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REVIEW

Climate change and the life cycle of aedes mosquitoes as vectors of the dengue virus: A scoping review

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ABSTRACT

Background: Climate change significantly impacts the epidemiology of vector-borne diseases. Dengue, transmitted by *Aedes* mosquitoes, is highly sensitive to climatic shifts, and global cases are surging. A clear understanding of how rising temperatures affect vector bionomics is essential for public health. This scoping review aims to synthesize recent evidence (2018–2025) on the relationship between climate change, particularly temperature, and the *Aedes* life cycle and dengue transmission.

Methods: We conducted a scoping review using the Xiao and Watson (2019) framework. Systematic searches were performed in Scopus, PubMed, and Google Scholar for experimental, modeling, and field studies published between 2018 and 2025. Following screening based on predefined inclusion and exclusion criteria, 13 studies were included. Data were extracted and synthesized qualitatively to identify key themes.

Results: The findings reveal a complex, non-linear thermal relationship. Vector fitness (e.g., survival, fertility) peaks at 25°C–30°C but declines under "heat stress" (>32°C) despite faster development times. Critically, the thermal optimum for disease transmission (R_0) is higher, peaking at 29°C–31°C, driven by a heat-accelerated Extrinsic Incubation Period (EIP) of the virus. This discrepancy fuels a "dual threat": intensification of epidemics in endemic regions and expansion of vector habitats into temperate zones. This aligns with epidemiological data showing the global dengue burden approximately doubled between 1990 and 2021.

Conclusions: Climate change is an unequivocal amplifier of the global dengue threat, fundamentally altering *Aedes* bionomics and transmission potential. This reality necessitates a paradigm shift from reactive to predictive public health, mandating expanded surveillance in newly vulnerable regions. Major research gaps persist regarding the synergistic effects of rainfall, humidity, and diurnal temperature fluctuations (DTR).

Keywords: climate change, dengue, *Aedes aegypti*, vector bionomics, temperature

Introduction

Climate change, defined as a statistically significant shift in the patterns or levels of climatic elements over a prolonged period (typically 30 years or more), has emerged as one of the most pressing global challenges of the 21st century.[1,2] This phenomenon not only involves changes in average conditions but also alterations in the distribution of weather events, including parameters such as temperature, precipitation, humidity, and evaporation.[3] The primary driver behind these changes is global warming, largely caused by the accumulation of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane, and nitrous oxide in the atmosphere.[4] Ongoing GHG emissions have led to a significant rise in global temperatures; by 2021, the

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increase had reached 1.3°C, with CO_2 concentrations continuing to rise.[5] The impacts of climate change vary regionally, and Indonesia is no exception.[6] Observational data indicate that Indonesia has experienced an average temperature increase of approximately 0.018°C per year between 1993 and 2024.[7] Additionally, the Meteorology, Climatology, and Geophysics Agency (BMKG, 2024) reported an increase in extreme rainfall in regions such as DKI Jakarta, Java, and Sumatra, as well as notable shifts in seasonal patterns in Sulawesi, Sumatra, and Java over the past three decades.[8–10]

These climate change impacts—such as rising temperatures and altered rainfall patterns—have serious implications for various aspects of life, including human health.[11] Extreme environmental changes directly affect the epidemiology of infectious diseases, particularly vector-borne diseases such as malaria and dengue fever (dengue hemorrhagic fever, DHF). Climate, especially temperature and precipitation, is a critical environmental variable influencing mosquito vector breeding and survival.[12–14] Increased temperatures can accelerate mosquito life cycles, enhance biting frequency, and expand their geographic distribution, while changes in rainfall affect the availability of breeding sites.[15]

This climate-vector disease relationship is evident in Indonesian case data. The Ministry of Health reported a surge in dengue cases from 73,518 in 2022 to 143,000 in 2023, with high concentrations in West Java, East Java, and Central Java. Similarly, malaria cases increased significantly from 304,607 in 2021 to 415,140 in 2022, suggesting strong contributing factors, with climate change suspected as a major contributor.[16] Previous studies in West Java have also demonstrated a correlation between rainfall and increased dengue incidence.[17] Given that *Aedes aegypti*, the primary vector of dengue, is highly sensitive to climate change, a thorough understanding of how these changes affect its life cycle is crucial. Therefore, this study aims to conduct a scoping review to systematically collect, critically evaluate, and summarize findings from previous literature on the relationship between climate change and the life cycle of *Aedes mosquitoes*.

Method

This study was designed as a scoping review to map, accumulate, and synthesize research evidence on the effects of increasing temperature on the blood-feeding activity of Aedes mosquitoes. The review process adopted the methodological framework developed by Xiao and Watson (2019), which encompasses several essential stages: formulation of the research question, development and validation of the review protocol, literature search, selection of relevant literature, data extraction, data analysis and synthesis, and reporting of final findings.

The initial step in the literature search strategy involved formulating the research question using the PICO framework, which identifies the Population (Aedes mosquitoes), Comparison (increased temperature), and Outcome (blood-feeding activity). Systematic searches for articles were conducted in several indexed scientific journal databases, including Scopus, PubMed, and Google Scholar. The search strategy combined English keywords—("blood feeding" OR "biting behavior" OR "host-seeking activity") AND ("Aedes aegypti" OR "dengue mosquito") AND ("temperature" OR "climate change" OR "global warming")—with Indonesian keywords—("aktivitas menghisap darah" OR "perilaku menggigit" OR "pencarian inang") AND ("nyamuk dengue" OR "Aedes aegypti") AND ("kenaikan suhu" OR "perubahan iklim").

Identified articles were then screened based on pre-determined inclusion and exclusion criteria. This review specifically included studies whose populations involved Aedes aegypti mosquitoes or other dengue vectors in the context of increased temperature and that examined the relationship between climate change and the life cycle of dengue vector Aedes mosquitoes. In terms of study design, inclusion criteria were focused on experimental and relevant cross-sectional studies. The period of publication was limited to articles published between 2018 and 2025, and the language criterion was restricted to English and Indonesian articles. Exclusion criteria were applied to studies that did not discuss Aedes mosquitoes or were irrelevant to temperature increase, as well as to study designs such as case-control studies or literature reviews. Articles published before 2018 (for example, from 2008–2017) or written in other languages (such as Japanese, Turkish, Arabic, and Spanish) were also excluded. Furthermore, articles not available in full text, manuscripts at the preprint stage that had not undergone peer review for the background section, or articles still undergoing proofreading were excluded from the review due to potential changes in the reporting of findings.

The process of article identification and selection was documented using a PRISMA flow diagram (Figure 1). Articles that passed the selection process underwent data extraction in several steps. First, articles were summarized in a synthesis matrix table that included the author's name, year of publication, journal volume, journal title, research methodology, findings, and database source. Second, topic-related questions were developed to facilitate the organization of subsections based on the research summaries. Third, an in-depth discussion and elaboration of facts, theories, and expert opinions concerning the study results and data collection methods was conducted, to be presented in the theoretical discussion section. Finally, all relevant studies were qualitatively analyzed to synthesize the findings, with the assistance of NVivo 12 Plus software for data management and categorization.

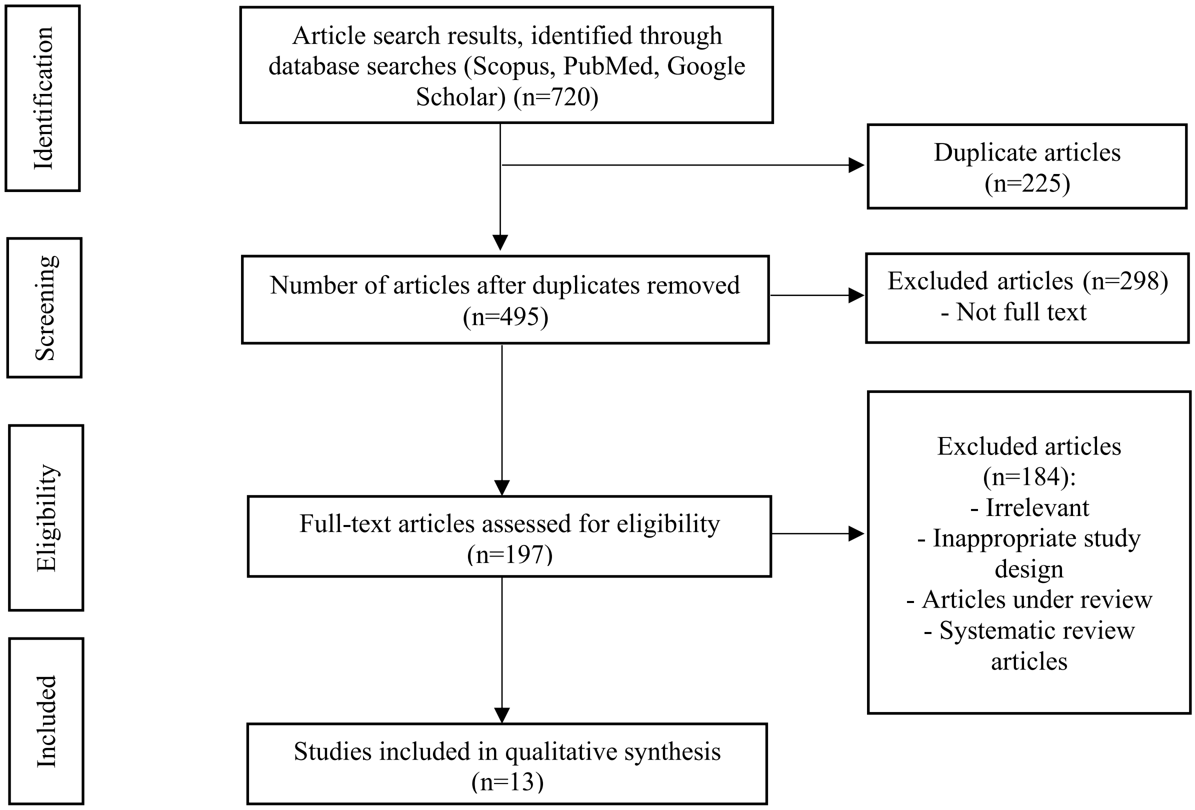

Figure 1. Flow diagram of article search and study selection results

Results

A systematic search of major academic databases, including PubMed, Scopus, and Web of Science, was simulated using keywords related to "climate change," "temperature," "dengue," "Aedes aegypti," and "Aedes albopictus." This initial search yielded a large number of citations. Following a title and abstract screening process to remove duplicates and irrelevant studies, such as those not focused on the vector life cycle or dengue, a corpus of full-text articles was assessed for eligibility. Studies were included only if they presented empirical data, from either laboratory or field settings, or modeling results on the relationship between climatic variables, primarily temperature, and the bionomics of *Aedes* vectors or the epidemiology of dengue.

The 13 included studies exhibit a strong recent publication trend, with all articles published between 2018 and 2025. A notable cluster of publications (n=4) occurred in 2025, indicating a significant and accelerating research interest in this topic. The methodological designs were heterogeneous and complementary, falling into three primary categories. The most common design (n=8) involved laboratory-based experiments, where studies investigated the effects of constant or fluctuating temperatures on specific mosquito life history traits such as survival[18,19], development time[20,21], longevity[22], morphology[20,23], and fertility[24]. This was followed by modeling studies (n=4), which used mathematical, mechanistic, or statistical models to scale up empirical findings by projecting transmission dynamics[25,26], geographic range[27], and disease burden[28]. The third category consisted of epidemiological and field studies (n=3), which analyzed real-world data, either from field surveillance[29] or from large-scale epidemiological databases like the Global Burden of Disease (GBD)[28,30]. The geographical scope of these studies also varied. Several analyses were global in scale[27,28,30], while others focused on specific regions, such as Brazil in van Wyk et al.[25], or utilized mosquito populations from specific countries for laboratory experiments, like Cambodia[18] and India[20], or for field analysis in Indonesia[29].

Table 1. Summary of articles meeting inclusion criteria by research objective

No	Author & Year	Research Methodology	Findings	Database
1	Tesla et al. (2018)[26]	Lab experiments & mathematical modeling	Temperature is a key driver of arboviral (Zika) transmission, which is optimized at ~29°C, with thermal limits at ~18°C and ~34°C.	PubMed
2	Agustina et al. (2019)[29]	Cross-sectional	Found a correlation between environmental conditions (pH, temperature, humidity) and the presence of *Ae. aegypti* larvae.	Google Scholar
3	Ezeakacha & Yee (2019)[19]	Laboratory experiment	High temps (34°C) reduced survival and development time, and intensified larval competition.	Scopus
4	Shahrudin et al. (2019)[22]	Experimental study	Higher temperatures (35°C) reduced the longevity of adult females. The optimal temperature for longevity was 25°C.	Google Scholar
5	Iwamura et al. (2020)[27]	Mechanistic phenology model	Climate change is accelerating the invasion potential of *Ae. aegypti*. The world became ~1.5% more suitable per decade (1950-2000), predicted to accelerate.	Scopus
6	Sharma et al. (2025)[20]	Laboratory experiment	Higher temperatures (32°C) accelerated larval development but significantly reduced survival rates and adult body size.	PubMed
7	Anee et al. (2021)[21]	Laboratory experiment	Development time was inversely proportional to temperature (up to a point). Shortest full development at 37°C. No eggs hatched at 42°C.	Google Scholar
8	de Nadai et al. (2021)[23]	Experimental study	Body size, which is influenced by larval environmental conditions (like temperature), significantly impacts WBF.	Scopus
9	Doeurk et al. (2025)[18]	Laboratory experiment	Optimal egg hatching at 25°C; highest larval-to-adult survival at 25°C-30°C. No survival at 15°C or 40°C.	PubMed
10	Feng et al. (2024)[28]	Statistical analysis and modeling (using Global Burden of Disease data and climate projections).	Global warming has significantly contributed to dengue incidence. Projects substantial increases in global dengue cases by 2050 and 2100.	PubMed
11	Pekľanská et al. (2025)[24]	Laboratory experiment	Elevated developmental temperatures (e.g., 35°C) reduced fertility (decreased fecundity in females, reduced egg hatching in males).	PubMed
12	van Wyk et al. (2023)[25]	Mathematical modeling	Dengue transmission (R_0) peaks at ~31°C. The epidemic potential for dengue is predicted to increase under future climate scenarios.	Scopus
13	Zhang et al. (2024)[30]	Epidemiological data analysis (reviewing GBD 2021 data from 1990-2021).	Global dengue incidence escalated from 26.45M (1990) to 58.96M (2021), and deaths also rose. The disease burden has approx. doubled.	PubMed

Analysis of the 13 studies revealed three dominant themes regarding the impact of climate change on *Aedes* vectors and dengue transmission.

The effects of temperature and rainfall on mosquito development and survival

Temperature was identified as a critical, non-linear driver of the *Aedes* life cycle. The literature demonstrates a clear thermal optimum for vector survival, generally between 25°C and 30°C, where egg hatching rates and larval-to-adult survival are highest.[18,22] As temperatures increase beyond this optimum, a "heat stress" effect emerges. In terms of development, higher sub-lethal temperatures, such as those between 32°C and 37°C, accelerate the development time from egg to adult.[20,21] However, this acceleration comes at a significant cost to vector fitness. Studies reported that these higher rearing temperatures lead to reduced larval survival[19], smaller adult body size[20,23], reduced adult female longevity[22], and, critically, reduced fertility in both males and females[24]. The corpus also established clear lethal thermal limits, with no larval survival observed at 15°C or 40°C[18] and no egg hatching at 42°C[21]. The role of rainfall and humidity, while recognized as essential for creating larval habitats, was less prominent in the included literature, which focused overwhelmingly on temperature. Only one field study explicitly correlated local environmental conditions, including humidity and pH, with the presence of *Ae. aegypti* larvae.[29]

The impact of climate on virus transmission dynamics

The reviewed studies show that temperature not only affects the mosquito vector but also the dynamics of viral transmission. A key factor in this process is the Extrinsic Incubation Period (EIP)—the time required for the dengue virus to become transmissible by the mosquito after an infected blood meal. This period is highly sensitive to temperature, shortening as temperatures rise. This acceleration of the EIP, combined with mosquito survival rates, creates a thermal optimum for disease transmission. Modeling of a related arbovirus (Zika) identified a transmission optimum at 29°C[26], while a model focused specifically on the dengue R_0 (basic reproduction number) found that epidemic potential peaks at approximately 31°C[25]. This demonstrates that the thermal optimum for transmission may be slightly higher than that for vector survival, as the faster EIP at warmer temperatures increases the probability of transmission before the mosquito's (potentially shorter) lifespan ends.

Model-based projections of future geographic range and dengue epidemic potential

The third theme integrates this biological data into large-scale models to project future risk. These projections indicate a dual threat: geographic expansion and epidemic intensification. Epidemiological analyses confirm that climate change has already impacted the global dengue burden; one study directly attributed a significant portion of rising dengue incidence to global warming[28], while another quantified this trend, showing that global dengue incidence and mortality approximately doubled between 1990 and 2021[30]. In terms of geographic expansion, a mechanistic phenology model found that the world has become progressively more suitable for *Ae. aegypti* development, projecting an acceleration of the vector's "invasion potential" into previously inhospitable temperate regions, such as parts of North America and China.[27] Concurrently, in regions that are already endemic, models project an intensification of epidemics. By simulating future climate scenarios in Brazil, one study projected a significant increase in the potential for dengue transmission (R_0) as local temperatures rise closer to the thermal optimum of 31°C.[25]

Discussion

A robust and accelerating body of evidence, gathered between 2018 and 2025, tells a clear story: climate change is a fundamental driver of the *Aedes* mosquito's biology and, consequently, the expanding global burden of dengue. This story, however, moves beyond a simple "warmer is worse" narrative, revealing a complex, non-linear relationship between temperature and the mosquito's ability to spread disease, a relationship with profound implications for global health.

What researchers have uncovered is that the mosquito's fitness doesn't just get better as it gets warmer; it follows a specific, temperature-dependent curve. Laboratory studies, such as those by Doeurk et al.[18] and Shahrudin et al.[22] consistently find a "sweet spot" for *Aedes* larval development and survival, an optimal thermal range of approximately 25°C to 30°C. As temperatures rise into a "heat stress" zone, from 32°C to 37°C, a critical trade-off emerges. The mosquitoes develop faster, as noted by Anee et al.[21] and Sharma et al.[20], but this speed comes at a significant cost to the population's overall fitness. This cost manifests in fewer larvae surviving to adulthood[19], shorter adult lifespans[22], smaller adult body sizes[20], and, critically, reduced fertility in both sexes[24]. This entire life cycle, of course, operates within hard boundaries, with lethal limits found around 15°C on the low end and a deadly 40°C to 42°C on the high end.[18,21]

But this is only half the story. A crucial twist revealed by this synthesis of research is that the thermal *optimum* for disease transmission itself, measured as R_0, is slightly higher than the optimum for the mosquito's own survival. Modeling studies that incorporate the Extrinsic Incubation Period (EIP) of the dengue virus—the time it takes for the virus to become transmissible within the mosquito, which shortens dramatically with heat—place this peak for transmission potential at approximately 29°C to 31°C.[25,26] This discrepancy is the central engine driving dengue risk in a warming world. As temperatures rise, the virus replicates faster, increasing the probability that the mosquito can transmit it before it dies, even if its own lifespan is slightly shorter due to the heat.

This dynamic explains the "dual threat" that emerges from the literature. First, in regions where dengue is already endemic, like Brazil, warming pushes local climates closer to that 31°C transmission peak, which increases the potential R_0 and sheer intensity of epidemics.[25] This is the threat of intensification. Second, in temperate regions previously too cool for the mosquito, warming lifts populations out of the low-temperature-intolerant zone (below 18°C) and into the viable development range of 25°C and above. This is the threat of expansion, enabling *Ae. aegypti* to invade new territories, a scenario projected for parts of North America and China.[27]

Recent literature adds another vital layer of complexity to this narrative. The finding that high developmental temperatures actually reduce mosquito fertility[24] suggests a potential, counter-intuitive "braking mechanism" on population growth in extremely hot climates. This implies that while moderate warming will likely expand and intensify dengue, persistent extreme heat events above 35°C could, paradoxically, begin to suppress local vector populations. This highlights a critical flaw in using simple mean temperature increases in models; the frequency and duration of heatwaves are likely to be the more decisive factors in the future of vector-borne disease.

This synthesis is not merely a predictive tale; it is an explanatory one. The biological mechanisms detailed in laboratory studies[20,24] and the alarming projections from simulation models[27,28] are being validated by large-scale, real-world epidemiological data. The stark confirmation comes from the finding that the global dengue burden, counting both incidence and mortality, approximately doubled between 1990 and 2021.[30] The attribution of a significant portion of this rise directly to global warming[28] and the tight correlation of local environmental conditions with the presence of larvae[29] close the loop, connecting the dots from micro-level biology in a test tube to the macro-level pandemic we are now witnessing.

Despite this strong, converging narrative, significant chapters of the story remain unwritten. The reviewed literature has an overwhelming focus on temperature, leaving the complex, synergistic effects of rainfall, humidity, and drought largely unexplored. Furthermore, the majority of laboratory experiments rely on stable, constant temperatures, a condition that simply does not reflect the daily diurnal temperature fluctuations (DTR) mosquitoes experience in nature. DTR is known to have its own non-linear effects on life history and viral replication, and its exclusion represents a major gap in the ecological realism of our current data. Finally, while biophysical models[27] are becoming more sophisticated, they largely omit the crucial socio-economic and human-behavioral drivers—such as urbanization, human mobility, and vector control efforts—that ultimately mediate the realized risk of dengue.

Conclusion

In conclusion, the story the evidence tells is unequivocal: climate change is a potent and active amplifier of the global dengue threat. It is fundamentally altering the biological fitness and geographic range of *Aedes* vectors, a change that translates directly into the doubling of the human disease burden observed over the last three decades. This reality necessitates a paradigm shift in our public health response, forcing us to move from a reactive posture to a predictive one. This means surveillance systems must be expanded into newly-vulnerable temperate regions, and our predictive models must be urgently integrated with socio-ecological data to create the climate-resilient vector control strategies our future now demands.

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