Assess the Productivity of Dengue Vector Breeding Habitat Through Pupal Productivity in Kalutara District, Sri Lanka.

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DOI: https://doi.org/10.51244/IJRSI.2026.1308000063

Received: 16 February 2026; Accepted: 21 February 2026; Published: 02 September 2026

ABSTRACT

Dengue is a rapidly spreading mosquito-borne disease, and infected female *Aedes aegypti* and *Aedes albopictus* serve as the vectors. The study was conducted to assess the pupal productivity across the different breeding habitats in the Kalutara District. The characteristics of pupae-positive breeding habitats and pupal counts were recorded. R version 4.5.2 was used for statistical analyses. Breeding Preference Ratio (BPR), Pupae-per-House Index (PHI) and Pupal per Person Index (PPI) were calculated. Pupal productivity was defined as the number of pupae recorded per positive breeding habitat. To identify breeding habitat characteristics associated with pupal productivity, a Quasi-Poisson regression model (QPRM) was used for *Ae. aegypti,* and Negative Binomial Regression Model (NBRM) were used for *Ae. albopictus.* Out of 2,400 premises surveyed, 23.92% were positive for *Aedes* pupae. The PHI and PPI showed no significant differences among the vectors. Among 1,480 potential breeding habitats, 21.55% contained *Aedes* immatures, and 23.5% of larval habitats had pupae. The highest BPR and pupal productivity of *Ae. aegypti* was found in tyres, with significant variation (p=0.004). For *Ae. albopictus*, BPR was highest in natural items, while pupal productivity was highest in temporary removed items, without significant differences. Water volume showed contrasting effects: *Ae. aegypti* preferred small (IRR = 6.12, p = 0.007) and medium (IRR = 7.17, p = 0.029) volumes, while *Ae. albopictus* reduced abundance in very small volumes (IRR = 0.46, p = 0.004). Indoor locations consistently reduced pupal abundance by approximately 87% for both species (*Ae. aegypti*: IRR = 0.122, p = 0.002; *Ae. albopictus*: IRR = 0.135, p = 0.011), representing the most robust shared vulnerability. Effective *Ae. aegypti* management requires targeted removal of key containers. But *Ae. albopictus* control demands community-wide elimination of outdoor breeding sources. Public health messaging should focus on species-specific breeding habits to reduce vector density and dengue risk.

Keywords: Ae. aegypti, Ae. albopictus, Breeding habitat, Pupal productivity

INTRODUCTION

Dengue is a rapidly spreading mosquito-borne disease (Schaffner & Mathis, 2014) and has become one of the most significant public health risks worldwide. As a South Asian country, Sri Lanka has been affected by dengue fever (DF)/dengue hemorrhagic fever (DHF) epidemics for over two decades, and DENV infections have been endemic in Sri Lanka since the mid-1960s (Sirisena & Noordeen, 2014). Currently, dengue is the most significant public health problem among infectious diseases in Sri Lanka (Liyanage et al., 2022) and is prevalent all over the country except for a few districts with seasonal and periodic epidemics. Approximately half of the total dengue incidences were reported in the Western Province, which comprises the Districts of Colombo, Gampaha and Kalutara (Withanage et al., 2020).

Dengue is caused by any one of four recognized serotypes of dengue virus: DENV-1, DENV-2, DENV-3 or DENV-4 and these viruses are transmitted to vertebrates, including humans, by the bite of an infected female mosquito belonging to the genus *Aedes,* notably *Aedes aegypti* (Linnaeus) and *Aedes albopictus* (Skuse) (Wilson-Bahun et al., 2020). *Ae. aegypti* is considered the main or primary vector (Edillo et al., 2012; Wilson-

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VIII August 2026

Bahun et al., 2020) and *Ae. albopictus* is considered the secondary vector (Edillo et al., 2012) in Asia. Other than Dengue, these vectors also act as vectors for Chikungunya, Zika, and Yellow fever. Both *Ae. aegypti* and *Ae. albopictus* have been recorded in Sri Lanka. Kalutara district is one of the districts severely affected by dengue, where both *Ae. aegypti* and *Ae. albopictus* are found in different proportions. Although *Ae. albopictus* is more prevalent in the Kalutara district, areas where *Ae. aegypti* is present are significantly more vulnerable to higher incidence rates of Dengue. As there is no efficient vaccine or specific treatment against dengue, vector control remains the cornerstone to prevent outbreaks (Wilson-Bahun et al., 2020). Vector control aims to limit the transmission of pathogens by reducing or preventing human contact with the vector, and a wide range of vector control tools exists. Immature vector control by breeding habitat elimination is a more efficient, economically and environmentally friendly tool than any other adult vector control methods. To implement proper breeding habitat elimination activities, it is essential to identify the productivity of breeding habitats. Most studies about the productive breeding habitat of dengue vectors focused on traditional Stegomyia larval indexes rather than pupal densities. However, these indices are insufficient for making decisions about control actions (Nathan et al., 2006) because these indices disregard key demographic factors, such as larval density and survival rates. As a result, predicting the abundance of adult mosquitoes, which is an epidemiologically significant stage, is challenging.

Moreover, the larval indices of Stegomyia mosquitoes fail to provide valuable insights into the productivity of various breeding habitats, making it challenging to identify which specific container types significantly contribute to the adult vector population (de Brito Arduino, 2014; Nathan et al., 2006) Since mosquito pupae are more proximal to adults than to the larval stages, and because pupal mortality is minimal, the number of pupae is highly correlated with the number of adult mosquitoes (Dana A Focks et al., 2006; Mwakutwaa et al., 2023). Also, pupal indices provide more accurate information about adult density compared to larval indices. Moreover, it was envisaged that pupal surveys, if combined with the collection of demographic data, could help elucidate the transmission dynamics of dengue, identify transmission risk, and quantify and validate target levels of vector abundance (Nathan et al., 2006). Therefore, this study was carried out to assess the productivity of dengue vector breeding habitats using pupal productivity in Kalutara District of Sri Lanka.

METHODOLOGY

Study area

Kalutara District is a district in the Western Province of Sri Lanka, located in the southwestern part of the island, and geographical boundaries fall within the latitudes of 6°47′ N and 6°91′ N and the longitudes of 79°570′ E and 80°18′ E (Liyanage et al., 2022). Kalutara District is located in Sri Lanka's low country wet zone, characterized by an average annual rainfall of 2,931 mm and an average annual temperature of 27.7 °C. The study area extends over 148.3 km² from Waskaduwa to Aluthgama along the southern coastal boundary of the Kalutara district (Fig 01).

Study design

During the surveillance, the premises of a house hold considered the basic sampling unit (Aryaprema & Xue, 2019). Simple random sampling method was used to select the first premises surveyed, and every second premise on the right side was included until the required sample size was reached. About 200 premises were surveyed for each month from October 2023 to September 2024 with informed consent from the owner of the premise-hold. Premises with immature mosquito stages were identified as positive during inspections of both indoor (domestic) and outdoor (peri-domestic) areas. Additionally, the size of the area and the number of residents living in the positive premises were recorded.

Methods of Entomological Collection

All pupae and a sample of larvae (3^{rd} and 4^{th} instars) from positive breeding habitats were collected according WHO Operational Guide (Azael Che-Mendoza, Pablo Manrique-Saide, Nidia Rizzo, Daniel Pilger, Audrey Lenhart, Axel Kroeger, 2011) with the aid of pipettes and ladles (Chadee et al., 2007). The number of larvae and pupae of the positive breeding habitats was recorded. Collected larvae and pupae were placed in labelled vials

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VIII August 2026

and transported to the entomological laboratory at the National Institute of Health Sciences in Kalutara. Collected larvae were identified using X33RTFS2 Olympus CX33 Trinocular biological microscope and standard larval identification keys. The collected pupae were allowed to emerge into adults and identified using a Zeiss Stereo Microscope (Stemi 2000) and standard adult mosquito identification keys. The generic or descriptive name of each pupae positive breeding habitat was recorded with location, building material, volume of water and source of water.

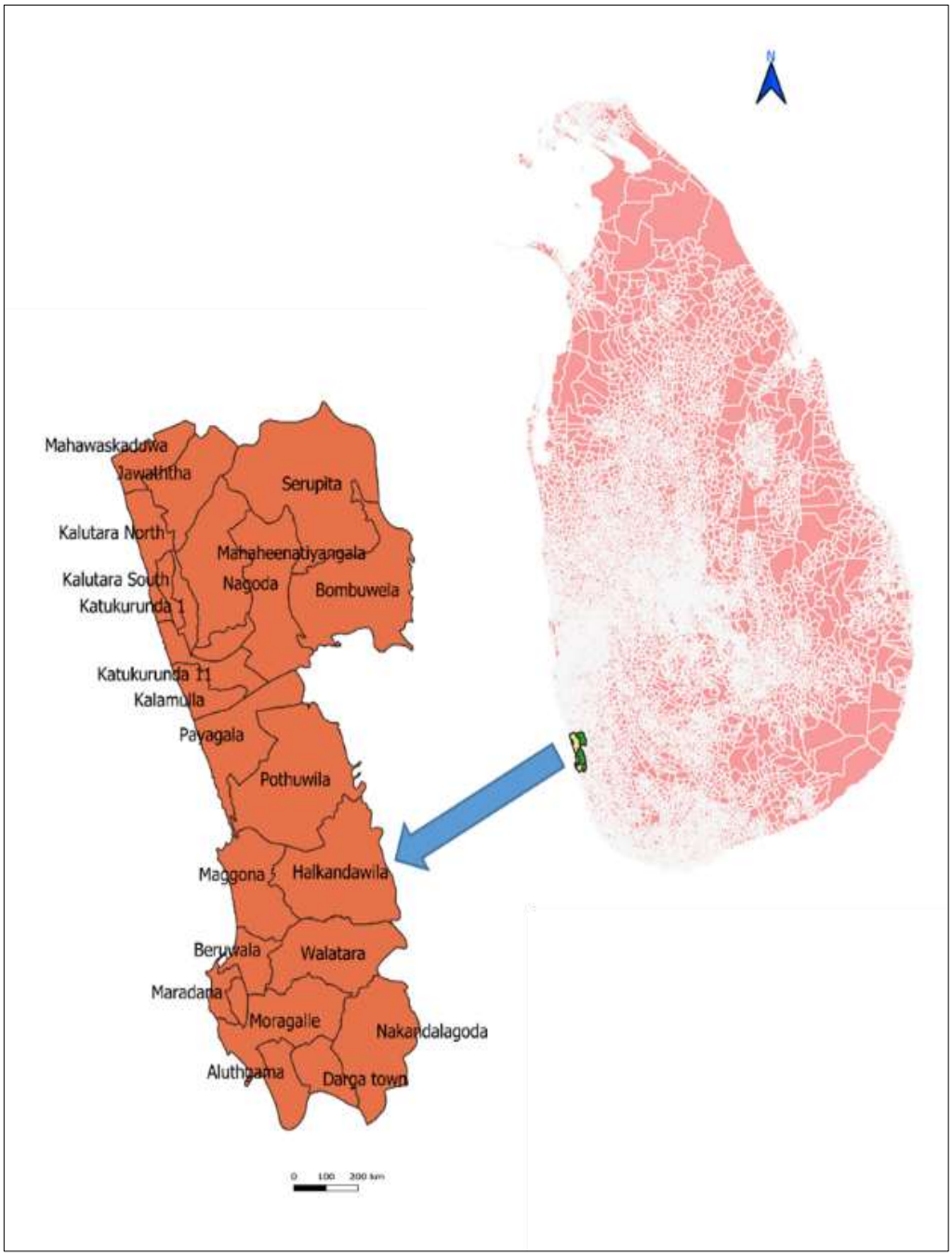

Fig 01 Map of study site

Data analysis

All statistical analyses were performed using R version 4.5.2.

Pupal demographic data analysis

Pupae-per-House Index (PHI) and Pupal per Person Index (PPI) were calculated as Pupal demographic indexes. PHI was calculated as the total number of recorded pupae, divided by the total number of households inspected

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VIII August 2026

and PPI was calculated as the total number of recorded pupae, divided by the total population of the inspected households (Jiménez-Alejo et al., 2017). Comparison of demographic indexes for both species was done using the Mann-Whitney U test.

Classification of Breeding habitats

Initially, breeding habitats were classified into 12 categories based on their nature: Covering Items, Discarded Items, Gutters, Natural Items, Ornamental Items, Pet Feeding Containers, Refrigerators, Slabs, Temporary Removed Items, Tyres, Water Storage Items, and Others. However, during statistical modelling, Gutters, Natural Items, Pet Feeding Containers, Refrigerators, and Slabs were combined into the "Other" category due to the very low pupal counts and small number of observations recorded in these habitat types. This reclassification was performed to reduce sparse data bias and improve the stability and interpretability of the regression model. Building materials of breeding habitats were classified into 6 categories: Cement and ceramic, Metal, Plastic and polythene, Rubber, Ceramic and clay and Other. However, during statistical modelling, the "Ceramic and Clay" category was combined into the "Other" category due to very low pupal counts. The locations of breeding habitats were classified into 3 categories: Indoor, Outdoor Open and Outdoor Shady. The sources of water in breeding habitats were classified into three categories: rainwater, tap water and others. Based on typical breeding habitat preferences, the water volume of breeding habitats was categorized as very small (10-100 ml), small (101-1,000 ml), medium (1,001-5,000 ml) and large (5,001-30,000 ml).

Calculation of Breeding Preference Ratio (BPR)

Index of Available Breeding Habitats (IABH) and Index of Contribution to Breeding Habitats (ICBH) for each breeding habitat were calculated to determine the Breeding Preference Ratio (BPR) of both species (Kumar et al., 2002). The IABH was calculated as the number of recorded breeding habitats from each category divided by the total number of breeding habitats recorded. The ICBH was calculated as the number of positive breeding habitats from each category divided by the total number of positive breeding habitats. The breeding preference ratio (BPR) was calculated as the ratio of ICBH to IABH for each category.

Modelling the relationship between breeding habitat characteristics and pupal productivity

Pupal productivity of a breeding habitat was defined as the number of pupae recorded per positive breeding habitat and used as the dependent variable (D A Focks et al., 2000). Independent variables included breeding habitat type, location of breeding habitat, type of building material, source of water and quantity of water contained in the breeding habitat. Due to small sample size, too many zeros and low variation, Quasi-Poisson Regression Model (QPRM) were used for species *Ae. aegypti* and Negative Binomial Regression Model (NBRM) were used for *Ae. albopictus* to identify breeding habitat characteristics associated with pupal productivity. The most common category was selected as the reference category for each explanatory variable. i.e., temporary removal items from breeding habitat types for both species, for *Ae. aegypti*, very small and *Ae. albopictus*, small from water volume class, for *Ae. aegypti* outdoor shady and for *Ae. albopictus* outdoor open from locations of breeding sites, Plastic and polythene form type of building material, and Rain from water source. Adjusted Incidence Rate Ratios (IRRs) with 95% confidence intervals were calculated by exponentiating the regression coefficients. Statistical significance was assessed at a 5% significance level ($p < 0.05$).

RESULTS

Pupal Demographic Data

A total of 2,400 premises were surveyed during the study period. Out of these, 3.29% (n=79), 6.91% (n = 166) and 0.41% (n = 10) were respectively positive with immatures of *Ae. aegypti*, *Ae. albopictus*, and both species. Among the premises positive with *Aedes* immatures, 23.92% (n = 61) were also positive for *Aedes* pupae. The PHI for both species was quite similar, with *Ae. aegypti* at 0.16 and *Ae. albopictus* at 0.17, without significant difference ($W = 482.5$, $p = 0.78$). The PPI was 0.039 for *Ae. aegypti* and 0.041 for *Ae. albopictus*, also without significant difference ($W = 468.5$, $p = 0.93$).

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Analysis of Breeding habitats

Among the surveyed premises, a total of 1,480 potential breeding habitats were recorded (Table 01). Of these, 85.54% (n = 1,266) were identified as water holding (wet), and 21.55% (n = 319) were positive for *Aedes* immatures. Temporary removed items were the most available breeding habitat on the study site (IABH = 35.15), followed by discarded items (IABH = 16.59) (Table 01). However, the highest BPR for *Ae. aegypti* was recorded in tyre, while for *Ae. albopictus*, it was recorded in ornamental and natural items (Table 01).

Table 01 Recorded larval details according to type of breeding habitats

Breeding Habitat	No. of breeding habitats				Larval Indexes				
	Wet	Larvae positive			IABH	ICBH (A)	ICBH (B)	BPR (A)	BPR (B)
		A	B	AB					
Covering items	74	10	17	0	5.85	9.62	7.94	1.65	1.36
Discarded items	210	26	30	0	16.59	25.00	14.02	1.51	0.85
Gutters	13	2	3	0	1.03	1.92	1.40	1.87	1.37
Natural items	26	1	8	0	2.05	0.96	3.74	0.47	1.82
Ornamental items	65	9	20	0	5.13	8.65	9.35	1.69	1.82
Pet Feeding Containers	38	3	3	0	3.00	2.88	1.40	0.96	0.47
Refrigerators	32	0	2	0	2.53	0.00	0.93	0.00	0.37
Slabs	51	0	1	0	4.03	0.00	0.47	0.00	0.12
Temporary remove items	445	19	92	1	35.15	18.27	42.99	0.52	1.22
Tyre	94	18	11	0	7.42	17.31	5.14	2.33	0.69
Water Storage items	199	13	21	0	15.72	12.50	9.81	0.80	0.62
Other	19	3	6	1	1.50	2.88	2.80	1.92	1.87

A: Ae. aegypti B: Ae. albopictus AB: Both

Pupal abundance and species distribution

A total of 75 breeding habitats were positive with *Aedes* pupae. That is approximately 23.5% of breeding habitats with larvae were positive for pupae of both species. *Ae. aegypti* pupae were positive in 30 breeding habitats (40%), while *Ae. albopictu*s pupae were positive in 45 breeding habitats (60%). Mean pupal abundance for both species was more similar (*Ae. aegypti* = 5.01, *Ae. albopictus* = 5.33).

Factors associated with pupal productivity

Separate regression models were fitted for each species to identify both shared and species-specific risk factors. For Species A (n = 30 containers), a Quasi-Poisson model was used due to convergence issues with Negative Binomial regression (dispersion parameter = 1.977). For Species B (n = 45 containers), a Negative Binomial model was used (θ = 3.097, SE = 0.886).

The Quasi-Poisson regression model for *Ae. aegypti* explained 95.2% deviance (residual deviance = 25.76 on 13 df; null deviance = 538.44 on 29 df), indicating excellent model fit. The dispersion parameter (1.977) confirmed overdispersion in the data, justifying the use of Quasi-Poisson over standard Poisson regression. The Negative Binomial model for *Ae. albopictus* converged successfully (θ = 3.097, SE = 0.886) and explained 50.6% of the deviance (residual deviance = 43.37 on 28 df; null deviance = 87.88 on 44 df). The AIC value of 293.78 indicated reasonable model fit.

Relationship between breeding habitat types and pupal productivity

Certain types of breeding habitats were associated with the high productivity of *Ae. aegypti* pupae. Tyres produced the highest mean pupal count, followed by water storage items (Fig. 02a). According to the QPRM, tyres produced a significantly higher number of *Ae. aegypti* pupae compared with temporary removed items

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(IRR = 80.47, 9% CI: [7.71, 840.23], p = 0.004), indicating that tyre contained approximately 80 times more pupae than the Temporary Removed Items. In contrast, Ornamental Items (p = 0.072), Covering Items (p = 0.8660), Discarded items (p = 0.8335) and Water Storage Items (p = 0.1919) were not significantly associated with *Ae. aegypti* pupal productivity.

Aedes albopictus demonstrated a more even distribution across breeding habitats, with mean pupal counts ranging between approximately 5 and 12 pupae (Fig. 02a). Notably, NBRM revealed none of the breeding habitat types significantly influenced pupal productivity of *Ae. albopictus,* including Covering Items (p =0.3877), Discarded Items (p = 0.6786), Ornamental Items (p = 0.6024), Tyre (0.7147) and Water Storage Item (p = 0.474) compared to Temporary Removed Items.

Relationship between locations of breeding habitats and pupal productivity

The locations of breeding habitats also had a significant effect on pupal productivity of both species (Fig.02b). According to the QPRM for *Ae. aegypti*, indoor breeding habitats had significantly lower pupal counts than outdoor shady habitats (IRR = 0.122, 95% CI: [0.042, 0.354], p = 0.002), indicating an 87.8% reduction in pupal productivity. Similarly, outdoor open habitats had significantly fewer pupae than outdoor shady habitats (IRR = 0.150, p = 0.0012), corresponding to an 85.0% reduction. According to the NBRM for *Ae. albopictus*, indoor habitats were also associated with significantly lower pupal counts compared to outdoor open habitats (IRR = 0.135, 95% CI: [0.029, 0.627], p = 0.011), representing an 86.5% reduction.

Relationship between building materials of breeding habitat and pupal productivity

Building material showed limited influence on pupal productivity for both species (Fig. 02c). According to the QPRM, for *Ae. aegypti*, none of the building materials were significantly associated with pupal abundance compared to the plastic and polythene, including cement (IRR = 17.35, p = 0.107), metal (IRR = 2.03, p = 0.268), other materials (IRR = 0.91, p = 0.933), ceramic and clay (IRR = 0.88, p = 0.833), and rubber (IRR = 0.117, p = 0.066). Similarly, according to the NBRA model for *Ae. albopictus*, none of the building materials significantly influenced pupal productivity compared to plastic and polythene, including cement (IRR = 0.429, p = 0.278), ceramic and clay (IRR = 0.486, p = 0.118), metal (IRR = 1.434, p = 0.304), and other materials (IRR = 0.675, p = 0.530).

Relationship between water source of breeding habitat and pupal productivity

Water source was not significantly associated with pupal productivity for either species (Fig. 02d). *Ae. aegypti* showed no significant difference between tap water and rainwater-filled habitats (IRR = 0.876, p = 0.833), despite slightly higher mean pupal counts in tap water (14.8 vs 12.0). Similarly, *Ae. albopictus* showed a non-significant difference between tap water and rainwater-filled habitats (IRR = 0.561, p = 0.080).

Relationship between Water volume and pupal productivity

Water volume significantly influenced pupal productivity of both *Ae. aegypti and Ae. albopictus,* but in markedly different ways (Fig 02e). For *Ae. aegypti*, breeding habitats with medium water volumes had approximately 7.2 times higher counts (IRR = 7.17, 95% CI: [1.45, 35.40], p = 0.029) compared to those with very small water volumes. Similarly, breeding habitats with small water volumes yielded about 6.1 times more pupae (IRR = 6.12, 95% CI: [2.05, 18.23], p = 0.007) than very small water volumes. However, breeding habitats with large water volumes were not significantly associated with *Ae. aegypti* pupal productivity (p = 0.7569).

In contrast, *Ae. albopictus* showed a different pattern: very small water volumes were associated with a 54% reduction in pupal productivity compared to small water volumes (IRR = 0.46, 95% CI: [0.272, 0.779], p = 0.004). Notably, no significant associations were found between large (IRR = 1.36, p = 0.527) or medium (IRR = 1.33, p = 0.563) water volumes and *Ae. albopictus* productivity.

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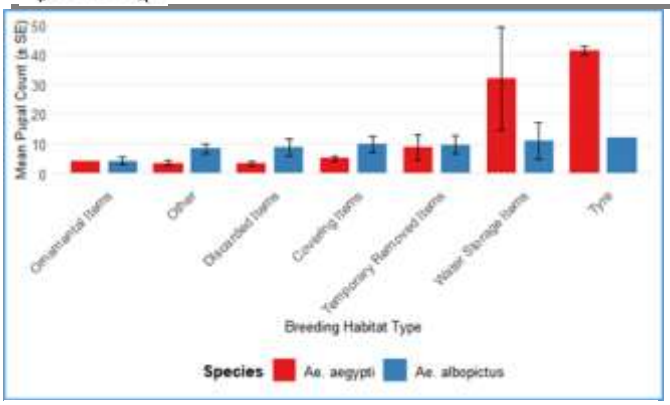

Fig 02a. Pupal abundance by breeding habitat type

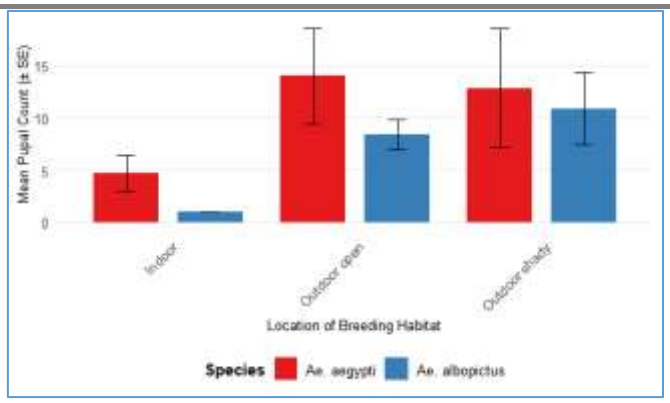

Fig 02b. Pupal abundance by location of breeding habitat

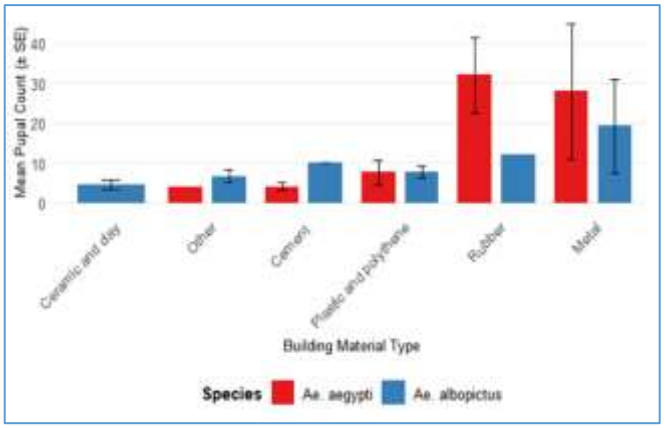

Fig 02c. Pupal abundance by building material of breeding habitat

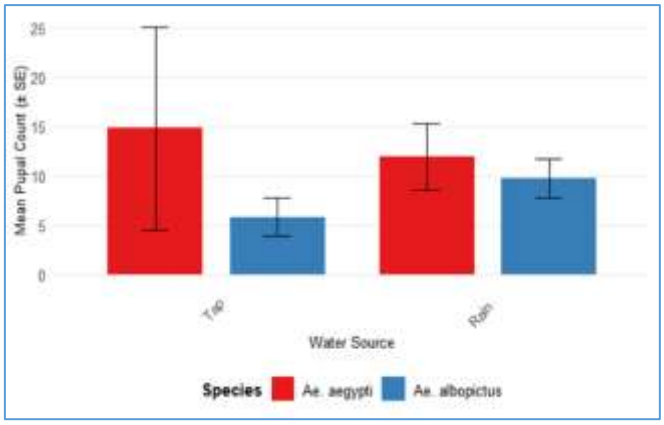

Fig 2d. Pupal abundance by water source in breeding habitat

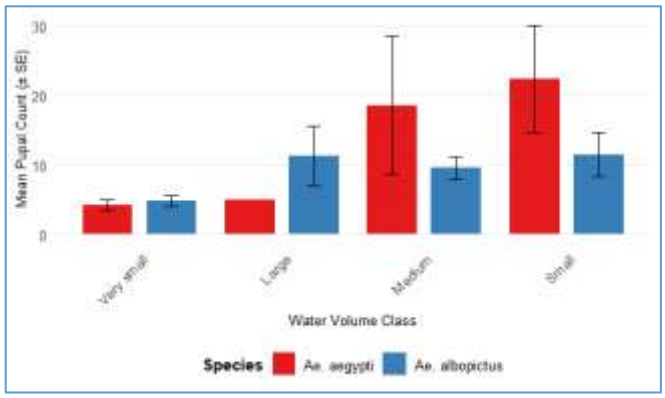

Fig 02e. Pupal abundance by water volume class

Fig 02 Variation of pupal production according to breeding habitats characteristics.

DISCUSSION

Even though positivity of *Ae. albopictus* significantly higher than *Ae. aegypti*, PHI was remarkably similar and statistically indistinguishable between the two species. This indicates that breeding habitats were positive for *Ae. aegypti* may contain more pupae on average, making them more efficient for mosquito production. Furthermore, the findings indicated that a significant proportion of infested households didn't facilitate the development of larvae into their adult stage. This is why pupal indices are considered a more direct measure of adult vector production and transmission risk than just measuring the container (Padonou et al., 2025). This type of study provides a valuable framework for prioritizing vector-control interventions, while also highlighting the limitations of data gathered from traditional Stegomyia larval surveys (Banerjee et al., 2015)

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The similarity in PPI indicates that the human population in this area experiences nearly equal biting pressure from both species. However, the highly anthropophilic, nervous, and discordant behavior of *Ae. aegypti* significantly increases the risk of disease transmission compared to *Ae. albopictus.* Conversely, it highlights that *Ae. albopictus* could have an equal or notably important secondary role in the dynamics of disease transmission (Paul et al., 2015). This emphasizes the need for control programs to actively incorporate this species into their strategies. Otherwise, the co-occurrence of *Ae. aegypti* and *Ae. albopictus* may increase arbovirus transmission (Padonou et al., 2025).

As previously well described, both *Aedes* species are container breeders and use various types of breeding habitats in different extend (Banerjee et al., 2015). The exploitation of certain type of breeding habitats is determined by different factors, leading to a major disparity between which habitats are commonly used (larval presence) and which are truly productive for generating adults (pupal presence).Such identification of the key container types should allow control efforts to be better focused and more cost-effective (Lenhart et al., 2006).

Pupal productivity differed in the larval habitats depending on several factors such as size, location, building materials, sun exposure, and water volume (Mwakutwaa et al., 2023). Due to significant variation in productivity of *Ae. aegypti* pupae across the surveyed breeding habitats indicates that not all positive habitat types contribute equally to pupal productions. Also *Ae. aegypti* exhibits strong selectivity and actively prefers a few key artificial breeding habitats especially tyre, which are not only commonly infested but are also extremely productive, making them high-value targets for control. This finding strongly supports the established concept of "key containers", where a small subset of artificial habitats produces the majority of pupae in a population. Tires are a well-recognized global "key container" for *Ae. aegypti,* reflecting its synanthropic behavior, thriving in man-made breeding habitats that are often neglected, durable, capable of retaining stagnant water and prone to accumulating organic debris (Getachew et al., 2015; Mwakutwaa et al., 2023). The dark colour of tyre enhance their heat retention capacity, which promotes rapid development of adults. Additionally, the shaded environment inside the tyre protects immatures from desiccation and predators. Recycling used tyres for dengue prevention has gained popularity globally in recent years (WHO, 2009). If recycling is not feasible, storage in a dry environment and proper disposal of used tyres should be encouraged.

In contrast to *Ae, aegypti*, the analysed results of *Ae. albopictus* indicate differences in the breeding preference and pupal productivity. While BPR was highest in natural and ornamental containers, pupal productivity demonstrated a more even distribution across breeding habitats without significant difference. This suggests that *Ae. albopictus* is a generalist, utilizing a wider range of breeding types without strong preferences.

This study finding shows that more than 97% of positive larval habitats and more than 90% of pupae-positive breeding habitats for both species are located outdoors, indicating predominant exophilic breeding behavior of these vectors (Arunachalam et al., 2010; Banerjee et al., 2015; Mwakutwaa et al., 2023). This challenge the well-known endophilic behaviour of *Ae. aegypti* and emphasizes the exophilic behavior of *Ae. albopictus*. According to findings, the control programme must be concentrated on outdoor focused source reduction. But it is crucial to address specific indoor breeding habitats for *Ae. aegypti*, as their neglect may result in a significant increase in infestation rates.

Building material showed limited influence on pupal productivity for both species, and water source was not significantly associated with pupal productivity for either species. These findings suggest that building material composition and source of water are less important than other ecological factors, such as habitat type, water volume and location, in determining pupal abundance for both species. Furthermore, lack of significant variation in pupal productivity based on water source for either species indicates that once a container is filled with water, regardless of its origin, it becomes a potential breeding site. This underscores the importance of managing container habitats themselves, rather than the water source, through covering, disposal, or regular emptying.

Another critical factor identified for pupal productivity was the water volume. Water volume significantly influenced pupal productivity of both *Ae. aegypti and Ae. albopictus,* but in markedly different ways. For *Ae. aegypti*, breeding habitats with medium and small water volumes had higher pupal productivity than very small water volumes. *But Ae. albopictus* showed higher productivity only in habitats with small water volumes compared to those with very small volumes. However, both species experienced a significant reduction in

productivity in habitats with very small water volumes, likely due to rapid drying or a lack of food resulting from high larval populations. Also, breeding habitats with large water volumes did not significantly correlate with pupal productivity in either species, possibly due to food scarcity for larval development

CONCLUSION

The Pupal Demographic Indexes clearly indicate that the human population in this area faces nearly equal biting pressure from both mosquito species. However, our analysis of breeding habitats shows that a significant proportion of positive breeding sites fails to support the development of larvae into the pupal stage. Thus, it can be concluded that traditional larval indices are inadequate for accurately predicting the risk of dengue transmission.

The highest BPR and pupal productivity for *Ae. aegypti* are found in tyre, highlighting strong selectivity on tyre as a key container type. Furthermore, the pupal productivity of *Ae. aegypti* is significantly enhanced by the volume of water in breeding habitats, with small and medium volumes leading to greater productivity than larger ones. Therefore, effective management of *Ae. aegypti* necessitates a strategic focus on removing key containers and managing small and medium artificial breeding habitats. In contrast, the observed variation in BPR and pupal productivity indicates that *Ae. albopictus* operates as an opportunistic generalist. This adaptability reduces its vulnerability to control measures targeting specific container types. Hence, a comprehensive community effort to eliminate outdoor breeding sources is crucial for effectively combating *Ae. albopictus*. Ultimately, public health messaging must be strategically designed to directly address the productive breeding habits of both species to effectively reduce overall vector density and mitigate the risk of dengue transmission.

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ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VIII August 2026

Annex 01: Details of containers except Refrigerators, Gutters, Slabs and Tyre (L: Larvae, P: Pupae, a: Ae. aegypti positive, b: Ae. albopictus positive, c: both positive

Covering Items Lc, Pc	Discarded items Lc, Pc	Temporary removed items Lc, Pc	Natura Items Lc,Pb	Ornamental Items Lc, Pc	Water Storage Items Lc, Pc	Pet Feeding Containers Lc,Pa	Others
Carpets	Buckets	Barrels	Bamboo stumps	Fish tanks	Barrels	Basins	Block drains
Covering sheets	Coconut shells	Basins	Fallen leaves	Flower pots	Buckets	Cups	Cement floors
Polythene sheets	Cooking wares	Boats	Leaf Axils	Flower vases	Tanks	Dishes	Cement holes
Rexene sheets	Cups	Boxes	Tree holes	Ponds		Pots	Earth pipes
	Flower Vases	Buckets					Non used commodes
	Ice cream containers	Cans					Tube wells
	Pots	Chairs					Wells
	PVC pipes	Commodes					
	Televisions	Cooking wares					
	Tins	Flower Vases					
	Toys	Kettles					
	Trays	Mortars					
	Vehicle parts	Plates					
	Washing machine parts	Pots					
		Roof tiles					
		Shoe racks					
		Sinks					
		Toys					
Refrigerators Lb,P0							
Gutters Lc,P0							
Slabs LbPb							
Tyre Lc, Pc							