

Impact of Climate Change on Dengue Incidence: A Systematic Review of Evidence from Southeast Asia

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Abstract

The issue of climate change has been recognized as a significant global concern, with the potential to have a profound impact on public health outcomes worldwide. Southeast Asia is a region highly susceptible to an increase in dengue incidence, which is influenced by climatic factors such as rainfall and temperature. The present study aims to investigate the relationship between climate change and the incidence of dengue in Southeast Asia. This systematic review, conducted in accordance with the PRISMA guidelines, searched the Scopus, PubMed, ScienceDirect, and Emerald databases using relevant keywords. Inclusion criteria were observational studies from peer-reviewed journals published between 2004 and 2024 that reported dengue incidence and quantitative associations with climate exposures. Eighteen articles met the inclusion criteria after a screening process. The analysis revealed an association of the incidence of dengue with temperature and rainfall. The majority of studies have reported that rising temperatures are associated with an increase in dengue cases. The majority of studies have identified a positive association with the incidence of dengue and rainfall. Findings for humidity were more complex, with some studies showing a negative correlation and others a positive correlation. Results for wind speed were also inconsistent across studies. This review highlights the significant association between climatic factors, particularly temperature and rainfall, of dengue transmission in Southeast Asia. Rising temperatures and increased rainfall are strongly associated with higher dengue incidence, likely by creating favorable conditions for mosquito breeding and virus transmission. The results underscore the need to incorporate climate data into dengue early warning systems and vector control strategies in dengue-endemic regions.

Keywords

Climate change; dengue; Southeast Asia; temperature; rainfall

Introduction

Dengue, an acute infectious disease of global health importance, is transmitted through the bite of infected mosquitoes, principally of the species *Aedes aegypti*, and to a lesser extent, *Aedes albopictus*. Over the past sixty years, these mosquitoes have proliferated, now affecting over 50% of the global population (Messina et al., 2019). Recent decades have seen a marked increase in the incidence of dengue fever in numerous countries, particularly within the Southeast Asian region. The observed increase is attributed to demographic influences, specifically rapid urbanization and climate change. These factors exert a substantial impact on the ecology of vector mosquitoes and the propagation of the dengue virus (Liu-Helmersson et al., 2014; Ryan et al., 2019).

The cycle of life and geographic distribution of *Aedes* mosquitoes are directly influenced by the rise in global average temperatures caused by climate change (Kraemer et al., 2019). According to Mordecai et al. (2017), higher temperatures shorten the time required for mosquito larvae to mature into adults, accelerate virus replication in mosquitoes, and increase the likelihood of mosquitoes biting humans. Furthermore, standing water in both urban and rural regions is more likely to serve as a breeding ground for mosquitoes due to the increasing rainfall and humidity resulting from climate change (Keman et al., 2022).

Climate variability has a significant impact on dengue incidence across various regions. Several systematic reviews and meta-analyses have been conducted in Southeast Asia, including countries such as Malaysia (Abdullah et al., 2022), Indonesia (Marina et al., 2023), Vietnam (Linh Tran et al., 2023), Thailand (Thisyakorn et al., 2022), and the Philippines (Agrupis et al., 2019). These studies have highlighted the relationship between climatic variables, including temperature, rainfall, and humidity, and the incidence of dengue fever. In Malaysia, both temperature and precipitation have been demonstrated to have a significant impact on the transmission of dengue fever, with increased rainfall creating ideal breeding conditions for *Aedes* mosquitoes (Abdullah et al., 2022). In Vietnam, extreme temperature and rainfall variability have been found to significantly increase dengue cases, especially during the monsoon season (Linh Tran et al., 2023).

In Thailand, higher temperatures and rainfall during the warmer months have been consistently linked to a rise in dengue cases (Thisyakorn et al., 2022). Similarly, in the Philippines, temperature and rainfall were identified as key climatic factors contributing to the cyclical nature of dengue outbreaks (Agrupis et al., 2019). In Indonesia, studies indicated that rainfall, mean temperature, and relative humidity were the primary climatic factors influencing dengue incidence, with rainfall being particularly critical in creating mosquito breeding sites (Marina et al., 2023). The present findings highlight the pivotal role of climatic elements, particularly temperature and rainfall, in shaping seasonal and regional patterns of dengue transmission across Southeast Asia.

Additionally, studies have shown that temperature increases, especially minimum temperatures above 18°C, are strongly associated with an increase in dengue cases (Colón-González et al., 2021; Hii et al., 2009). Rainfall also plays a significant role, with moderate rainfall levels correlating with an increase in dengue cases (Khairunisa et al., 2018; Su, 2008). Sea surface temperature (SST) has been identified as a significant predictor, with each 1°C increase in SST corresponding to a 3.4 to 5.2-fold rise in dengue incidence (Méndez-Lázar et al., 2014). The effects of climate variables on dengue transmission often exhibit time lags,

typically ranging from several weeks (Hurtado-Díaz et al., 2007). While climatic elements are significant, non-climatic conditions, including vector surveillance, urbanization, and socioeconomic conditions, are equally crucial in the context of dengue transmission (Colón-González et al., 2023).

Non-climatic factors, including urbanization, population density, and socioeconomic disparities, have been demonstrated to have a significant impact on dengue transmission. Urbanization, in particular, leads to overcrowded environments with inadequate sanitation, which serve as ideal breeding grounds for mosquitoes. Poor access to healthcare and vector control programs in low-income communities exacerbates the problem, as these populations are less likely to receive timely diagnosis and treatment, thus rendering them susceptible to outbreaks (Aminuddin et al., 2025). Furthermore, migration patterns driven by climate events, such as flooding, heatwaves, or droughts, often result in the movement of populations to areas more vulnerable to dengue outbreaks, thereby increasing the spread of the virus to new regions. Land-use changes, such as deforestation and urban sprawl, are significant contributors to the proliferation of mosquito habitats. This has the potential to increase susceptibility to dengue transmission in both urban and rural contexts (Udayanga et al., 2018).

Previous systematic reviews have also emphasized how rapid and unplanned urban growth, particularly in high-density areas, creates conditions that facilitate *Aedes* mosquito reproduction, thereby increasing the potential for dengue outbreaks. The risk is exacerbated by socioeconomic vulnerabilities, such as low-income housing and inadequate sanitation, particularly in the context of emerging nations where public health facilities may be deficient (Kolimenakis et al., 2021). Further research has highlighted the pivotal role of urban heat islands in intensifying climate change impacts, thereby rendering urban regions more susceptible to dengue transmission due to elevated temperatures and increased mosquito population density (Fernando & Rajapaksha, 2023).

The findings thus obtained serve to highlight the complex relationship between climate and the transmission of dengue. While climatic factors significantly influence dengue incidence, the relationship is complex and varies by region. For example, although temperature increases generally raise dengue risk, extremely high temperatures can reduce mosquito survival, as observed in some studies (Bellone & Failloux, 2020). This complexity underscores the need for region-specific studies and tailored preventive measures to effectively monitor and mitigate the risk of dengue in the context of climate change.

Given this, it is crucial to understand how climate change affects the rising incidence of dengue in Southeast Asia. This systematic review aims to analyze the correlation between climate change and dengue incidence in the Southeast Asian region by systematically reviewing existing literature. It is anticipated that synthesizing data from multiple studies will provide a comprehensive understanding of the relationship between increasing dengue incidence and climate change, as well as implications for future public health policies. Furthermore, the study's findings could help policymakers develop adaptation and mitigation plans that mitigate the adverse effects of climate change on public health, particularly in Southeast Asia, where dengue prevention and control are a significant concern. As a result, our work may contribute to the development of a more comprehensive and integrated strategy for controlling infectious diseases associated with climate change.

Method

This review was conducted per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. These guidelines encompassed the following: defining resources, establishing eligibility criteria, determining inclusion and exclusion criteria, outlining the systematic review process, extracting data from existing literature, and analyzing the data (Shaffril et al., 2018). Several methodologies are available for conducting systematic literature reviews, including the Cochrane Handbook, the Realist Review Approach, and the Meta-Analysis Guidelines. Nevertheless, PRISMA was selected for this study because it provided a structured and transparent approach to study selection, thereby minimizing bias while ensuring reproducibility. The 2020 PRISMA statement had superseded the 2009 version, incorporating novel reporting guidelines that align with established methodologies for identifying, selecting, appraising, and synthesizing studies (Page et al., 2021). The PRISMA statement played a crucial role in facilitating the retrieval of review-related terms and guided the essential elements that must be included in a review for publication purposes (Mohamed Shaffril et al., 2021).

Search strategy

A systematic and thorough research was undertaken using Scopus, PubMed, ScienceDirect, and Emerald to amass scientific papers that address the nexus between climate change and the escalating prevalence of dengue in Southeast Asia. The articles were identified through the use of keyword combinations, with the Boolean operators “AND” and “OR” employed in this process. The following keywords were utilized in the search: climate OR “climate change” OR weather AND dengue OR “dengue fever” OR “dengue hemorrhagic fever” OR “dengue incidence” AND “Southeast Asia”. In addition to these keywords, the search incorporated filters to restrict the studies to those published in English and human studies, thereby ensuring the relevance and specificity of the results. The search strategy encompassed a comprehensive selection of databases, including articles published between 2004 and December 2024.

Inclusion criteria: All observational studies, including those employing correlation or cross-sectional designs, were conducted between 2004 and 2024. These studies were published in peer-reviewed journals, both in Indonesia and abroad, and were presented in English and accessible in full text. The studies were required to meet the following criteria: firstly, they had to be original research projects that had undergone the peer-review process; secondly, they were required to report on the incidence of dengue fever and quantitative associations between epidemiological effect sizes and population health outcomes, as well as climate exposures.

Exclusion criteria: This study excluded animal studies, case reports, correspondence, review articles, seminar abstracts or proceedings, editorials, or expert opinions. These studies lacked the necessary dengue-related human outcome data. This deficiency is characterized by the exclusion of studies that merely alluded to mosquitoes and/or zoonotic transmission, without providing any detailed description of dengue incidence or prevalence. Books were also excluded, as they generally do not provide the thorough, up-to-date data on dengue incidence in human populations that were essential for the focus of this research.

Selection of studies

The articles retrieved from the database were then subjected to an independent review by three authors, each of whom performed an initial title screening based on the predefined eligibility criteria. The second stage of the process involved screening the abstracts of the selected articles, and the third stage was the full-text screening. Following the completion of the full-text review, the three authors compared their findings to identify any discrepancies. In the event of any discrepancies that arose, the authors endeavored to resolve them through discussion and consensus. In instances where consensus could not be reached, a fourth reviewer was consulted to ensure an objective resolution. The papers excluded from the analysis, along with the final list of included papers, were presented, along with detailed reasons for exclusion. This ensured transparency in the selection process.

Data extraction and management

Data extraction was performed using Rayyan to facilitate systematic screening of articles (Ouzzani et al., 2016). An Excel spreadsheet was utilized to extract and organize the data from the included studies. The extracted data were categorized into the following parameters for consistency and clarity: last name of the first author, year of publication, country of study, study design, climate variables, and incidence of dengue. To ensure accuracy and reduce redundancy, each study's data was reviewed twice by two independent reviewers, with discrepancies resolved through discussion. Any duplicated or incomplete data were flagged, and only the most complete and relevant data were included in the final dataset. Data cleaning procedures were followed to ensure that the extracted data met the required quality standards. Additionally, any ambiguities or unclear data were addressed by consulting the original article or contacting the study authors when necessary.

Per the journal's policy on AI usage, we would like to clarify that Rayyan, a machine learning-based tool, was used to assist with the systematic screening of articles in this study. While Rayyan helped streamline the data extraction process, the final decision-making, data categorization, and analysis were conducted by the authors.

Meta-Analysis

A meta-analysis was not conducted as part of this systematic review. Although meta-analysis could potentially provide a quantitative synthesis of the results, it was deemed inappropriate for this review due to the heterogeneity among the studies, including differences in study designs, climate variables, and geographical contexts. The variations in study methodologies and data reporting also contributed to the decision not to conduct a meta-analysis. Conversely, this review adopted a qualitative synthesis approach, facilitating a more comprehensive understanding of the relationship between climate factors and dengue incidence across the Southeast Asian region. A qualitative approach was adopted to ensure that the complexities and nuances of the climatic variables in different contexts were captured and discussed. This approach enabled the provision of valuable insights into the relationship between climate and dengue that might not have been possible through a quantitative synthesis.

Quality assessment

The evaluation of the papers was conducted using a quality checklist developed to assess the quality of a selection of articles (Constenla et al., 2015; Rassa et al., 2023). This checklist consisted of 19 questions, divided into five categories: Population, Method of selection of exposure (or comparison) group, Outcomes, Analyses, and Summary. There were five possible answers for each question:

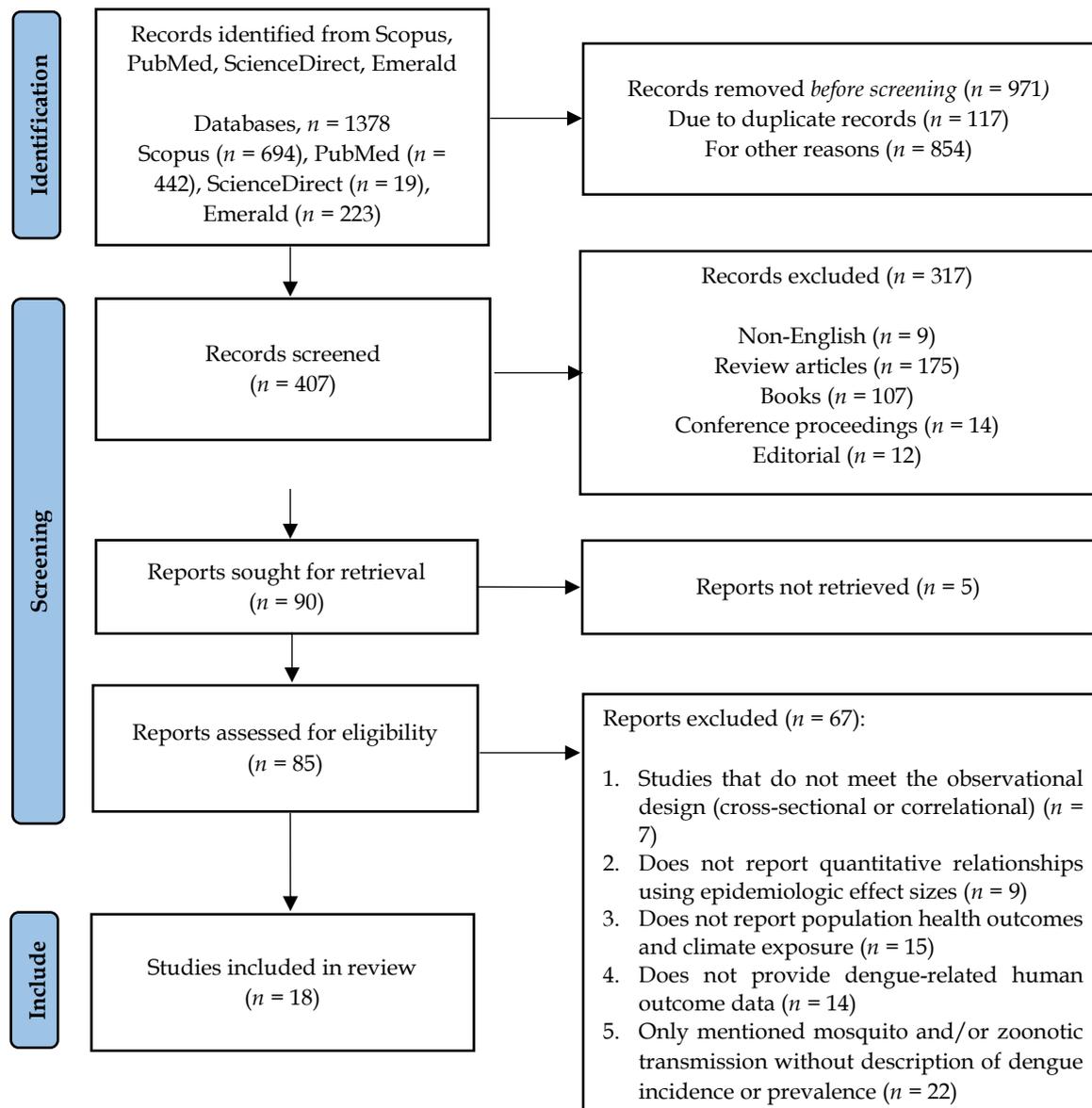
- “++”: The study had been designed or conducted in such a way as to minimize the risk of bias
- “+”: Aspects of the study design were developed or implemented to minimize the risk of bias
- “-”: Significant sources of bias may have existed
- “NR”: Not reported, and
- “NA”: It should be noted that the following does not apply to the study design under review.

The quality of each study was then evaluated using two distinct grades: internal validity (IV) and external validity (EV). “++” It was evident that the majority of the checklist criteria had been met. In instances where this was not the case, it was highly improbable that the conclusions would be subject to alteration. “+” It was evident that the checklist criteria had been fulfilled in some instances, while others had not been met or were not adequately described. Consequently, it was anticipated that the conclusions would remain unaltered. “-” It was evident that a paucity of checklist criteria had been fulfilled, and it was highly probable, or at least very likely, that the conclusions would be subject to alteration (National Institute for Health and Care Excellence, 2012).

Results

The present study employed keyword summarization to identify articles on the incidence of dengue and its relationship with climate factors across four databases: Scopus, PubMed, ScienceDirect, and Emerald. Out of 1,378 articles initially identified, 18 were selected after screening, eligibility assessment, and journal evaluation.

Figure 1 illustrates the systematic review process employed in this investigation.

Figure 1: Systematic Review Flow

In this review, the primary dependent variable was dengue incidents, which were found to be associated with meteorological determinants (sunlight, wind speed, rainfall, humidity, and temperature) in Southeast Asia.

Table 1 summarizes the reviewed articles. The studies included in this review showed that temperature was most commonly considered in the research, with 18 articles addressing its impact. Seventeen articles examined rainfall, and 12 articles included humidity as a variable. A smaller subset of studies (5) included wind speed as a factor influencing dengue transmission. Additionally, other articles incorporated parameters such as sun exposure, sea level pressure, and demographic factors that influence dengue incidence.

Table 1: Summary of Reviewed Articles

No	Author (Year)	Location	Variable	Finding
1	Cheong et al. (2013)	Selangor, Kuala Lumpur, and Putrajaya, Malaysia	Number of dengue cases Minimum temperature Two weeks of accumulated rainfall Wind speed	A positive correlation has been observed between the incidence of dengue cases and minimum temperature, with a cumulative percentage change of 11.92%. Furthermore, a strong positive correlation was observed between the two-week precipitation accumulation and the subsequent incidence of dengue cases, with a cumulative percentage change of 21.45%. The maximum impact of rainfall is monitored with a time lag of 26 to 28 days. The present study hypothesizes that wind speed is negatively associated with the incidence of dengue fever and that an increase in wind speed may consequently result in a reduction in the number of cases.
2	Ibrahim Abdulsalam et al. (2021)	Nakhon Si Thammarat Province, Thailand	Number of dengue cases Temperature Relative humidity Rainfall Number of rainy days Wind speed Evaporation Cloud cover Sea level pressure	The present study hypothesizes that there is a positive correlation between temperature and the number of dengue cases, and a negative correlation between sea level pressure and the number of dengue cases. It was also demonstrated that other variables, including wind speed and the number of rainy days, exhibited significant associations, albeit in divergent directions.
3	Sugeno et al. (2023)	Laos	Dengue incidence Temperature Rainfall Elevation of the location, which may affect vector habitat	Higher temperatures significantly increase the risk of dengue incidence. The total weekly rainfall peaked at 82 mm, with a relative risk of 1.76 compared to no rainfall at all. Nevertheless, this risk decreased significantly when rainfall exceeded 200 mm, indicating that very high rainfall can have a protective effect. The study found no evidence that altitude modifies the relationship between meteorological factors and dengue incidence.
4	Rusli & Yushananta (2020)	Bandar Lampung, Indonesia	Number of dengue cases Rainfall Temperature Humidity	The analysis revealed a significant correlation between rainfall and the incidence of dengue cases. This finding suggests a potential correlation between increased rainfall and a proportional rise in dengue cases. However, the data did not reveal a notable association between temperature and

No	Author (Year)	Location	Variable	Finding
				humidity and the number of dengue cases. The regression results indicated that precipitation exhibited a 19.0% impact on the number of dengue cases.
5	Thi Tuyet-Hanh et al. (2018)	Hanoi, Viet Nam	<p>Number of dengue cases</p> <p>Monthly total of sunshine hours</p> <p>Average monthly rainfall</p> <p>Monthly average evaporation</p> <p>Average monthly temperature</p> <p>Monthly relative humidity</p>	The present study revealed a noteworthy correlation between the occurrence of dengue cases and several climatic variables, including the monthly average evaporation, the monthly relative humidity, and the monthly total sunshine hours. In contrast, no substantial direct correlation was identified between the number of cases and either average monthly rainfall or temperature. Moreover, the study highlighted a considerable model lag, indicating a delay between the maximum temperature recorded in June and the subsequent peak in dengue cases, which occurred from October to November.
6	Do et al. (2014)	Hanoi, Vietnam	<p>Number of dengue cases from 2002 to 2009.</p> <p>Climate variables: Including temperature, rainfall, relative humidity, and vapor pressure</p>	The findings indicated that temperature, precipitation, and vapor pressure displayed marked seasonality, while relative humidity exhibited significant seasonality and sub-annual periodicity. The findings suggest that temperature, rainfall, and vapor pressure precede the onset of dengue fever by 8-10 weeks, while relative humidity precedes the onset of dengue fever by 18 weeks for the annual cycle and by a reduction from 14 to 5 weeks for the sub-annual cycle.
7	Pham et al. (2011)	Dak Lak, Vietnam	<p>Number of dengue cases</p> <p>Household Index (HI)</p> <p>Container Index</p> <p>Breteau Index (BI)</p> <p>Temperature</p> <p>Sunlight duration</p> <p>Amount of rainfall</p> <p>Relative humidity</p>	The results demonstrated that the variables significantly associated with dengue incidence were the Household Index (HI), the Household mosquito index, the Container Index, the Breteau Index, temperature (with a 2°C increase), rainfall (with a 50 mm increase), and humidity (with a 5% increase).
8	Xuan et al. (2014)	Haiphong, Vietnam.	Number of dengue cases during the period 2008-2012	The results of multivariate Poisson regression analysis indicate a positive correlation among rainfall, temperature, and the risk of dengue fever. It has

No	Author (Year)	Location	Variable	Finding
			Average monthly temperature Monthly rainfall amount Monthly relative humidity percentage	been demonstrated that there is a direct correlation between increases in rainfall and increases in the risk of dengue. Specifically, for every 50 mm increase in rainfall, there is a corresponding and demonstrable increase in the risk of dengue. Similarly, a positive correlation has been observed between humidity levels and the incidence of dengue fever. It has been demonstrated that a 1% increase in humidity is associated with a corresponding rise in the risk of dengue fever.
9	Husnina et al. (2019)	Pulau Sumatra and Kalimantan, Indonesia	Reported dengue cases Forest cover Relative humidity with a lag of 2 months Minimum temperature with a 1-month lag	In Sumatra, a 9% reduction in the risk of dengue was observed for every 1% increase in forest cover. In Kalimantan, there was no statistically significant decrease in forest cover. However, there was a 7.6% increase in the risk of dengue for every 1°C increase in minimum temperature. In Sumatra, a 12.2% reduction in the risk of dengue was observed with each 1% increase in relative humidity. In Kalimantan, a 17.6% reduction in the risk of dengue was observed with each 1% increase in relative humidity.
10	Wang et al. (2023)	Singapura (Singapore) Colombo (Sri Lanka) Selangor (Malaysia) Chiang Mai (Thailand)	Dengue incidence Daily average temperature Daily rainfall	The results of this study indicate that climate change will increase the incidence of dengue, with a greater peak incidence and epidemic size, particularly under a scenario with high emissions. It is anticipated that the timing of epidemic peaks will occur earlier in the year, and that the duration of dengue outbreaks will be prolonged. This will result in extended periods during which environmental conditions will be conducive to the spread of dengue vectors.
11	Wang et al. (2022)	Singapura, Malaysia, Sri Lanka, Thailand	Dengue infection Weekly average temperature, with a focus on temperature extremes (high and low temperatures) Weekly rainfall totals, with special attention to rainfall extremes	The risk of dengue infection is elevated within 1-3 weeks following periods of extremely high temperatures. Conversely, extreme rainfall was associated with a decreased risk of dengue infection compared to no rainfall at all. Furthermore, the study found that an increased number of days with extreme rainfall (for example, seven consecutive days of extreme rainfall) was associated with a lower risk of dengue infection.

No	Author (Year)	Location	Variable	Finding
12	Adnan et al. (2020)	Kuala Lumpur, Malaysia	Dengue cases Temperature Relative humidity Rainfall Wind speed	A positive correlation has been demonstrated between temperature and the incidence of dengue cases. An inverse correlation characterizes the relationship between humidity and the incidence of dengue fever, indicating a negative relationship between the two variables. A positive correlation has been demonstrated between rainfall and the incidence of dengue cases. Wind speed showed no significant correlation. The regression model shows that the model is significant. The t value for each variable: Temperature: $t = 5.448, p = .001$, Relative Humidity: $t = -8.479, p = .001$, Rainfall: $t = 2.541, p = .011$, Wind Speed: $t = -2.613, p = .09$ (not significant).
13	Iguchi et al. (2018)	Davao Region, Filipina	Dengue incidence Average temperature Rainfall Dew point	It is evident from the data that a positive correlation exists between average temperature and dengue incidence; moreover, a high-risk period has been identified, which occurs between weeks 6 and 15. Additionally, rainfall demonstrated a significant association with dengue incidence, with increased rainfall contributing to a higher number of cases. This variable also exhibited a contributory effect on dengue incidence, although the results were more variable.
14	Thammapalo et al. (2005)	Thailand	Dengue incidence Monthly rainfall Minimum average daily temperature Average relative humidity	A correlation has been observed between the incidence of dengue fever and maximum temperatures recorded in Nakhon Nayok province. Specifically, a 1°C increase in maximum temperature has been found to correspond to an approximate 0.7% rise in dengue incidence. In some provinces, such as Sing Buri, Suphan Buri, Trat, Pattani, and Phuket, rainfall exhibited a notable negative regression coefficient, indicating that an increase in rainfall was associated with a reduction in dengue incidence. Most of the variability in dengue incidence can be attributed to trends and cyclical changes (between 14.7% and 75.3%), while independent climatic factors account for a relatively minor proportion (between 0.2% and 3.6%) of the observed variability.
15	Singh et al. (2022)	Selangor and Kelantan, Malaysia	Dengue cases Rainfall Temperature Wind speed	The results of the multivariate linear regression analysis revealed that 48.2% of the variance can be attributed to the meteorological variable. Regression Coefficient for each variable presented below: Rainfall: Beta = -0.806

No	Author (Year)	Location	Variable	Finding
				(significant), wind speed: Beta = 0.046 (not significant), Temperature: Beta = -0.409 (significant).
16	Pinto et al. (2011)	Singapura, Singapura	Number of dengue cases Maximum and minimum temperature Total rainfall Maximum and minimum relative humidity	It has been demonstrated that both maximum and minimum temperatures have a considerable influence on the incidence of dengue cases. The analysis reveals a positive correlation between temperature increases and increases in dengue cases. Collectively, temperature and rainfall account for 45.4% of the observed variance, while relative humidity explains 22.4% of the variance. The analysis reveals a negative relationship between rainfall and temperature, with relative humidity contributing to the variability of dengue cases.
17	Lover et al. (2014)	Phnom Penh, Kamboja	Cases of dengue infection in children Demographic factors: age, gender, and place of residence Climatic factors: temperature, relative humidity, rainfall, and rainfall index	The weekly minimum temperature and median relative humidity exhibited significant effects at time lags of 1 to 6 weeks. They were negatively associated with maximum rainfall.
18	Sutriyawan et al. (2024)	Bangung Indonesia	Temperature Humidity Rainfall Wind Velocity	A significant relationship has been demonstrated between humidity and the prevalence of dengue hemorrhagic fever ($p = .018$, $r = 0.873$). A correlation has been shown between wind velocity and the prevalence of dengue hemorrhagic fever, with a p value of .018 and a coefficient of determination (r) of 0.629. The coefficient of determination test yielded an R^2 value of 0.745 when the variables of temperature, humidity, rainfall, and wind velocity were considered in the context of DHF cases.

Climate impact on dengue incidence

Temperature

A clear and positive correlation was observed between temperature and the incidence of dengue in Southeast Asia. The majority of studies reported that rising temperatures led to an increase in dengue cases. For instance, a temperature increase from 25.4°C to 26.5°C has been associated with a rise in dengue incidence in Malaysia. A statistically substantial correlation was identified between temperature and dengue incidence in Thailand ($\beta = 0.170$, $p < .001$). In Vietnam, every 2°C increase led to a 39% rise in dengue incidence (RR 1.39, 95% CI [1.25, 1.55]). Similarly, in Indonesia, dengue risk increased by 7.6% for every 1°C rise in minimum temperature (95% CI [6.9, 8.4%]). The studies from the Philippines, Singapore, and Cambodia also showed a positive correlation between temperature and dengue incidence.

Rainfall

The preponderance of research findings has indicated an affirmative correlation between variations in rainfall and the subsequent occurrence of dengue cases. In Malaysia, a 21.45% increase in dengue cases was observed, which was found to be associated with an increase in rainfall from 215 mm to 302 mm (95% CI [8.96, 51.37]). In Laos, the cumulative relative risk of dengue increased with rainfall, peaking at 82 mm (RR 1.76, 95% CI [0.91, 3.40]). In Vietnam, a 50 mm increase in rainfall was associated with a relative risk of 1.14 (95% CI [1.12, 1.15]), indicating a significant impact of rainfall on dengue transmission across the region.

Humidity

The relationship between humidity and dengue incidence was more complex. While 52% of studies indicated a negative correlation, other findings suggested a positive correlation. For instance, in Indonesia, humidity was negatively correlated with dengue incidence, with a 12.2% decrease in dengue risk for every 1% increase in relative humidity in Sumatra and 17.6% in Kalimantan. Conversely, Haiphong, Vietnam, showed a positive correlation, where a 1% increase in humidity resulted in a 5% increase in dengue risk (RR = 1.05, 95% CI [1.02, 1.08]). The findings suggest that while high humidity generally favors mosquito survival, other factors such as temperature and local environmental conditions influence the ultimate impact on dengue.

Wind speed

The results regarding wind speed were inconsistent across studies. In Thailand, a negative correlation was observed between wind speed and dengue incidence ($\beta = -0.11$, $p < .001$), indicating that increased wind speeds may lead to a decline in mosquito activity. Nonetheless, Malaysian research has indicated a lack of a significant relationship between wind speed and the incidence of dengue. This finding suggests that wind may not be a primary factor influencing dengue transmission within this geographical area.

Discussion

Climatic factors significantly influence the biology of mosquitoes, the viruses they transmit, and the broader dengue transmission cycle. Temperature has a direct impact on the life cycle and behavior of *Aedes* mosquitoes. An increase in temperature accelerates mosquito reproduction, shortens the virus incubation period within mosquitoes, and boosts mosquito activity (Bellone & Failloux, 2020; Liu et al., 2023; Liu-Helmersson et al., 2014). There is substantial evidence linking temperature rise with increased dengue incidence (Adnan et al., 2020; Cheong et al., 2013; Do et al., 2014; Husnina et al., 2019; Ibrahim Abdulsalam et al., 2021; Iguchi et al., 2018; Lover et al., 2014; Pham et al., 2011; Pinto et al., 2011; Singh et al., 2022; Sugeno et al., 2023; Thammapalo et al., 2005; Wang et al., 2022; Xuan et al., 2014).

These studies, employing diverse statistical methods and temperature parameters, consistently indicate that dengue epidemics are at least partially driven by climate. Many studies have observed higher dengue incidence during warmer months. While this study focuses on Southeast Asia, the findings may also be relevant to other tropical regions with similar climatic conditions, such as parts of Central and South America and Sub-Saharan Africa (Barcellos et al., 2024; Estallo et al., 2020; Giesen et al., 2022). In these regions, the interplay between rising temperatures, increased rainfall, and urbanization may similarly exacerbate the risk of dengue. Adapting the strategies and interventions outlined in this study could help mitigate the effects of climate change on populations in other vulnerable areas. In tropical regions, higher temperatures often coincide with the rainy season, providing optimal conditions for mosquito breeding. Research in Malaysia has highlighted a positive correlation between temperature rise and an increase in dengue cases, with temperature fluctuations preceding dengue outbreaks (Husnina et al., 2019; Singh et al., 2022). To effectively mitigate outbreaks, early warning systems using climate data should be implemented to predict and allocate resources in regions vulnerable to temperature extremes.

In addition to climatic factors such as temperature, rainfall, and humidity, non-climatic factors, including socioeconomic status, population density, and urbanization conditions, also contribute to dengue transmission dynamics. Urbanization in rapidly growing cities increases population density, thereby creating more breeding sites for mosquitoes. In addition, socioeconomic vulnerabilities, such as limited health services and sanitary conditions, worsen the risk of dengue transmission in marginalized communities. Addressing these vulnerabilities, particularly in impoverished urban areas, is crucial for controlling dengue outbreaks. Furthermore, the interplay between climate change and urban growth needs to be carefully considered in policy development to mitigate the effects of both factors on dengue transmission.

Furthermore, it is essential to emphasize that urban planning strategies must consider the specific climate vulnerabilities of each region. For instance, cities like Singapore may have more advanced infrastructure for controlling mosquito populations. Still, urbanization in countries like Indonesia or rural Thailand may require different intervention strategies tailored to local needs. These strategies should focus on improving drainage systems and reducing stagnant water sources in high-risk areas. Research indicates a time lag between rising temperatures and an increase in dengue cases, with temperature effects observable within 0 to 3 weeks. This delay underscores the complex interplay between temperature and other environmental factors (Husnina et al., 2019; Wang et al., 2023).

Public health policies must integrate climate adaptation strategies, such as predictive models, to guide dengue control during periods of peak temperatures. In addition to average temperature, temperature variability is a critical factor. Extreme fluctuations in temperature can influence dengue patterns, with elevated temperatures stressing mosquito populations. However, when temperatures stabilize at moderate levels, they can create conditions favorable for mosquito reproduction, contributing to higher transmission rates (Singh et al., 2022). Moreover, the use of geospatial techniques, such as remote sensing and GIS, is becoming increasingly important for monitoring environmental factors that influence dengue transmission, enabling more accurate spatial and temporal analysis of risk factors (Abdullah et al., 2022; Kamaruzzaman et al., 2025).

Rainfall can also impact the life cycle of *Aedes* mosquitoes, particularly in tropical regions with seasonal rainfall patterns. It is essential to acknowledge regional variations in how rainfall influences dengue transmission. For example, rainfall patterns impact breeding habitats differently in urban centers, such as Singapore, compared to rural areas in Indonesia or Thailand. Heavy rainfall creates stagnant water, which is conducive to mosquito breeding. In Singapore, for example, heavy rainfall has expanded breeding habitats in urban areas, especially during the rainy season (Benedum et al., 2018; Seidahmed & Eltahir, 2016). Several studies in other tropical countries, including Indonesia and Sri Lanka, have shown that stable rainfall consistently increases breeding habitats, thereby heightening the risk of dengue transmission. Therefore, urban planning strategies that reduce mosquito breeding sites in densely populated areas are essential. Conversely, extreme rainfall can precipitate a seasonal decline in dengue fever cases when environmental conditions become suboptimal for larval development (Sajib et al., 2024).

The next step in controlling dengue requires spatial risk mapping. This approach could inform the allocation of resources and the development of targeted prevention measures for specific areas. Heavy precipitation increases water puddles, which become breeding places for *Aedes aegypti* mosquitoes. Evidence suggests a direct correlation between increased rainfall and higher dengue cases, as stagnant water facilitates mosquito breeding (Adnan et al., 2020; Singh et al., 2022). Studies from Malaysia, the Philippines, and Vietnam have shown a correlation between rainfall and dengue incidence, with rainfall preceding an increase in dengue incidence (Iguchi et al., 2018; Singh et al., 2022; Thi Tuyet-Hanh et al., 2018; Xuan et al., 2014). The present results suggest the need for climate-sensitive campaigns targeting the community to prevent dengue during the rainy season.

High relative humidity, particularly between 70% and 90%, creates an ideal environment for *Aedes* mosquitoes to survive and reproduce. Studies show that high humidity extends the lifespan of mosquitoes and enhances their blood-seeking activity, promoting the gonotrophic cycle, which is essential for virus transmission. With rising humidity due to climate change, tropical and subtropical regions are likely to see an increase in dengue risk. Research in France and Kenya confirms that high humidity extends the infectivity period of mosquitoes, directly influencing local dengue transmission (Goindin et al., 2015; Kamau et al., 2023). These effects must be incorporated into predictive models for dengue control policies. Studies in Peru confirm that high humidity, combined with elevated temperatures, creates an ideal micro-ecosystem for accelerating the mosquito life cycle and enhancing virus spread in local communities (Campbell et al., 2015). Furthermore, climate change-induced increases in humidity in subtropical and tropical regions are expanding the range of *Aedes* mosquitoes. Predictive models suggest a higher risk of transmission in urban areas with high humidity levels, requiring adaptive control strategies (Benedum et al., 2018; Ryan et al., 2019).

High wind speeds can negatively affect *Aedes* mosquitoes' flight ability, reducing their capacity to breed and feed in regions with higher wind speeds. As a result, mosquito populations decrease, resulting in lower dengue transmission rates (Singh et al., 2022). Research from Malaysia suggests that stronger winds have a negative correlation with dengue cases, disrupting the flight behavior of mosquitoes (Cheong et al., 2013). A study conducted in Singapore between 2012 and 2019 found that elevated wind speeds were associated with a significant reduction in the risk of dengue transmission. The relative risk of dengue declined by 30% when wind speeds reached 13 km/h, compared to a lower reference speed of 7.52 km/h. This suggests that stronger winds may hinder mosquitoes' ability to settle and seek human hosts in densely populated urban areas (Gui et al., 2021). Similarly, a study conducted in Colombia between 2007 and 2017 showed a negative correlation between high wind speeds and dengue incidence. Stronger winds in some areas of Colombia were found to reduce mosquito activity, lowering the probability of mosquitoes biting humans and transmitting the virus (Morgan et al., 2021). In Indonesia, research conducted between 2011 and 2017, particularly in areas like Makassar, also showed that wind speed negatively influenced dengue incidence. Strong winds were identified as a factor that restricted mosquito dispersal in urban environments, reducing the likelihood of mosquito bites and consequently decreasing disease transmission (Niu et al., 2021).

In addition to these climatic factors, social and demographic factors must be considered in dengue transmission. The risk of dengue and the distribution of *Aedes* mosquitoes are also affected by ecological factors, such as vegetation and microclimate. These factors must be considered in urban planning and vector control strategies (Abdullah et al., 2025). Urbanization, particularly in rapidly growing cities, increases population density and the availability of standing water, which facilitates breeding. Combined with socioeconomic factors such as inadequate sanitation and limited access to healthcare, these elements exacerbate the risk of dengue transmission in vulnerable communities (Luna et al., 2020). Migration due to climate change, such as displacement caused by floods and heat waves, also increases the risk of dengue fever spreading. To address these challenges, it is essential to consider climate change adaptation and social interventions. Therefore, early warning systems, combined with public education on vector control during extreme weather, are vital in reducing dengue fever outbreaks (Udayanga et al., 2018). These strategies enhance community resilience to climate-related health risks.

Socioeconomic inequality plays a critical role in dengue transmission. Low-income communities, particularly those with inadequate sanitation, overcrowding, and limited access to healthcare, are more susceptible to outbreaks. These groups are disproportionately impacted by climate change, which exacerbates health disparities. Addressing these inequities through better healthcare access and improved urban planning can significantly reduce dengue transmission risks (Luna et al., 2020). Public health policies must encompass initiatives to control the risk of climate change on dengue transmission. Integrating climate-sensitive surveillance systems and strengthening community-based vector control programs are essential.

This review has several limitations. Firstly, the studies reviewed employed various methods and parameters to measure dengue incidence and climatic factors, and had a limited period. This introduces heterogeneity, with studies differing in their definitions of dengue cases and measurements of climatic factors, which can affect the comparability of results. Secondly, not all countries affected by dengue in Southeast Asia were included in this review, limiting the scope of regional climate-variable impacts. Furthermore, this review focused on open-access

articles published in English, which may have resulted in a smaller sample size and potential publication bias, excluding relevant studies in other languages or behind paywalls.

Additionally, there were differences in epidemiological methodologies across studies, including variations in study designs and data analysis, which could impact the interpretation of the findings. This review primarily focused on climatic factors and did not extensively explore the influence of social determinants such as urbanization, sanitation, and public health policies on dengue transmission, which could limit the comprehensiveness of the findings. Longitudinal studies are necessary to gain a deeper understanding of the long-term dynamics of dengue incidence and the role of climatic factors in this context. Further research is needed to investigate the complex relationships between climatic factors and dengue epidemiology. This should include longitudinal studies that can provide a more profound understanding of the long-term effects of climate change on public health.

Conclusion

The increase in dengue fever incidents is linked to rising temperatures and increased rainfall. The relationship between humidity and dengue fever incidents is more complex. The majority of studies demonstrate a positive correlation between the two; however, some studies suggest that excessive humidity may reduce dengue fever cases under specific conditions. The findings on wind speed are inconclusive, with the majority of studies indicating no significant correlation between wind speed and the variable of interest. Furthermore, population density, urbanization, and socioeconomic inequality have been demonstrated to play a role in the transmission of dengue fever. Policymakers should enhance climate monitoring systems to track temperature, rainfall, humidity, and wind speed, thereby predicting and mitigating dengue outbreaks more effectively. Public education campaigns are also essential for raising awareness about the link between climatic factors and dengue incidence, equipping communities with the knowledge to reduce transmission risks, particularly during extreme weather conditions. Given the similar climatic conditions in other tropical regions, the findings from this review can inform global public health strategies. These regions may face similar challenges in controlling dengue and other mosquito-borne diseases due to changes in climate, socioeconomic, and urbanization factors.

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