Letter to the Editor

Climate Matters: Integrating Bioclimatology into Dengue Vector Control within the One Health Framework

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Dear Editor,

I am writing this because I am concerned about the transmission and explosion of dengue virus infection (DVI) cases, particularly in Bali, Indonesia. In the last decade, the incidence of DVI has continued to increase, which is in line with the incidence rate (IR) and case fatality rate (CFR). Bali Province has never met the national target of an IR of >10 per 100,000 population annually; although the CFR tends to be under control at <1%, increasing mortality is still reported (1). Our recent surveillance data show that the IR in Bali reached 155.32 per 100,000 population in 2023, which is significantly higher than the national average of 41.36, highlighting the urgent need for improved intervention strategies based on local conditions. This letter underscores the importance of integrating bioclimatology into dengue vector control strategies that aim to prevent the spread of dengue virus infection within the One Health framework. The novelty of our approach lies in identifying Bali-specific bioclimatic thresholds that contradict generalized assumptions about dengue transmission, particularly regarding rainfall patterns and mosquito proliferation in island ecosystems. Understanding the intricate relationship between climate and vector-borne diseases, such as dengue fever, is critical for effective public health interventions, as global temperatures continue to rise and climate patterns become increasingly unpredictable.

The One Health approach recognizes the interconnectedness of human, animal, and environmental health and emphasizes the need for collaborative and interdisciplinary efforts to address complex health challenges (2). This approach is particularly relevant for dengue control, as it integrates environmental monitoring (climate and ecosystem changes), vector surveillance (mosquito population dynamics), and human health metrics (case detection and treatment) into a unified framework for intervention. The bioclimatological component specifically addresses the environmental pillar of One Health, providing crucial data that inform both vector control and clinical preparedness. In the case of dengue fever, which is transmitted primarily by *Aedes* mosquito species, physical and environmental factors play important roles in determining vector abundance, distribution, and bionomics (3). Bioclimatology examines the effects of climate on living organisms, providing valuable insights into how changes in climatic variables (such as temperature, air humidity, wind speed, air pressure, rainfall, rainy days, nature of rain, standardized precipitation index, and sunshine duration) affect mosquito populations and their ability to transmit dengue virus. By incorporating bioclimatological data into vector control programs, public health authorities can develop interventions that are targeted and responsive to local environmental conditions, reduce the risk of dengue transmission more effectively, and provide efficient and targeted control efforts (4, 5).

Our study covered 57 subdistricts in Bali from January 2022 to January 2023. We obtained dengue case data from the Bali Provincial Health Office's integrated disease surveillance system, with laboratory confirmation by NS1 antigen or immunoglobulin M (IgM) antibody detection. High-resolution climate data (daily measurements aggregated to monthly values) were acquired from nine meteorological stations operated by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), which are strategically positioned across Bali's diverse topography. We analyzed the relationships between bioclimatic variables and dengue incidence via structural equation modeling with partial least squares (SEM-PLS), which allowed us to accommodate potential multicollinearity among climate predictors through a variance-based approach. Statistical significance was set at p< 0.01, with regression coefficients (β) reported alongside 99% confidence intervals.

Our previous study (Fig. 1 and Table 1) revealed that warmer temperatures accelerated the development of *Aedes* mosquito larvae, thereby shortening the incubation period and increasing the rate of virus replication within the mosquito. Specifically, our structural equation model (SEM–PLS) analysis demonstrated that temperature had a direct positive correlation (β: 0.226, p< 0.001, 99% CI: 0.090–0294) with dengue incidence in Bali. We found that each 1 °C increase in the mean monthly temperature was associated with a 22.6% increase in dengue cases when the temperature ranged from 27–32 °C, which represents the optimal temperature range for *Aedes* (*Stegomyia*) *aegypti* reproduction and viral replication, respectively. Higher temperatures also shorten the extrinsic incubation period of the virus, thereby increasing the likelihood of dengue transmission from mosquitoes to humans (6, 7). This is also supported by high humidity levels, which create optimal conditions for breeding and survival. Although humidity showed no statistically significant association in our model (β: -0.123, p= 0.297, 99% CI: -0.174–0.189), the interaction between temperature and humidity warrants further investigation. A humid environment supports the productive development of *Aedes* mosquito larvae and increases the adult mosquito population, thus increasing the potential for dengue transmission and infection in the community. This predisposition is mediated by low wind speeds, which potentially affect mosquito distribution. High wind speeds can inhibit mosquito flight, reducing dispersal, whereas stagnant conditions can trigger localized outbreaks in areas with high mosquito densities, as proven by studies conducted in Bali, Indonesia.

Changes in air pressure can also affect mosquito bionomics and breeding patterns. Our analysis revealed a strong positive correlation between air pressure and dengue incidence (β: 0.290, p< 0.001, 99% CI: 0.190–0.350), with the highest correlation coefficient among all the bioclimatic variables studied. This finding suggests that relatively stable air pressure conditions in Bali (typically ranging from 1008–1013 hPa) create an environment that facilitates sustained mosquito activity and viral transmission. Low air pressure, such as that during heavy rains or tropical storms, creates a conducive environment for mosquito breeding, leading to increased vector abundance and an increased risk of dengue transmission. Similarly, our data showed that moderate wind velocity (β: 0.207, p< 0.001, 99% CI: 0.124–0.286) were significantly associated with increased dengue transmission, likely because light-to-moderate winds (1–3 m/s) facilitate mosquito dispersal without hindering flight, whereas stronger winds above 3 m/s appeared to suppress transmission by limiting mosquito mobility. This is also supported by the El Niño and La Niña phenomena that impact Indonesia and the surrounding tropical countries, resulting in increased abundance and virulence of the vectors spreading dengue virus (DENV) (8, 9).

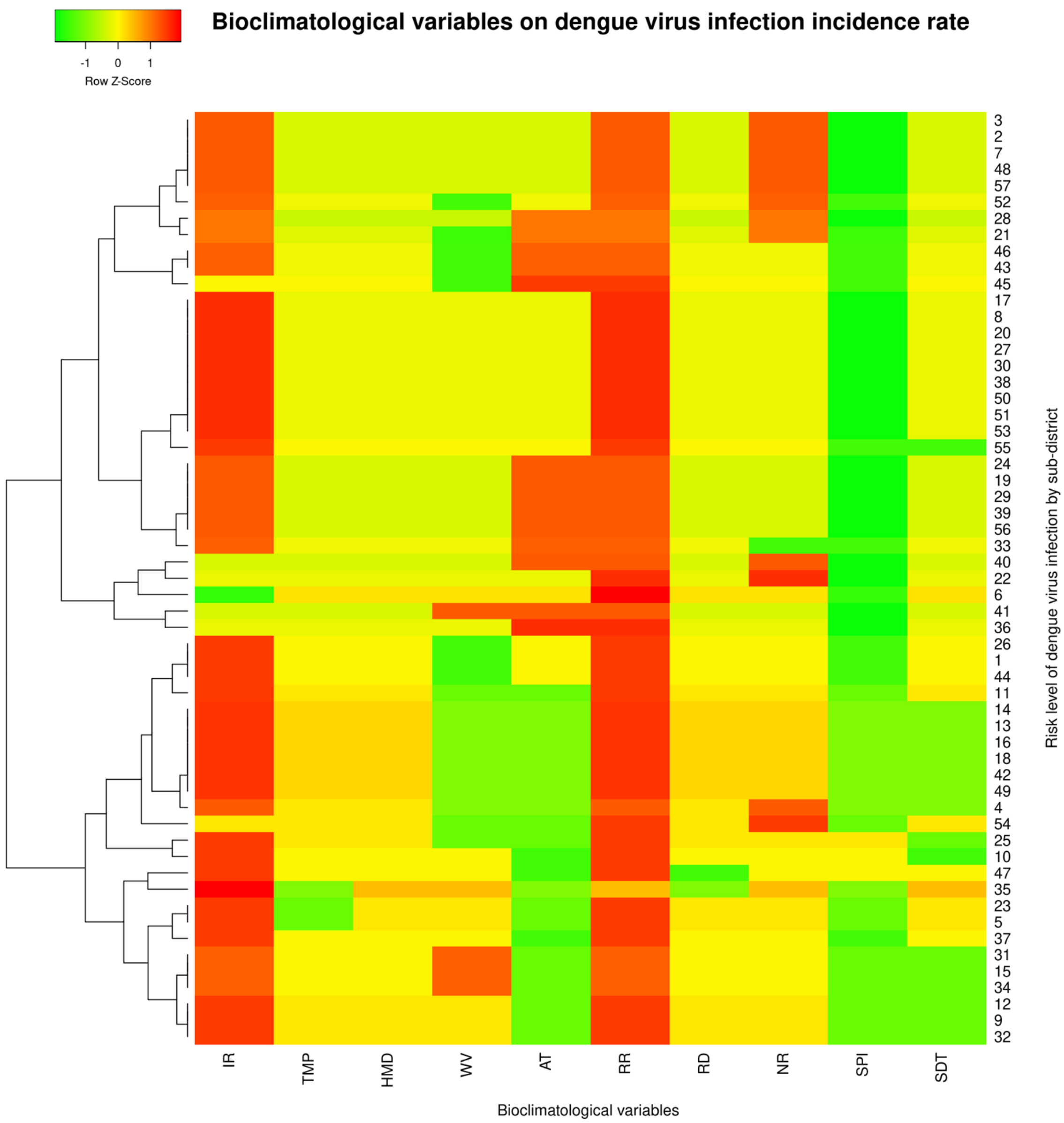

Fig. 1. Mapping of dengue virus infection (DVI) risk levels in each subdistrict (n= 57) based on bioclimatic variables (January 2022–January 2023). Remarks: IR, incidence rate; TMP, temperature; HMD, humidity; WV, wind velocity; AT, air pressure; RR, rainfall rate; RD, rainy days; NR, nature of rain; SPI, standardized precipitation index; SDT, sunshine duration

Table 1. Correlation of bioclimatic determinants with the incidence of dengue virus infection in Bali, Indonesia

Indicator	Original Sample	Mean± SD	t-stat.	p value	Confidence Intervals (CI)	
					2.5%	97.5%
Temperature → incidence of DVI	0.226	0.202±0.059	3.804	<0.001***	0.090	0.294
Humidity → incidence of DVI	- 0.123	-0.023±0.118	1.045	0.297	- 0.174	0.189
Wind velocity → incidence of IVD	0.207	0.203±0.051	4.038	<0.001***	0.124	0.286
Air pressure → incidence of DVI	0.290	0.273±0.041	7.145	<0.001***	0.190	0.350
Rainfall intensity → incidence of DVI	0.171	0.097±0.148	1.154	0.249	- 0.208	0.229
Rainy days → incidence of DVI	- 0.199	-0.184±0.041	4.916	<0.001***	-0.261	-0.100
Nature of rain → incidence of DVI	- 0.071	-0.091±0.060	1.186	0.236	-0.211	0.021
Standardized precipitation index → incidence of DVI	- 0.223	-0.223±0.035	6.332	<0.001***	-0.287	-0.151
Sunshine duration → incidence of DVI	0.045	0.025±0.055	0.822	0.411	-0.097	0.118

Remarks: p value: ***= significant at 99.9%; **= significant at 99%; *= significant at 95%

Our findings regarding rainfall patterns in Bali reveal a unique relationship with dengue transmission that differs significantly from that in mainland Southeast Asian regions. Climate change causes unconsciously high and low rainfall, both of which affect mosquitoes. Our analysis of rainfall patterns in Bali revealed a nuanced relationship with dengue transmission that differed from findings in other tropical regions. While rainfall intensity is commonly associated with increased vector breeding sites in many endemic areas, our data from Bali show that the total rainfall amount (β: 0.171, p= 0.249, 99% CI: -0.208–0.229) does not significantly correlate with dengue incidence. This suggests that in Bali's unique island ecosystem, the volume of precipitation alone is not a determining factor for dengue transmission, contrary to the patterns observed in mainland Southeast Asian countries. Instead, our research demonstrated that the frequency of rainy days significantly influences dengue transmission in Bali, with a notable negative correlation (β: -0.199, p< 0.001, 99% CI: -0.261– -0.100). This counterintuitive finding that more rainy days are associated with reduced dengue incidence represents a distinctive characteristic of dengue epidemiology in Bali. We hypothesized that frequent rainfall events may continually flush out breeding containers and interrupt mosquito breeding cycles, whereas intermittent rain allows for more stable breeding conditions.

The standardized precipitation index (SPI) emerged as a critical predictor in our model, showing a significant negative correlation with dengue incidence (β: -0.223, p< 0.001, 99% CI: -0.287– -0.151). This finding indicates that in the context of Bali, drought conditions (negative SPI values) are paradoxically associated with increased dengue transmission. This finding aligns with Bali's cultural practice of water storage during dry periods, where household water containers become ideal breeding sites for *Aedes* mosquitoes in the absence of natural water bodies. The strong statistical significance of this relationship underscores the importance of monitoring SPI values as early warning indicators for dengue outbreaks in Bali (4, 6). Unlike the other variables that showed strong correlations, sunshine duration did not demonstrate a statistically significant relationship with dengue incidence in Bali (β: 0.045, p= 0.411, 99% CI: -0.097–0.118). This finding contrasts with studies from continental regions, where solar radiation has a significant impact on vector behavior. This suggests that in Bali's consistently tropical climate, variations in sunshine duration remain within a range that does not substantially affect mosquito activity or viral replication. This distinction highlights the importance of region-specific bioclimatic modeling rather than applying generalized assumptions across different dengue-endemic areas.

By utilizing bioclimatic models and predictive analyses, health authorities can anticipate changes in vector populations and proactively implement control measures, such as larval eradication, insecticide spraying, and habitat modification, to prevent outbreaks before they occur. We recommend the following specific and actionable interventions: (1) Develop a real-time bioclimatic monitoring system that integrates data from local weather stations with mosquito surveillance and human case reporting. This system should trigger targeted interventions when specific thresholds are met, such as intensified vector control in areas experiencing optimal temperature conditions (27–32 °C) combined with humidity levels of 70–80%; (2) Implement proactive container inspections and larviciding campaigns when the SPI falls below -0.5, indicating drought conditions that are historically correlated with increased dengue risk; (3) Deploy targeted spatial residual spraying when sustained wind speeds of 1–3 m/s are recorded, as these conditions optimize mosquito dispersal; (4) Establish formal collaboration between the Ministry of Health, the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), and local government authorities to ensure timely data sharing and coordinated responses.

Community engagement and educational initiatives can empower individuals to take proactive steps to reduce mosquito breeding sites around their homes and protect themselves from being bitten. Bioclimatological models periodically provide the latest information and insights related to the level of vulnerability of dengue epidemic areas. Understanding this predisposition will provide insight for all sectors seeking to provide treatment in high-risk areas because, thus far, the control and prevention measures, including the number of fogging foci, the sowing of larvicide powder, and the ineffectiveness of the control program due to less proactive government attention, are the same in both high- and low-risk areas (2).

The incorporation of bioclimatology into a country's One Health implementation framework also highlights the importance of addressing socioeconomic factors that contribute to dengue transmission, such as inadequate sanitation, urbanization, rapid population growth, and high levels of mobilization (10). By adopting a holistic approach that addresses the environmental, animal, human, and social determinants of health, we can create more resilient and sustainable communities that are better equipped to prevent and respond to dengue epidemics, particularly in the tropics. In conclusion, policymakers, public health authorities, researchers, academics, and community leaders should prioritize the integration of bioclimatology into vector control strategies as part of a broader One Health agenda (11). By harnessing the power of interdisciplinary collaboration and capitalizing on advances in climate science, we can mitigate the impact of dengue and other vector-borne diseases on human and animal health, ultimately safeguarding the well-being of current and future generations of animals and humans.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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