposition-sites choice under semi-field conditions. Med Vet Entomol 37 (4): 683-692. DOI: 10.1111/mve.12670.

de Almeida PS, De Moura LB, de Sousa IBA, Fernandes MG, Pupo GV, de Souza LS, Abreu HCN. 2025. Ovitrap-based monitoring and infestation analysis of *Aedes aegypti* in Brazil. Rev Patol Trop 54 (2): 1-14. DOI: 10.5216/rpt.v54i2.82678.

Dharmamuthuraja D, Rohini PD, Lakshmi MI, Isvaran K, Ghosh SK, Ishtiaq F. 2023. Determinants of *Aedes* mosquito larval ecology in a heterogeneous urban environment- a longitudinal study in Bengaluru, India. Plos Negl Trop Dis 17 (11): e0011702. DOI: 10.1371/journal.pntd.0011702.

Djiappi-Tchamen B, Nana-Ndjangwo MS, Nchoutpouen E, Makoudjou I, Ngangue-Siewe IN, Talipouo A, Mayi MPA, Awono-Ambene P, Wondji C, Tchuinkam T, Antonio-Nkondjio C. 2022. *Aedes* mosquito surveillance using ovitraps, sweep nets, and biogent traps in the city of Yaoundé, Cameroon. Insects 13 (9): 793. DOI: 10.3390/insects13090793.

Dom NC, Abdullah NAMH, Dapari R, Salleh SA. 2025. Fine-scale predictive modeling of *Aedes* mosquito abundance and dengue risk indicators using machine learning algorithms with microclimatic variables. Sci Rep 15 (1): 37017. DOI: 10.1038/s41598-025-17191-y.

Duffield GE, Acri DJ, George GF, Sheppard AD, Beebe NW, Ritchie SA, Burkot TR. 2019. Diel flight activity of wild-caught *Anopheles farauti* (s.s.) and *An. hinesorum* malaria mosquitoes from northern Queensland, Australia. Parasit Vectors 12 (48): 1-14. DOI: 10.1186/s13071-018-3271-0.

Facchinelli L, Badolo A, McCall PJ. 2023. Biology and behaviour of *Aedes aegypti* in the human environment: Opportunities for vector control of Arbovirus transmission. Viruses 15 (3): 636. DOI: 10.3390/v15030636.

Farnesi LC, Alves G, Araripe LO, Bruno RV. 2025. *Aedes aegypti* reproductive aspects: Constant light significantly affects the embryonic development. Mem Inst Oswaldo Cruz 120: e240233. DOI: 10.1590/0074-02760240233.

Fikri MAM, Ar FA, Nurhadzira EM, Hazrin MH, Hanipah S, Riza IH. 2025. Spatial and breeding site analysis of *Aedes* spp. at dengue-prone areas in Kuala Lumpur, Malaysia. Intl J Environ Health Res 1 (1): 1-20. DOI: 10.1080/09603123.2025.2488484.

Fitria R. 2021. The Relationship between Physical Environmental Factors and Community Actions with Dengue Fever Cases in the Sering Community Health Center Working Area [Thesis]. Ilmu Kesehatan Masyarakat, Universitas Islam Negeri Sumatera Utara, Medan. [Indonesian]

Gimenez JO, Alvarez CN, Almirón WR, Stein M. 2020. Meteorological variables associated with the temporal oviposition rate of *Aedes aegypti* (Diptera: Culicidae) in Resistencia city, Chaco province, Northeastern Argentina. Acta Trop 212: 105678. DOI: 10.1016/j.actatropica.2020.105678.

Harapan H, Rajamoorthy Y, Anwar S et al. 2018. Knowledge, attitude, and practice regarding dengue virus infection among inhabitants of Aceh, Indonesia: a cross-sectional study. BMC Infect Dis 18 (96): 1-16. DOI: 10.1186/s12879-018-3006-z.

Herath JMMK, De Silva WAPP, Weeraratne TC, Karunaratne SHPP. 2024. Breeding habitat preference of the dengue vector mosquitoes *Aedes aegypti* and *Aedes albopictus* from urban, semiurban, and rural areas in Kurunegala District, Sri Lanka. J Trop Med 2024 (1): 4123543. DOI: 10.1155/2024/4123543.

Ipa M, Hendri J, Hakim L, Muhammad R. 2017. Susceptibility of larvae *Aedes aegypti* against Temefos (Organophospate) in three districts Aceh Province. Aspirator 9 (2): 77-84. DOI: 10.22435/aspirator.v9i2.5812.77-84.

Kertapati DTN, Aminah DJ. 2024. Dengue Fever Still Lurks. Mediakom. https://kemkes.go.id/app_asset/file_content_download/171799677966668cebe32e93.49845686.pdf.

Knoblauch S, Su-Yin M, Chatrinan K, de Aragão-Rocha AA, Haddawy P, Biljecki F, Lautenbach S, Resch B, Arifi D, Jänisch T, Morales I, Zipf A. 2024. High-resolution mapping of urban *Aedes aegypti* immature abundance through breeding site detection based on satellite and street view imagery. Sci Rep 14 (1): 18227. DOI: 10.1038/s41598-024-67914-w.

Kramer IM, Pfeiffer M, Steffens O, Schneider F, Gerger V, Phuyal P, Braun M, Magdeburg A, Ahrens B, Groneberg DA, Kuch U, Dhimal M, Müller R. 2021. The ecophysiological plasticity of *Aedes aegypti* and *Aedes albopictus* concerning overwintering in cooler ecoregions is driven by local climate and acclimation capacity. Sci Total Environ 778: 146128. DOI: 10.1016/j.scitotenv.2021.146128.

Krishna G, Dasari T, Sreedevi S. 2024. Dengue virus infection: Etiology, epidemiology, pathogenesis, diagnosis, and prevention. In: Saxena SK (esd). Viral Infectious Diseases Annual Volume 2024. IntechOpen, Rijeka. DOI: 10.5772/intechopen.114323.

Leandro A, Maciel-de-Freitas R. 2024. Development of an integrated surveillance system to improve preparedness for arbovirus outbreaks in a dengue endemic setting: Descriptive study. JMIR Publ Health Surveill 10: e62759. DOI: 10.2196/62759.

Liu Z, Zhang Q, Li L, He J, Guo J, Wang Z, Huang Y, Xi Z, Yuan F, Li Y, Li T. 2023. The effect of temperature on dengue virus transmission by *Aedes* mosquitoes [Review]. Front Cell Infect Microbiol 13: 1242173. DOI: 10.3389/fcimb.2023.1242173.

Lustiyati ED, Astuti P. 2018. The correlation of physical environment condition to level of *Aedes* sp. larvae density at area of elementary schools of Kasihan Sub-district Bantul District. J Publ Health Sci 9 (3): 464988. DOI: 10.26553/jikm.2018.9.3.216-225.

Meyerhof GT, Dhavan P, Blunk S, Bourd A, Singh R, Chandel A, Montell C. 2025. Visual threat avoidance while host seeking by *Aedes aegypti* mosquitoes. Cell Rep 44 (4): 115435. DOI: 10.1016/j.celrep.2025.115435.

Mondal R, Azmi SA, Sinha S, Bose C, Ghosh T, Bhattacharya S, Tyagi B. 2025. Ecology and behavior. In: Tyagi B (eds). Mosquitoes of India. CRC Press, United States. DOI: 10.1201/9781003326991-14.

Mozūraitis R, Hajkazemian M, Zawada JW, Szymczak J, Pålsson K, Sekar V, Biryukova I, Friedländer MR, Koekemoer LL, Baird JK, Borg-Karlson AK, Emami SN. 2020. Male swarming aggregation pheromones increase female attraction and mating success among multiple African malaria vector mosquito species. Nat Ecol Evol 4 (10): 1395-1401. DOI: 10.1038/s41559-020-1264-9.

Musunzaji PS, Ndenga BA, Mzee S, Abubakar LU, Kitron UD, Labeaud AD, Mutuku FM. 2023. Oviposition preferences of *Aedes aegypti* in Msambweni, Kwale County, Kenya. J Am Mosq Control Assoc 39 (2): 85-95. DOI: 10.2987/22-7103.

Ouattara CA, Traore TI, Traore S, Sangare I, Meda CZ, Savadogo LGB. 2022. Climate factors and dengue fever in Burkina Faso from 2017 to 2019. J Publ Health Afr 13 (1): 2145. DOI: 10.4081/jphia.2022.2145.

Rahman MS, Pientong C, Zafar S, Ekalaksananan T, Paul RE, Haque U, Rocklöv J, Overgaard HJ. 2021. Mapping the spatial distribution of the dengue vector *Aedes aegypti* and predicting its abundance in northeastern Thailand using machine-learning approach. One Health 13: 100358. DOI: 10.1016/j.onehlt.2021.100358.

Ratnasari A, Jabal AR, Rahma N, Rahmi SN, Karmila M, Wahid I. 2020. The ecology of *Aedes aegypti* and *Aedes albopictus* larvae habitat in coastal areas of South Sulawesi, Indonesia. Biodiversitas 21 (10): 4648-4654. DOI: 10.13057/biodiv/d211025.

Reinhold JM, Lazzari CR, Lahondère C. 2018. Effects of the environmental temperature on *Aedes aegypti* and *Aedes albopictus* mosquitoes: A Review. Insects 9 (4): 158. DOI: 10.3390/insects9040158.

Romiti F, Casini R, Del Lesto I, Magliano A, Ermenegildi A, Droghei S, Tofani S, Scicluna MT, Pichler V, Augello A, Censi F, Scaringella PL, Mastrobuoni G, Bacciotti D, Nencetti A, De Liberato C. 2025. Characterization of overwintering sites (hibernacula) of the West Nile vector Culex pipiens in Central Italy. Parasit Vectors 18 (1): 74. DOI: 10.1186/s13071-025-06710-5.

Rund SSC, Labb LF, Benefiel OM, Duffield GE. 2020. Artificial light at night increases *Aedes aegypti* mosquito biting behavior with implications for arboviral disease transmission. Am J Trop Med Hyg 103 (6): 2450-2452. DOI: 10.4269/ajtmh.20-0885.

Russell TL, Staunton K, Burkot T. 2022. Standard Operating Procedure for Assembly and Deployment of Ovitraps. Protocol Integer ID: 64751. protocols.io. Pacific Mosquito Surveilance Strengthening for Impact (PACMOSSI), James Cook University, Australia. DOI: 10.17504/protocols.io.14egn7r4pv5d/v1.

Sari E, Wahyuningsih NE, Murwani R. 2017. The relationship between the physical environment of houses and the incidence of dengue hemorrhagic fever in Semarang. Jurnal Kesehatan Masyarakat 5 (5): 609-617. DOI: 10.14710/jkm.v5i5.19183.

Sasmita HI, Neoh KB, Yusmalinar S, Anggraeni T, Chang NT, Bong LJ, Putra RE, Sebayang A, Silalahi CN, Ahmad I, Tu WC. 2021. Ovitrap surveillance of dengue vector mosquitoes in Bandung City, West Java Province, Indonesia. Plos Negl Trop Dis 15 (10): e0009896. DOI: 10.1371/journal.pntd.0009896.

Souza CDFd, Nascimento RPdS, Bezerra-Santos M, Armstrong AdC, Gomes OV, Nicácio JM, Júnior JVJS, Carmo RFd. 2024. Space-time dynamics of the dengue epidemic in Brazil, 2024: An insight for decision making. BMC Infect Dis 24 (1): 1056. DOI: 10.1186/s12879-024-09813-z.

Tedjou AN, Kamgang B, Yougang AP, Wilson-Bahun TA, Njiokou F, Wondji CS. 2020. Patterns of ecological adaptation of *Aedes aegypti* and *Aedes albopictus* and stegomyia indices highlight the potential risk of arbovirus transmission in Yaoundé, the Capital City of Cameroon. Pathogens 9 (6): 491. DOI: 10.3390/pathogens9060491.

Walker MA. 2021. Discrete and Continuous Mathematical Investigation of Juvenile Mosquito Dynamics. [Dissertation]. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Westby KM, Adalsteinsson SA, Biro EG, Beckermann AJ, Medley KA. 2021. *Aedes albopictus* populations and larval habitat characteristics across the landscape: Significant differences exist between urban and rural land use types. Insects 12 (3): 196. DOI: 10.3390/insects12030196.

Wijewardana C, Chen Y, Zhou Y, Jiang C, Zhang D, Hou M, Xu Z, Chen L, Ji M, Chen L. 2025. Circadian rhythm of mosquitoes: Blood feeding and disease transmission. Decoding Infect Transmiss 3: 100050. DOI: 10.1016/j.dcit.2025.100050.

Wiyata AD, Handoyo W, Sayono S. 2023. The key associated factor of the emergence of the dengue vector in peri-urban and rural settlements. J Environ Health 15 (4): 291-299. DOI: 10.20473/jkl.v15i4.2023.291-299.

World Health Organization. 2024. Global Malaria Programme Operational Strategy 2024-2030. World Health Organization, Geneva.

Wynne NE. 2023. Variations in Time-Dependent Mosquito-Host Interactions Across *Aedes* Species. [Dissertation]. Biochemistry, Virginia Polytechnic Institute and State University, Virginia Tech.

Yani A. 2024. The influence of environmental factors on the development of dengue fever. Intl Sci Health J 2 (4): 116-123. DOI: 10.59680/ishel.v2i4.1569.