

Determinants of dengue prevalence: Aedes density and environmental factors in Johor, Malaysia

Azwani Alias¹, Siti Norliyana Harun^{2*}, Nur Azalina Suzianti Feisal³, Mohd Khairudin Abd Razak¹, Noorashikin Md Noor⁴, Wee Hin Boo²

^{1*} Faculty of Allied Health Sciences, City University Malaysia (Cyberjaya Campus), 3500, Jalan Teknokrat 3, Cyber 4, 63000 Cyberjaya, Selangor, Malaysia

² Centre for Tropical Climate Change System, Institute of Climate Change, The National University of Malaysia, 43600 Bangi, Selangor, Malaysia.

³ Department of Diagnostic and Allied Health Science, Faculty of Health and Life Sciences, Management and Science University, 40150 Shah Alam, Selangor, Malaysia.

⁴ Earth Observation Centre, Institute of Climate Change, The National University of Malaysia, 43600 Bangi, Selangor, Malaysia.

ARTICLE INFO

Article history:

Received 07 Maret 2025

Accepted 05 April 2025

Published 2 May 2025

Keyword:

Climate Action
Climate Change
Environmental Health
Public Health
Vector-Borne Diseases

*) corresponding author

Dr. Siti Norliyana Harun
Centre for Tropical Climate Change
System, Institute of Climate Change,
The National University of Malaysia,
43600 Bangi, Selangor, Malaysia.

Email: sitinorliyana@ukm.edu.my

DOI: 10.47679/makein.2025233

ABSTRACT

Dengue is a common tropical disease transmitted by mosquitoes, influenced by factors like rainfall, temperature, and urbanization. This study explores how these factors affect Aedes mosquito distribution and dengue transmission in suburban and rural areas of Kluang district, Johor. Weekly ovitrap surveys took place at 20 sites over four weeks, with traps collected and replaced every seven days. Temperature and humidity were recorded three times daily to assess their relationship with mosquito populations. The results show significantly higher Aedes populations and dengue incidence in the suburban area (Taman Sri Kluang) compared to the rural area (Kampung Palembang). Higher temperatures and lower humidity were linked to increased mosquito abundance and dengue prevalence. Statistical analysis using R version 4.4.3 confirmed significant differences in Aedes density and environmental conditions between the areas. These findings emphasize the need for targeted vector control, climate-adaptive health strategies, and enhanced dengue surveillance in high-risk regions. Interventions should include intensified vector control in suburban areas, such as frequent larvicidal treatments and improved drainage. In rural areas, pre-emptive source reduction before rainy seasons and promoting covered water storage can help reduce mosquito breeding. Additionally, climate-based early warning systems should be integrated into vector surveillance to predict and mitigate dengue outbreaks effectively. Community engagement through education campaigns and neighborhood clean-ups should be prioritized for sustained dengue prevention. These findings improve understanding of climate variability's impact on mosquito populations, highlighting the importance of integrating environmental monitoring into dengue prevention programs. Future research should explore climate change's long-term effects on dengue transmission dynamics.

This open access article is under the [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.



Kata kunci:

Tindakan Iklim
Perubahan Iklim
Kesehatan Persekitaran
Kesehatan Awam
Penyakit Bawaan Vektor

ABSTRAK

Demam berdarah adalah penyakit tropis umum yang ditularkan oleh nyamuk, dipengaruhi oleh faktor-faktor seperti curah hujan, suhu, dan urbanisasi. Penelitian ini mengeksplorasi bagaimana faktor-faktor tersebut memengaruhi distribusi nyamuk Aedes dan penularan demam berdarah di daerah pinggiran kota dan pedesaan di distrik Kluang, Johor. Survei ovitrap mingguan dilakukan di 20 lokasi selama empat minggu, dengan perangkap dikumpulkan dan diganti setiap tujuh hari. Suhu dan kelembapan dicatat tiga kali sehari untuk menilai hubungannya dengan populasi nyamuk. Hasilnya menunjukkan populasi Aedes

dan insiden demam berdarah yang secara signifikan lebih tinggi di daerah pinggiran kota (Taman Sri Kluang) dibandingkan dengan daerah pedesaan (Kampung Palembang). Suhu yang lebih tinggi dan kelembapan yang lebih rendah terkait dengan peningkatan kelimpahan nyamuk dan prevalensi demam berdarah. Analisis statistik menggunakan R versi 4.4.3 mengonfirmasi perbedaan signifikan dalam kepadatan Aedes dan kondisi lingkungan antara daerah tersebut. Temuan ini menekankan perlunya pengendalian vektor yang ditargetkan, strategi kesehatan adaptif iklim, dan peningkatan pengawasan demam berdarah di wilayah berisiko tinggi. Intervensi harus mencakup pengendalian vektor yang intensif di daerah pinggiran kota, seperti perlakuan larvasida yang sering dan perbaikan drainase. Di daerah pedesaan, pengurangan sumber daya sebelum musim hujan dan promosi penyimpanan air tertutup dapat membantu mengurangi perkembangbiakan nyamuk. Selain itu, sistem peringatan dini berbasis iklim harus diintegrasikan ke dalam pengawasan vektor untuk memprediksi dan mengurangi wabah demam berdarah secara efektif. Keterlibatan masyarakat melalui kampanye pendidikan dan pembersihan lingkungan harus diprioritaskan untuk pencegahan demam berdarah yang berkelanjutan. Temuan ini meningkatkan pemahaman tentang dampak variabilitas iklim pada populasi nyamuk, menyoroti pentingnya integrasi pemantauan lingkungan ke dalam program pencegahan demam berdarah. Penelitian di masa depan harus mengeksplorasi efek jangka panjang perubahan iklim pada dinamika penularan demam berdarah.



This open access article is under the [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.

INTRODUCTION

Dengue fever is a viral disease transmitted by mosquitoes, primarily by *Aedes aegypti* and *Aedes albopictus*. Dengue fever continues to pose a considerable public health challenge, especially in tropical and subtropical areas. According to Krishna et al. 2024, there are approximately 380 million dengue infections globally, with 100 million cases exhibiting clinical characteristics annually, affecting 129 countries. The World Health Organisation (WHO) reported over 7.6 million dengue cases worldwide as of April 30, 2024. This figure includes approximately 3.4 million laboratory-confirmed infections, over 16,000 severe cases, and over 3,000 associated fatalities. The increasing burden of dengue is driven by climate change, urbanization, and inadequate vector control efforts.

Urbanization is one of the most critical drivers of dengue transmission. According to WHO (2017), urbanization will contribute to the rise of vector-borne diseases and exacerbate the spread of existing ones, particularly those transmitted by *Aedes* mosquitoes. This is due to the rapid expansion of urban areas creates ideal breeding conditions for *Aedes* mosquitoes by providing abundant artificial water storage containers, which serve as breeding sites. Additionally, the issue is further exacerbated by improper waste disposal, inadequate drainage systems, and construction activities, which enable mosquitoes to breed continuously in stagnant water collections. Moreover, the urban heat island effect, which accelerates mosquito development and viral replication within the vector, is a contributing factor to the elevated temperatures that urban areas typically experience (Lahondère & Bonizzoni, 2022). This condition is exacerbated by socio-economic factors, climate variability, and inadequate vector control measures, leading to increased transmission rates, particularly in densely populated areas.

Malaysia is grappling with a significant dengue epidemic due to its tropical climate and high population density, and rapid urbanization. Between 2015 and 2021, over 600,000 cases and 1,200 fatalities were reported

(Yenamandra et al. 2024; Kolimenakis, 2021). Despite the implementation of vector control measures such as the Destruction of Disease-Carrying Insects Act 1975 (APSP-1975), dengue cases continue to rise. Historically, Malaysia has faced persistent dengue outbreak dating back to the 1970s (Malaysia Ministry of Health, 2015). While early interventions were largely managed by local and state authorities, the escalating epidemic necessitates a more comprehensive approach (Guad et al. 2021; Bhatia et al, 2022). As of August 2024, approximately 100,158 dengue cases, with 88 deaths, were reported in Malaysia, with Selangor, Johor and Wilayah Persekutuan bearing the highest burden (Figure 1) (Malaysia Ministry of Health, 2024). The country's diverse geography, rapid urbanization, and the impact of climate change have exacerbated the problem by creating ideal breeding conditions for the *Aedes* mosquito.

At the district level, dengue prevalence shows substantial environmental variation. Based on the 2019 Annual Report from the Kluang District Health Office, the urban area of Taman Sri Kluang recorded eight dengue cases, while the rural area of Kampung Palembang reported only one case throughout epidemiological weeks 1 to 52. These contrasting cases reflect significant differences in environmental, demographic, and environmental factors between the two locations. Previous studies further reinforce the impact of environmental factors on dengue transmission as shown in Table 1. Previous studies highlighted that temperature, humidity, rainfall and urbanization are factors in mosquito density and dengue prevalence. For instance, Silva & Bastos (2025), and Lima-Camara (2024) have identified temperature, rainfall, and humidity as key drivers of mosquito abundance and dengue prevalence, especially under the influence of climate anomalies and socioeconomic vulnerabilities. The findings from Abdullah et al., (2025) shown that the significance of temperature and humidity by demonstrating that higher temperatures and lower humidity levels increase mosquito abundance, while vegetation cover contributes to microclimatic conditions affecting the *Aedes* distribution. Studies from Sajib et al., (2024) and Dutra et al., (2024)

highlighted how urbanisation and temperature affect infection rates and mosquito proliferation. Although these studies demonstrate a basic understanding of environmental factors influencing dengue transmission, many focus on macro-scale urban vs. rural comparisons, paying little

attention to localised microclimatic changes within smaller geographic areas. Furthermore, few studies explicitly compare mosquito density and environmental characteristics among physiologically distinct areas within the same district.

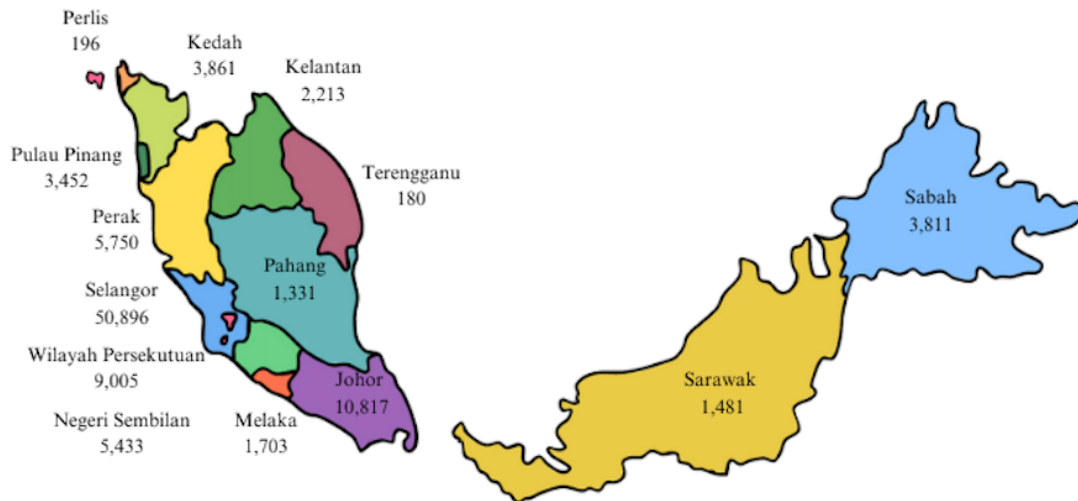


Figure 1. Number of dengue fever cases reported in Malaysia up to September 2024 (Source: i-Dengue official website MOH 2024)

Table 1 Summary of previous studies on *Aedes* mosquito density, environmental factors, and dengue prevalence

Author	Findings
Silva & Bastos (2025)	<i>Aedes</i> density and environmental factors, such as temperature, rainfall, and humidity, significantly influence dengue prevalence. Urbanization and socio-economic vulnerabilities exacerbate mosquito breeding habitats, while climatic changes, like those associated with El Niño, further amplify transmission dynamics in affected areas.
Abdullah et al., (2025)	<i>Aedes</i> density and environmental factors, such as temperature, humidity, and vegetation cover, significantly influence dengue prevalence. Higher temperatures and lower humidity correlate with increased mosquito abundance, while greater vegetation cover contributes to microclimatic conditions affecting <i>Aedes</i> distribution and dengue risk.
Sajib et al., (2024)	The mean temperature and urbanization positively impact dengue infection rates, while maximum temperature, precipitation, and population density negatively influence them. <i>Aedes</i> density was not specifically addressed, but environmental factors play a crucial role in dengue prevalence.
Dutra et al., (2024)	The urban environments significantly increase <i>Aedes aegypti</i> larval densities, which, combined with factors like temperature, influence adult traits and dengue virus loads, ultimately enhancing dengue transmission potential in urban settings.
Lima-Camara (2024)	<i>Aedes aegypti</i> mosquito density and environmental factors, such as temperature and rainfall, significantly influence dengue prevalence. Increased temperatures and rainy periods enhance mosquito populations, while socioeconomic conditions also affect disease incidence, highlighting the multifactorial nature of dengue outbreaks.

Therefore, this study aims to investigate the relationship between environmental factors, specifically temperature and humidity, and *Aedes* mosquito populations in two environmentally diverse sites within Kluang district, Johor: Taman Sri Kluang (suburban) and Kampung Palembang (rural). These study areas were selected based on their contrasting environmental and demographic characteristics. Taman Sri Kluang represents a densely populated suburban setting with a high incidence of dengue cases. In contrast, Kampung Palembang is a rural area with lower population density, greater vegetation cover, and fewer urban structures that facilitate mosquito breeding. Comparing these two locations allows for a deeper analysis of how temperature, humidity, and urbanization influence *Aedes* mosquito density and dengue transmission. This study involves weekly ovitrap surveys and the monitoring of environmental conditions over a four-week period to identify the main factors influencing dengue prevalence in suburban and rural areas. The findings will inform the development of targeted mosquito control strategies, enhance public awareness, and support public health efforts to reduce dengue burden. Ultimately, this study contributes to a deeper understanding of dengue epidemiology and provides actionable insights for improved disease prevention and control.

METHOD

Description of Study Sites

Johor covers an area of 2079.95 km² and is between 1°25' N to 1°42' N and 103°21' E to 104°00' E (Figure 2). The tropical climate of the study region is characterized by consistently high average daily temperatures, ranging from 21°C to 32°C, with a mean annual temperature of 26°C. Additionally, the region experiences persistently high average daily humidity levels, exceeding 80%, and receives an annual rainfall of approximately 2,500 millimetres. The climate of

Johor is influenced by two distinct monsoonal wind patterns. The northeast monsoon prevails from October to February, while the southwest monsoon dominates from May to September (Wong et al. 2016). While Selangor and Kuala Lumpur report the highest number of dengue cases, Johor follows closely behind. Despite this, Johor has received relatively less research attention compared to the other two states. A cross-sectional study was conducted in Taman Sri

Kluang and Kampung Palembang, Johor, Malaysia. The two study areas, Taman Sri Kluang (suburban area) and Kampung Palembang (rural area) of Kluang district were selected based on their distinct dengue case rates and differing environmental conditions that are more conducive to the proliferation of *Aedes albopictus* or *Aedes aegypti* mosquitoes.

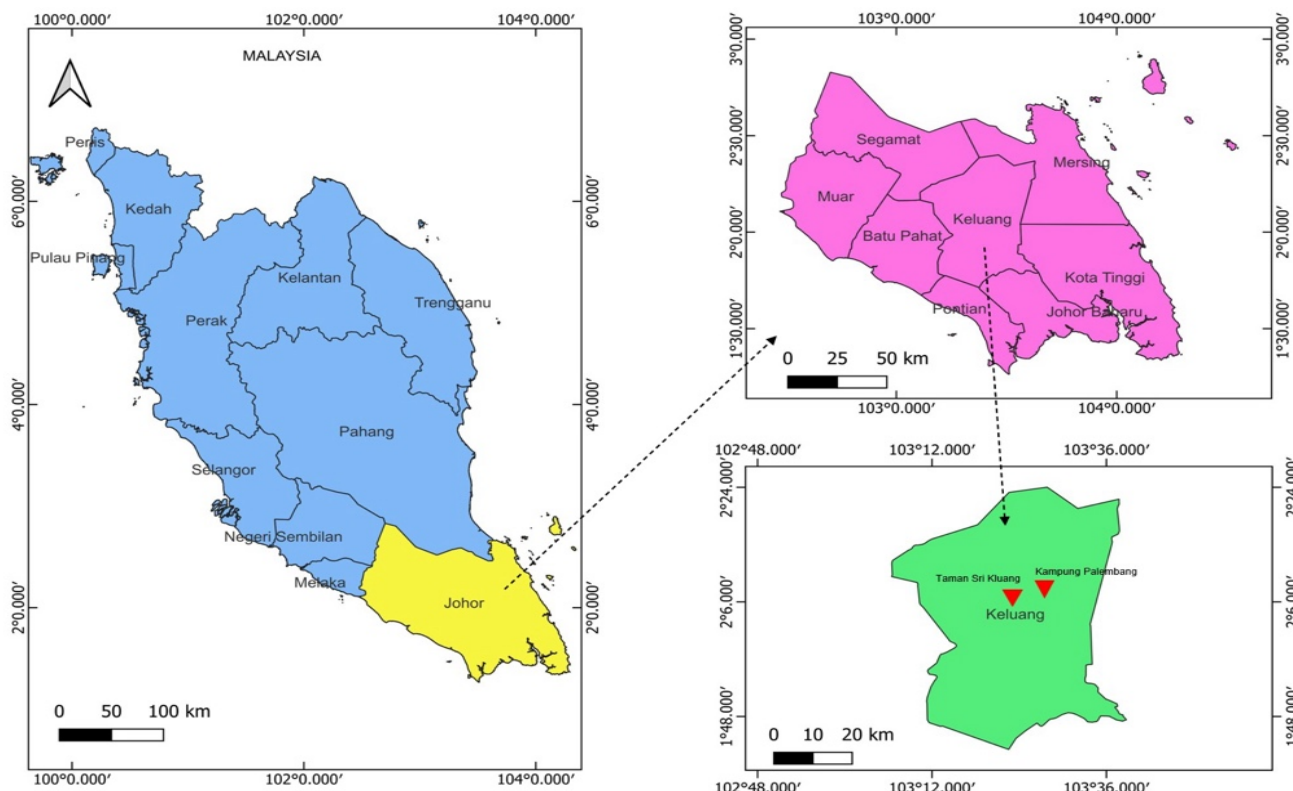


Figure 2. Map of study areas in Johor, Malaysia

Ovitrap Surveillance

Ovitrap surveys were conducted at the housing areas weekly for 4 weeks following the Ministry of Health (MOH) guidelines. An ovitrap, cylindrical, consists of a black plastic container, 10.6 cm in diameter and 13.5 cm in height. The inner ovitraps were placed with oviposition paddles (10 cm x 2.5 cm x 0.3 cm), with two-thirds of the ovitrap filled with substrate and clean tap water as a female *Aedes* oviposition site. Within each study area, 20 ovitraps were strategically positioned at intervals of 200 meters and 400 meters from the selected households. Each ovitrap was assigned a serial number and house address to facilitate data collection and management. The ovitraps were retrieved after seven days of deployment for four weeks in designated areas.

Temperature and Relative Humidity

This study investigated the descriptive relationship between temperature, relative humidity, and *Aedes* mosquito populations. The temperature and relative humidity were measured using portable digital hygrometers and thermometers (Model: HTC-2; Accuracy: ±1°C for temperature, ±5% RH for humidity; Range: -10°C to 50°C for temperature, 10% to 99% RH for humidity). To assess

microclimatic conditions, instruments were positioned centrally within each study area, mounted 1.5 meters above ground level and shielded from direct sunlight and precipitation to reduce environmental bias. Temperatures and humidity readings were collected three times daily (6:00 AM, 2:00 PM, and 7:00 PM) over four weeks. Daily average values were then calculated for both areas.

Control of External Interventions

Throughout the observation period, local health authorities refrained from utilising pesticides or conducting fogging operations at both study areas. The residents also were requested to disclose their domestic mosquito control methods usage, such as aerosol pesticides, mosquito coils, and larvicides. Although these were documented and assessed as potential confounding variables in interpreting the results, they exerted no influence over these personal behaviours.

Data Analysis

Descriptive statistical analyses of *Aedes* larvae collection and environmental parameters (relative humidity and temperature) were conducted. The analysis were conducted

using R version 4.4.3. The Ovitrap Index (OI) was calculated using the following formula:

$$\text{Ovitrap Index (OI)} = \frac{\text{Number of positive ovitraps with eggs}}{\text{Number of ovitrap deployed}} \times 100\%$$

The Shapiro-Wilk test was applied to assess the continuous data variables distribution such as larvae count, temperature, and humidity. The test showed that all data were non-normally distributed ($p < 0.001$), non-parametric tests were used for further analysis. The Mann-Whitney U test was performed to compare *Aedes* mosquito density, temperature, and humidity between the suburban and rural areas. This test is a robust non-parametric alternative to the independent samples t-test and is suitable for comparing differences in central tendency between two independent groups when data do not meet parametric assumptions. Additionally, a Spearman correlation test was conducted to evaluate the relationship between mosquito density and environmental factors. Unlike Pearson's correlation, Spearman's method does not require linearity or normal distribution and is ideal for detecting monotonic associations between ranked variables in ecological data. The Chi-Square test was applied to determine the significance of associations between environmental conditions and *Aedes* mosquito prevalence. This test is appropriate for evaluating non-parametric associations between two or more categorical variables, allowing for the identification of statistically significant relationships in surveillance data.

Ethical Considerations

This study adhered to ethical research guidelines, ensuring that all mosquito collection procedures followed environmental safety protocols. No human subjects were involved, and all methodologies complied with vector surveillance regulations set by the Ministry of Health Malaysia.

RESULTS OF STUDY

Manual counts have been used to determine the ovitrap index (OI) by calculating the mean number of eggs found in each ovitrap. The OI ranged from 60% to 95% in both areas, the highest in week four in suburban and week three in rural areas (Table 2). Over four weeks, 1,583 *Aedes* mosquito eggs were collected in Taman Sri Kluang (suburban) and in Kampung Palembang (rural). The highest number of eggs was recorded in the third week for both areas: 439 in Taman Sri Kluang and 283 in Kampung Palembang, whereas the lowest

was in the week second with 365 in Taman Sri Kluang and 112 in Kampung Palembang. The earlier peak in Kampung Palembang are due to the short-term environmental changes such as rainfall events that temporarily create suitable breeding conditions. On the other hands, the delayed peak in Taman Sri Kluang reflects more stable and persistent breeding environments, often associated with artificial water-holding containers and human-modified structures. Hence, this indicates that mosquito populations in suburban areas could have longer breeding cycles, hence gradually increasing population density. These dynamics emphasize the need for different timing strategies in mosquito control efforts between urban and rural areas.

Earlier validation of normality distribution of continuous data for larvae count, temperature and relative humidity found all data were non-normally distributed (Shapiro-Wilk: $p < 0.001$). Thus, non-parametric tests were utilized for the statistical analyses conducted among and between groups. The mean number of larvae per ovitraps in suburban areas exhibited a range of 18.25 ± 12.15 to 21.95 ± 12.59 . In contrast, rural areas displayed a lower range, with a minimum of 5.65 ± 6.02 and a peak of 14.15 ± 5.06 observed in the third week of the study. A Mann-Whitney test was conducted to compare the mean number of *Aedes* larvae per ovitrap between suburban and rural areas. The results indicated a statistically significant difference ($U = 1482.50$, $z = -3.92$, $p < 0.001$), with suburban areas exhibiting a higher (mean rank = 101.97, $n = 80$) compared to rural areas (mean rank = 59.03, $n = 80$). The study showed a significant correlation between ovitrap index (OI) and the mean number of larvae per ovitrap of both Taman Sri Kluang (suburban) and Kampung Palembang (rural) ($r = 0.236$, $p < 0.05$) (Figure 3).

Figure 3 illustrates the ovitrap index and mean number of larvae collected in suburban and rural areas across four consecutive weeks. The ovitrap index, a measure of mosquito breeding activity, shows a slightly increasing trend in both areas, peaking in week 3. Interestingly, while the ovitrap index suggests a higher breeding activity in the rural area during week 3, the mean number of larvae collected was higher in the suburban area. This discrepancy may indicate differences in larval survival or dispersal rates between the two locations. Overall, the figure highlights the dynamic nature of mosquito breeding activity across different environments and emphasizes the importance of continuous monitoring to understand temporal and spatial variations in mosquito populations. This study demonstrates that ovitraps continue to be a valuable tool for monitoring the abundance of container-breeding mosquitoes like *Aedes aegypti* and *Aedes albopictus*. The findings indicate that ovitraps are more effective than traditional larval surveys in collecting these mosquitoes.

Table 2 Ovitrap index and mean number of *Aedes* larvae per ovitrap for two different locations for four weeks of continuous surveillance

Collection week	Ovitrap Index (%)		Mean number \pm SD (Median) larvae per ovitrap		Mann-Witney U
	Suburban area	Rural area	Suburban area	Rural area	
Week 1	70.00	60.00	18.40 ± 13.18 (23.50)	8.80 ± 8.13 (8.50)	$U = 1482.50$
Week 2	75.00	50.00	18.25 ± 12.15 (21.00)	5.65 ± 6.02 (4.00)	$Z = -5.92$
Week 3	80.00	95.00	21.95 ± 12.59 (25.50)	14.15 ± 5.06 (14.00)	$p < 0.001$
Week 4	85.00	70.00	20.55 ± 11.74 (24.50)	11.45 ± 8.13 (14.00)	

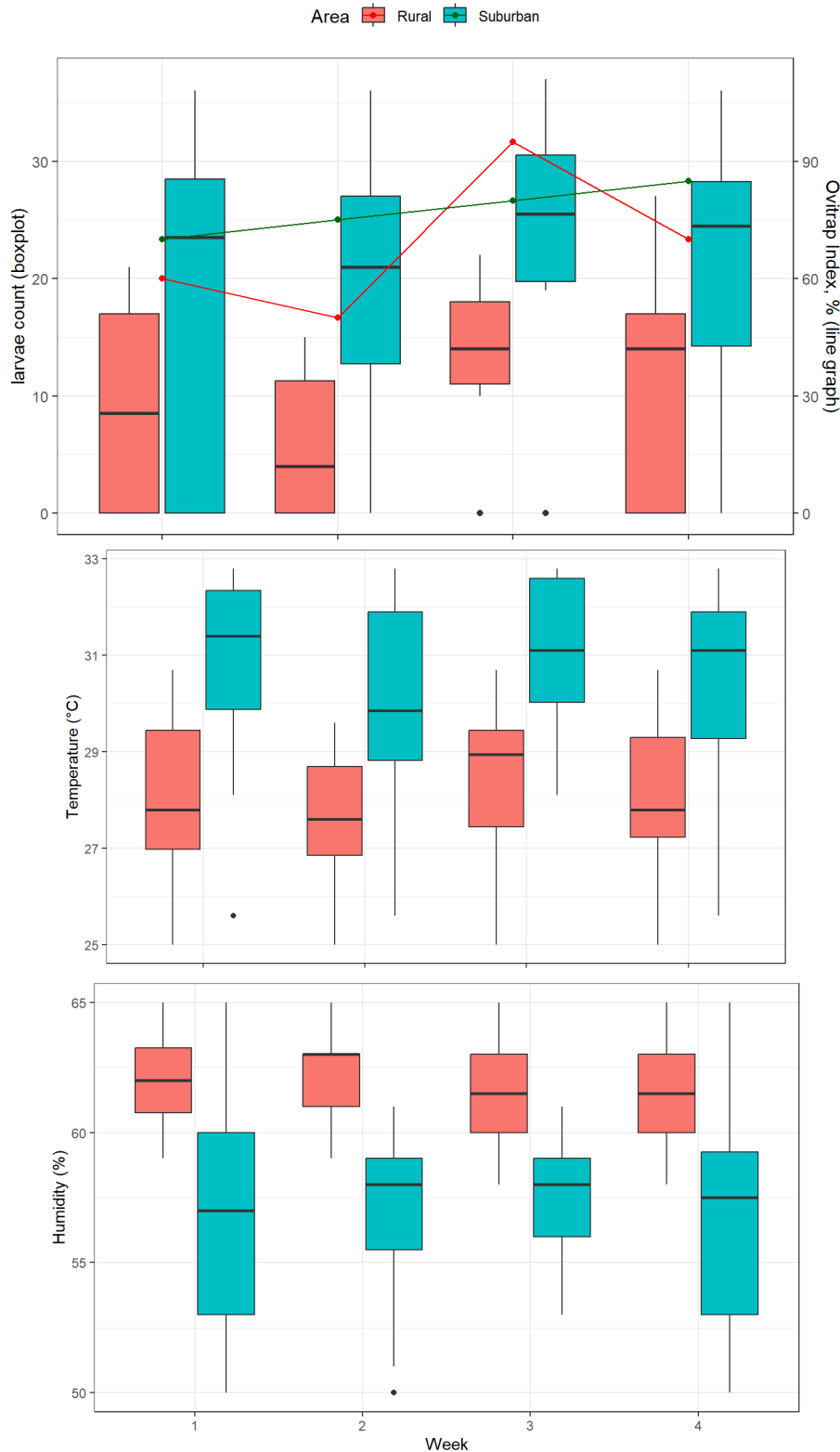


Figure 3. Boxplot representing the weekly larvae count (top), temperature (middle), and humidity (bottom) based on Areas: Rural (Red), Suburban (Green). The line graph represents the Ovitrap Index (%).

Table 2 presents the mean, standard deviation, and median of temperature and relative humidity collected in suburban and rural areas across four collection weeks. Statistically significant differences ($p < 0.001$) between the two environments were observed in temperature and relative humidity. Suburban areas (Overall = 30.67 ± 1.85 °C) consistently exhibited higher temperatures than rural areas

(28.08 ± 1.48 °C), while rural areas generally had higher relative humidity (Suburban = $56.76 \pm 3.61\%$; Rural = $61.89 \pm 1.82\%$). These microclimatic variations could have significant implications for mosquito abundance and distribution. Warmer temperatures in suburban settings may favor mosquito development and survival, potentially leading to higher populations. Furthermore, the differences in

temperature and humidity could influence the distribution of different mosquito species, with some species potentially thriving in warmer, drier suburban conditions compared to cooler, more humid rural areas. These findings underscore the importance of considering microclimatic factors when investigating mosquito ecology and the transmission of mosquito-borne diseases.

Temperature and Humidity Differences

Table 3 presents the mean, standard deviation, and median of temperature and relative humidity collected in suburban and rural areas across four collection weeks. Statistically significant differences ($p < 0.001$) between the two environments were observed in temperature and relative humidity. Suburban areas (Overall = 30.67 ± 1.85 °C) consistently exhibited higher temperatures than rural areas (28.08 ± 1.48 °C), while rural areas generally had higher relative humidity (Suburban = $56.76 \pm 3.61\%$; Rural = $61.89 \pm 1.82\%$). These microclimatic variations could have significant implications for mosquito abundance and distribution.

Temperature and humidity data (Tables 4 and 5) further confirm that Taman Sri Kluang (suburban) consistently had higher average temperatures (ranging from 30.06 °C to 31.03 °C) compared to Kampung Palembang (rural) (27.70 °C to 28.49 °C). Conversely, Kampung Palembang exhibited higher average humidity levels (ranging from 61.65% to 62.20%) compared to Taman Sri Kluang (ranging from 54.85% to 57.00%).

The differences in microclimatic conditions between suburban and rural areas observed in this study may have important implications for mosquito control strategies. In suburban areas, where consistently higher temperatures and lower humidity levels are paired with persistent artificial breeding sites, continuous mosquito proliferation is supported. This suggests a need for year-round control interventions. Meanwhile, the rural area's higher humidity and lower temperature conditions appear to influence more temporally concentrated mosquito breeding, likely tied to rainfall patterns. These findings suggest that mosquito control in rural areas may be more effective when timed seasonally, aligned with environmental fluctuations such as rainfall events.

Table 3 Comparison of Temperature and Relative Humidity between Suburban and Rural Areas

Collection week	Mean \pm SD (Median) of temperature		t-statistic (df)	p-value
	Suburban area	Rural area		
Week 1	30.99 ± 1.89 (31.40)	28.09 ± 1.59 (27.80)	9.782 (158)	<0.001*
Week 2	30.06 ± 2.13 (29.85)	27.70 ± 1.18 (27.60)		
Week 3	31.03 ± 1.48 (31.10)	28.49 ± 1.48 (28.95)		
Week 4	30.59 ± 1.90 (31.10)	28.04 ± 1.48 (27.80)		
Overall	30.67 ± 1.85 (31.10)	28.08 ± 1.48 (28.00)		

Collection week	Mean \pm SD (Median) of relative humidity		t-statistic (df)	p-value
	Suburban area	Rural area		
Week 1	56.45 ± 4.28 (57.00)	62.00 ± 1.71 (62.00)	-11.33 (158)	<0.001*
Week 2	57.00 ± 3.27 (58.00)	62.2 ± 1.66 (63.00)		
Week 3	54.85 ± 12.33 (58.00)	61.65 ± 1.54 (61.50)		
Week 4	56.50 ± 4.15 (57.50)	61.70 ± 2.18 (61.50)		
Overall	56.76 ± 3.61 (58.00)	61.89 ± 1.82 (62.00)		

Correlation Analysis

Non-parametric Spearman correlation (Figure 4) was conducted to observe the relationship between temperature, relative humidity and larvae counts for the overall data and separated within the areas. Overall, there were significant moderate negative correlation between humidity with temperature ($r_s = -0.423$, $p < 0.001$) and larvae count ($r_s = -0.324$, $p < 0.001$). While, high relative humidity showed positive correlation with larvae count ($r_s = 0.313$, $p < 0.001$). However, no significant correlation relationship was observed when the tests were conducted individually for Taman Palembang (Rural: $r_s < |0.124|$, $p > 0.05$), and Taman Sri Kluang (Suburban: $r_s = |0.071|$, $p > 0.05$). This showed that the moderate correlations relationship of temperature, relative humidity and larvae counts were mainly due to the discrepancy of the locations.

This inconsistency indicates that humidity has a significant impact on the abundance of larvae, but its impact is highly context dependent. The artificial containers significantly influence mosquito reproduction in suburban areas due to the consistent water source. In contrast, rural areas are more reliant on natural water sources, which are

more susceptible to environmental changes and fluctuate with rainfall. In rural areas, increased humidity may suggest that there has been recent rainfall, which could result in the formation of new reproductive habitats or the removal of larvae from existing ones. Furthermore, the larval survival rate may be diminished as a result of the potential for microbial growth to be facilitated by the increase in humidity.

Meanwhile, the higher temperatures in Taman Sri Kluang could enhance mosquito activity and breeding, as *Aedes* mosquitoes are known to thrive in warmer conditions (Lahondère and Bonizzoni, 2022). Conversely, the higher humidity in Kampung Palembang, while still within the suitable range for mosquito breeding, might not be as optimal as the conditions in Taman Sri Kluang.

Statistical Tests

The Mann-Whitney U test indicated significant differences in *Aedes albopictus* density, temperature, and relative humidity between the two study areas, with $p < 0.001$ for all variables (Table 4). Similarly, the Chi-Square test results (Table 5) confirmed a significant relationship between temperature, humidity, and *Aedes* larvae density ($p < 0.001$).

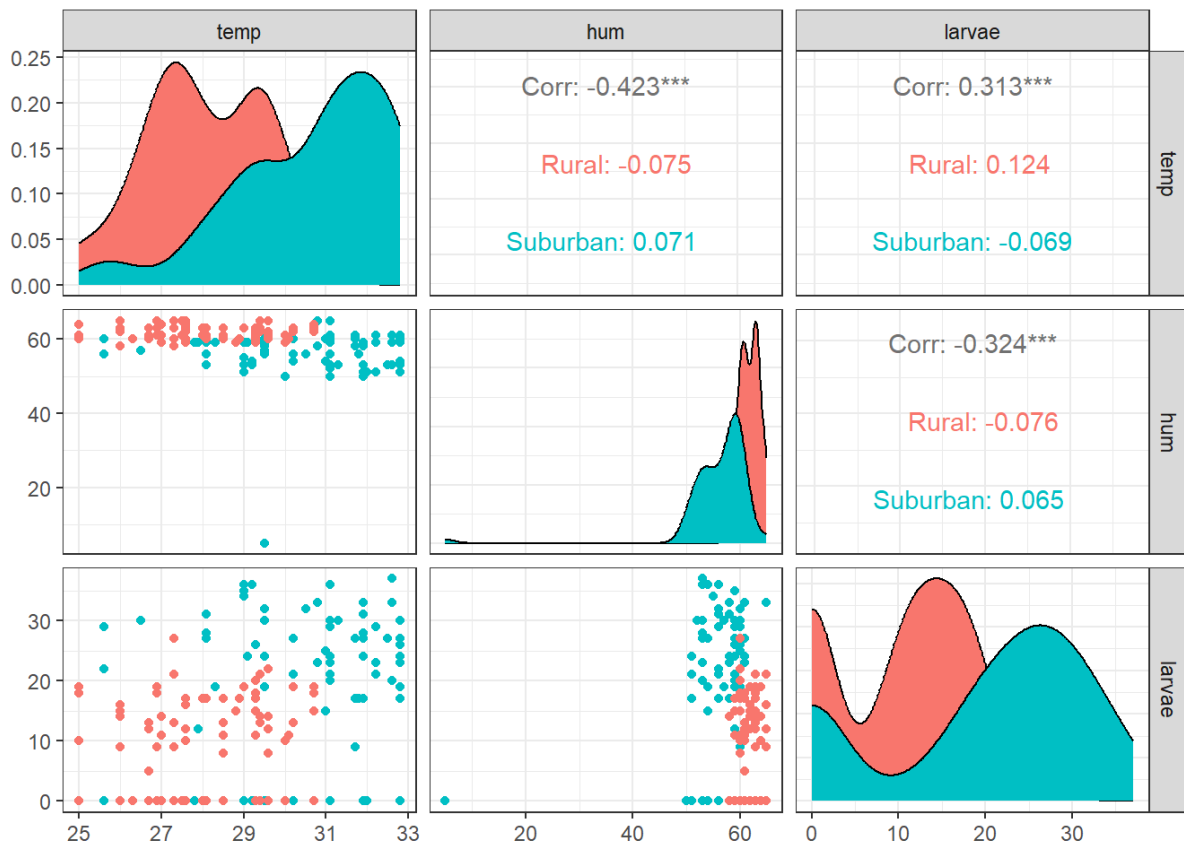


Figure 4. Correlations test (Spearman) between Temperature (temp), Humidity (hum), and Larvae count for Overall (grey), Rural (Red), Suburban (Green).

Table 4. Mann-Whitney U test for temperature, relative humidity and number of larvae

Null Hypothesis	Test	Sig.	Decision
There is no difference in the density of <i>Aedes albopictus</i> , temperature and relative humidity of the population in the study area.	Independent-Samples Mann-Whitney U Test	0.001	Reject the null hypothesis
There is no difference in the prevalence of dengue fever cases in the study area.	Independent-Samples Mann-Whitney U Test	0.001	Reject the null hypothesis

Chi-Square Test for Relationship Between Variables

The Chi-Square test results (Table 5) further affirm the significant relationship between temperature, humidity, and *Aedes* larvae density, with all p-values at 0.001. This strong correlation supports the hypothesis that higher temperatures and lower humidity levels in Taman Sri Kluang contribute to greater *Aedes* mosquito density and, consequently, a higher rate of dengue fever cases. These findings align with previous studies that have documented the impact of climatic factors on mosquito vector populations and dengue transmission dynamics (Vaidya & Wang 2021; Nguyen et al. 2020; Lee et al. 2018).

Table 5 Chi-Square test for temperature, relative humidity and number of larvae

	X ²	Df	P
Temperature °C	138.921 ^a	42	0.001
Air Humidity (%)	108.414 ^a	41	0.001
Number of Larva	75.162 ^a	3	0.001

DISCUSSIONS

Moisquito Density and Breeding Patterns

The findings indicate that *Aedes* mosquito density was significantly higher in suburban areas than in rural areas, suggesting that urbanization and human activities contribute to increased mosquito breeding. The peak ovitrap index (OI) in week four in suburban areas and week three in rural areas may reflect differences in environmental conditions and human-related factors that influence mosquito breeding. This pattern aligns with studies by Amusuk et al. (2024) and Bedoya-Rodriguez et al. (2022), which highlight the role of urban structures, artificial water containers, and waste accumulation in sustaining high mosquito populations.

Interestingly, while the ovitrap index in rural areas was higher in week three, the actual number of larvae collected was consistently higher in suburban areas. This discrepancy suggests that although mosquitoes laid more eggs in rural areas during that period, larval survival rates were higher in suburban areas. This could be due to differences in predation, water quality, or availability of stagnant water bodies, which

require further investigation. Additionally, the relatively lower larvae count in rural areas could be attributed to greater vegetation cover, which may support natural mosquito predators, reducing larval survival rates.

The difference in peak ovitrap activity between the two areas may also highlight differences in breeding habitat stability. In Kampung Palembang, the breeding environment may be more dependent on temporary natural water sources, which fluctuate with rainfall and evaporate quickly. This could result in a brief but intense breeding window, as seen in the sharp rise and fall of OI in week three. In contrast, the delayed peak in Taman Sri Kluang indicate that a more sustained breeding environment resulted from human-made water containers and infrastructure that consistently hold water, independent of rainfall. These consistent breeding conditions could let mosquito populations in suburban areas expand slowly and survive over longer periods. From a public health perspective, the results shown that mosquito control measures should be timed differently in each location, aiming rural areas early, just before expected breeding surges, and assuring constant intervention in suburban areas where breeding is more persistent.

Impact of Temperature and Humidity on Mosquito Density

The results confirm a strong positive correlation between temperature and mosquito density, supporting previous findings that higher temperatures accelerate mosquito development and increase their reproductive rates (Lahondère & Bonizzoni, 2022; Liu, et al, 2023; Akinsulie & Idris, 2024). The suburban area, which consistently exhibited higher temperatures (30.67 ± 1.85 °C) compared to rural areas (28.08 ± 1.48 °C), recorded a higher *Aedes* mosquito density, reinforcing the hypothesis that warmer temperatures provide optimal conditions for mosquito proliferation.

Conversely, the negative correlation between humidity and larvae count suggests that while humidity is essential for mosquito survival, excessively high humidity may limit mosquito activity. The higher relative humidity in rural areas ($61.89 \pm 1.82\%$) compared to suburban areas ($56.76 \pm 3.61\%$) may have created less favourable conditions for mosquito breeding, possibly due to increased fungal growth, changes in larval development rates, or higher water evaporation rates in urban settings (Vaidya & Wang, 2021; Gottero et al, 2023; Hasan & Nair, 2014). However, when analysed separately, no significant correlation was observed between temperature, humidity, and larvae counts in individual locations, indicating that the interaction between these environmental factors is complex and location dependent.

These findings emphasize that mosquito control strategies should be adapted to reflect microclimatic conditions specific to each location. In suburban areas, the combination of consistently higher temperatures and stable artificial breeding sites supports year-round mosquito activity. This necessitates continuous control measures, including regular larviciding, source reduction, and sustained public awareness campaigns. In contrast, rural areas experience more variable breeding conditions tied to rainfall and humidity fluctuations. Therefore, control strategies in rural settings should be timed strategically around seasonal rainfall patterns, focusing on intensive interventions during periods of peak humidity. Tailoring mosquito control efforts to local microclimates can enhance the efficiency and impact of dengue prevention programs.

Implication for Public Health and Dengue Control

The significant association between higher mosquito density, temperature, and dengue prevalence underscores the urgent need for targeted public health interventions. Given that suburban areas exhibited higher *Aedes* mosquito densities, vector control programs should prioritize high-risk urbanized regions where mosquito breeding is more prevalent. This includes:

1. Eliminating artificial breeding sites (e.g., water containers, clogged drains, and construction sites)
2. Implementing routine larvicidal treatments in areas with high ovitrap index values
3. Strengthening community engagement through awareness campaigns on mosquito control measures

Furthermore, integrating climate monitoring into dengue surveillance programs could enhance early outbreak detection. Since temperature and humidity are key factors influencing mosquito population dynamics, real-time environmental monitoring could be used to predict and preemptively mitigate potential dengue outbreaks. This aligns with Tahir et al. (2023) and Hussain-Alkhateeb et al. (2021), who advocate for data-driven vector surveillance systems to improve public health preparedness.

Strategic Solutions for Dengue Control: Targeted Actions and Future Directions

Based on the findings from this study, several actionable recommendations are proposed to mitigate dengue fever outbreaks and enhance public health responses in the affected areas. First, there is a pressing need for enhanced vector control programs. The data highlights significant differences in *Aedes* larvae density and dengue case rates between Taman Sri Kluang and Kampung Palembang. Intensifying vector control efforts in areas with higher larval counts, such as Taman Sri Kluang, is critical. This can be achieved through regular inspections and treatments of potential breeding sites, as well as community-based initiatives to educate residents about eliminating standing water and other mosquito breeding habitats (Amusuk et al. 2024; Bedoya-Rodriguez et al. 2022). Second, the study underscores the importance of monitoring environmental conditions, specifically temperature and humidity, which are known to influence dengue transmission. Implementing a climate and vector surveillance system can help anticipate outbreaks and enable timely interventions (Tahir et al. 2023; Pley et al. 2021; Hussain-Alkhateeb et al. 2021). Regular monitoring will allow for better prediction of dengue risk and facilitate proactive measures to address potential outbreaks before they escalate (Mani et al. 2021; Sim & Lindsay 2020; Soni et al. 2023).

Public awareness campaigns also play a crucial role in dengue prevention. Increasing community knowledge about protective measures, such as the use of repellents, protective clothing, and mosquito nets, can significantly reduce human-mosquito contact (Phuyal et al. 2022; Thongsripong et al. 2021). Educational initiatives should emphasize the importance of personal protection and active community involvement in reducing mosquito breeding sites. Strengthening health infrastructure is another key recommendation. Enhancing healthcare facilities and resources for early diagnosis and treatment of dengue cases can reduce morbidity and mortality rates (Ali & Mat Deli, 2024); Sood et al. 2023). This includes providing training for healthcare workers on the latest management protocols and ensuring the availability of necessary diagnostic tools and medications. In light of the potential impacts of climate change on dengue transmission, integrating climate adaptation strategies into dengue prevention programs is

essential. Developing and implementing policies that address the health impacts of climate change, such as the increased risk of vector-borne diseases, will be crucial in managing future outbreaks. Finally, further research is needed to explore the complex interactions between climate change, environmental factors, and mosquito biology. Understanding these interactions will help in developing more effective control measures and adapting strategies to changing climatic conditions.

CONCLUSIONS

This study provides valuable insights into the environmental and vector-related determinants of dengue prevalence, focusing on the influence of *Aedes* mosquito density, temperature, and humidity in two contrasting ecological areas in Johor, Malaysia. The findings highlight that suburban areas, characterized by higher temperatures and lower humidity levels, exhibit a significantly greater density of *Aedes* mosquitoes and higher dengue incidence compared to rural areas.

The observed differences in peak mosquito activity between urban and rural areas emphasize the need for adaptive and spatially targeted control strategies. Suburban zones require sustained year-round vector control, while rural interventions may be most effective when timed with environmental changes, particularly rainfall. Statistical analyses confirmed strong associations between environmental variables and mosquito abundance, supporting the integration of climate-informed surveillance into public health strategies. In addition, community engagement and health education are essential components of successful dengue prevention, especially in high-risk areas.

Future research should explore long-term climate variability and its implications for dengue transmission dynamics. Investigating additional ecological and socio-economic factors could further refine predictive models for dengue outbreaks. Ultimately, a multidisciplinary approach that combines environmental monitoring, public health interventions, and climate adaptation strategies is essential to effectively manage and reduce the burden of dengue in Malaysia and similar region.

Acknowledgments

The authors would like to thank the Faculty of Allied Health Sciences (FOAHS), City University Malaysia and Institute of Climate Change, The National University of Malaysia, for their support and resources to facilitate this research.

DECLARATION

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of Data and Material (ADM)

Not applicable

Competing interests

Not applicable

Funding

No applicable

Authors' contributions

First Author (Azwan Alias): Conceptualization, supervision, methodology, and manuscript review.

Second Author (Siti Norliyana Harun): Conceptualization, review and editing of the manuscript.

Third Author (Nur Azalina Suzianti Feisal): Data analysis, statistical interpretation, and manuscript review

Fourth Author (Mohd Khairudin Abd Razak): Field study coordination, data collection, data analysis and manuscript drafting.

Fifth Author (Noorashikin Md Noor): Data analysis and manuscript review.

Sixth Author (Wee Hin Boo): Data analysis, data curation and manuscript review.

REFERENCES

- Abdullah, N. A. M. H., Dom, N. C., Salleh, S. A., Dapari, R., & Precha, N. (2025). Dengue's climate conundrum: How vegetation and temperature shape mosquito populations and disease outbreaks. *BMC Public Health*, *25*(1), 4. <https://doi.org/10.1186/s12889-024-21105-4>
- Akinsulie, O. C., & Idris, I. (2024). Global re-emergence of dengue fever: The need for a rapid response and surveillance. *The Microbe*, *4*, 100107. <https://doi.org/10.1016/j.microb.2024.100107>
- Amusuk, D. J., Hashim, M., & Pour, A. B. (2024). Reclamation of mining sites to eradicate mosquito breeding in semiarid environments: An overview. *Journal of Environmental Engineering Critical Challenges*, *3*(1), 104. <https://doi.org/10.33790/jeecc1100104>
- Bedoya-Rodriguez, F. J., Guevara-Fletcher, C. E., & Vera-Lizcano, O. (2022). Identification, ecological indices, and management of mosquitoes (Diptera: Culicidae) influencing environmental education processes in Colombian high schools. *International Journal of Tropical Insect Science*, *42*(2), 1401–1420. <https://doi.org/10.1007/s42690-021-00657-7>
- Bhatia, S., Bansal, D., Patil, S., Pandya, S., Ilyas, Q. M., & Imran, S. (2022). A retrospective study of climate change affecting dengue: evidences, challenges and future directions. *Frontiers in public health*, *10*, 884645. <https://doi.org/10.3389/fpubh.2022.884645>
- Dutra, H. L., Marshall, D. J., Comerford, B., McNulty, B. P., Diaz, A. M., Jones, M. J., & McGraw, E. A. (2024). Larval crowding enhances dengue virus loads in *Aedes aegypti*, a relationship that might increase transmission in urban environments. *PLoS Neglected Tropical Diseases*, *18*(9), e0012482. <https://doi.org/10.1371/journal.pntd.0012482>
- Gottero, E., Larcher, F., & Cassatella, C. (2023). Defining and regulating peri-urban areas through a landscape planning approach: The case study of the Turin metropolitan area

- (Italy). *Land*, 12(1), 217. <https://doi.org/10.3390/land12010217>
- Guad, R. M., Wu, Y. S., Aung, Y. N., Sekaran, S. D., Wilke, A. B. B., Low, W. Y., Sim, M. S., Carandang, R. R., Jeffree, M. S., Taherdoost, H., Sunggip, C., Lin, C. L. S., Murugaiah, C., Subramaniam, V., & Azizan, N. (2021). Different domains of dengue research in Malaysia: A systematic review and meta-analysis of questionnaire-based studies. *International Journal of Environmental Research and Public Health*, 18(9), 4474. <https://doi.org/10.3390/ijerph18094474>
- Hasan, A. R., & Nair, P. L. (2014). Urbanisation and growth of metropolitan centres in Malaysia. *Malaysian Journal of Economic Studies*, 51(1), 87–101. <https://doi.org/10.3316/informit.554433876393606>
- Hussain-Alkhateeb, L., Rivera Ramirez, T., Kroeger, A., Gozzer, E., & Runge-Ranzinger, S. (2021). Early warning systems (EWSs) for chikungunya, dengue, malaria, yellow fever, and Zika outbreaks: What is the evidence? A scoping review. *PLoS Neglected Tropical Diseases*, 15(9), e0009686. <https://doi.org/10.1371/journal.pntd.0009686>
- Kolimenakis, A., Heinz, S., Wilson, M. L., Winkler, V., Jakob, L., Michaelakis, A., Papachristos, D., & Richardson, C. (2021). The role of urbanisation in the spread of *Aedes* mosquitoes and the diseases they transmit—A systematic review. *PLoS Neglected Tropical Diseases*, 15(9), e0009631. <https://doi.org/10.1371/journal.pntd.0009631>
- Krishna, G., Sreedevi, S., & Thrimothi, D. (2024). Dengue virus infection: Etiology, epidemiology, pathogenesis, diagnosis, and prevention. In *Viral Infectious Diseases Annual Volume 2024*. IntechOpen.
- Lahondère, C., & Bonizzoni, M. (2022). Thermal biology of invasive *Aedes* mosquitoes in the context of climate change. *Current Opinion in Insect Science*, 51, 100920. <https://doi.org/10.1016/j.cois.2022.100920>
- Lee, H., Kim, J. E., Lee, S., & Lee, C. H. (2018). Potential effects of climate change on dengue transmission dynamics in Korea. *PLoS One*, 13(6), e0199205. <https://doi.org/10.1371/journal.pone.0199205>
- Li, C., Lu, Y., Liu, J., & Wu, X. (2018). Climate change and dengue fever transmission in China: Evidences and challenges. *Science of the Total Environment*, 622, 493–501. <https://doi.org/10.1016/j.scitotenv.2017.11.326>
- Lima-Camara, T. N. (2024). Dengue is a product of the environment: An approach to the impacts of the environment on the *Aedes aegypti* mosquito and disease cases. *Revista Brasileira de Epidemiologia*, 27, e240048. <https://doi.org/10.1590/1980-549720240048>
- 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. *Frontiers in Cellular and Infection Microbiology*, 13, 1242173. <https://doi.org/10.3389/fcimb.2023.1242173>
- Mani, S., Ghosh, S., Sharma, R., Ajith, A., & Prabhakaran, P. (2021). Controlling dengue, an urban pandemic—A case study of Delhi, India. In *Inoculating Cities* (pp. 1–19). Academic Press. <https://doi.org/10.1016/B978-0-12-820204-3.00001-2>
- Malaysia Ministry of Health. (2015). *Clinical practice guidelines: Management of dengue infection in adults*. <https://www.moh.gov.my>
- Mohd Makhbul, Z., Ali, M. H., & Mat Deli, M. (2024). *Artificial intelligence for advancing healthcare in Kuwait. Digital Transformation in Healthcare Management for Society 5.0*. Penerbit UKM: Bangi.
- Nguyen, L. T., Le, H. X., Nguyen, D. T., Ho, H. Q., & Chuang, T. W. (2020). Impact of climate variability and abundance of mosquitoes on dengue transmission in central Vietnam. *International Journal of Environmental Research and Public Health*, 17(7), 2453. <https://doi.org/10.3390/ijerph17072453>
- Phuyal, P., Kramer, I. M., Kuch, U., Magdeburg, A., Groneberg, D. A., Lamichhane Dhimal, M., Montag, D., Harapan, H., Wouters, E., Jha, A. K., & Dhimal, M. (2022). The knowledge, attitude, and practice of community people on dengue fever in Central Nepal: A cross-sectional study. *BMC Infectious Diseases*, 22(1), 454. <https://doi.org/10.1186/s12879-022-07404-4>
- Pley, C., Evans, M., Lowe, R., Montgomery, H., & Yacoub, S. (2021). Digital and technological innovation in vector-borne disease surveillance to predict, detect, and control climate-driven outbreaks. *The Lancet Planetary Health*, 5(10), e739–e745.
- Sajib, A. H., Akter, S., Saha, G., & Hossain, Z. (2024). Demographic-environmental effect on dengue outbreaks in 11 countries. *PLoS one*, 19(9), e0305854. <https://doi.org/10.1371/journal.pone.0305854>
- Sim, S., Ng, L. C., Lindsay, S. W., & Wilson, A. L. (2020). A greener vision for vector control: The example of the Singapore dengue control programme. *PLoS Neglected Tropical Diseases*, 14(8), e0008428. <https://doi.org/10.1371/journal.pntd.0008428>
- Sood, S. K., Sood, V., Mahajan, I., & Sahil. (2023). An intelligent healthcare system for predicting and preventing dengue virus infection. *Computing*, 105(3), 617–655. <https://doi.org/10.1007/s00607-020-00877-8>
- Soni, S., Gill, V. J. S., Anusheel, Singh, J., Chhabra, J., Gill, G. J. S., & Bakshi, R. (2023). Dengue, chikungunya, and Zika: The causes and threats of emerging and re-emerging arboviral diseases. *Cureus*, 15(7), e41717. <https://doi.org/10.7759/cureus.41717>
- Tahir, F., Madandola, M. G., & Al-Ghamdi, S. G. (2023). Enhancing resilience: Surveillance strategies for monitoring the spread of vector-borne diseases. *Sustainable Cities in a Changing Climate: Enhancing Urban Resilience*, 263–276. <https://doi.org/10.1002/9781394201532.ch16>
- Thongsripong, P., Hyman, J. M., Kapan, D. D., & Bennett, S. N. (2021). Human-mosquito contact: a missing link in our understanding of mosquito-borne disease transmission dynamics. *Annals of the Entomological Society of*

- America*, 114(4), 397-414.
<https://doi.org/10.1093/aesa/saab011>
- United Nations. (1997). *Glossary of environment statistics, studies in methods*. United Nations.
- Vaidya, N. K., & Wang, F. B. (2021). Persistence of mosquito vector and dengue: Impact of seasonal and diurnal temperature variations. *Discrete & Continuous Dynamical Systems-B*. <https://doi.org/10.3934/dcdsb.2021048>
- World Health Organization. (2017). *Global vector control response 2017–2030*.
- Wong, C. L., Liew, J., Yusop, Z., Ismail, T., Venneker, R., & Uhlenbrook, S. (2016). Rainfall characteristics and regionalization in Peninsular Malaysia based on a high-resolution gridded dataset. *Water*, 8(11), 500.
<https://doi.org/10.3390/w8110500>
- Yenamandra, S. P., et al. (2024). Molecular epidemiology of dengue in Malaysia: 2015–2021. *Frontiers in Genetics*, 15, 1368843. <https://doi.org/10.3389/fgene.2024.1368843>