Climate Variables and Dengue Incidence in Three Cambodian Provinces: A Longitudinal Observational Study Comparing Centralized and Localized Meteorological Data

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Abstract

Background

Dengue fever is endemic in Cambodia, and climate-informed early warning may strengthen surveillance. Whether localized micro-climate sensing offers meaningful advantages over centralized meteorological data across ecologically diverse provincial settings remains unknown.

Methods

This longitudinal observational study was conducted in Kandal, Kam-pong Cham, and Siem Reap, Cambodia, from June 2025 to January 2026. Dengue case data were obtained from the National Dengue Control Program routine surveillance. Local climate data were collected using portable weather stations; regional climate data were sourced from the Ministry of Water Resources and Meteorology. Negative binomial regression models assessed lagged associations (0–5 weeks) between climate variables and dengue incidence.

Findings

In Kandal, a 1°C rise in temperature was associated with an incidence rate ratio (IRR) of 1·31 (p<0·001) at a 3-week lag using centralized data. In Kampong Cham, temperature and humidity were associated with IRRs of 1·20 (3-week lag) and 1·03 (1-week lag) from centralized data; confidence intervals and p-values were not available for these estimates, and the humidity unit was not specified. In Siem Reap, localized relative humidity was associated with an IRR of 1· 09 (p<0· 001) at a 4-week lag; centralized data were non-significant, though no formal comparison metrics were reported. Confidence intervals were unavailable for all estimates.

Interpretation

These exploratory findings suggest that centralized meteorological data may provide useful dengue surveillance signals in some Cambodian provinces, while localized micro-climate sensing may add value in complex urban settings. The study period covered a single partial season; validation across multiple transmission seasons, additional provinces, and with complete statistical reporting is required before any operational application.

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Introduction

Dengue fever is one of the most important vector-borne viral diseases in tropical and subtropical regions. The World Health Organization (WHO) reports that more than 14.6 million dengue cases were recorded globally in 2024, the highest number within a single 12-month period and a marked increase from 505,430 reported cases in 2000, with dengue now endemic in more than 100 countries.1 In Cambodia, national surveillance data from 2002 to 2020 document sustained dengue transmission, rising incidence, and a shifting age distribution of infection.2 These trends underscore the need for responsive, evidence-based early warning systems that can support timely public health action.

The biological basis for climate-informed dengue surveillance is well established. Temperature influences mosquito development rates, adult survival, biting frequency, and the extrinsic incubation period of dengue virus. Rainfall can expand breeding-site availability, though this association is modified by local water storage, drainage infrastructure, and environmental management. Relative humidity affects adult mosquito survival and may reflect micro-environmental conditions not captured by distant regional weather stations. Because climate first alters mosquito ecology before changes appear in reported human cases, lagged associations between climate variables and dengue incidence are expected and biologically coherent.

Cambodia-specific evidence supports the feasibility of climate-informed surveillance. Choi and colleagues found that a 1°C increase in average maximum temperature was associated with increased dengue cases in Siem Reap and Kampong Thom, while a 1°C increase in average minimum temperature was associated with increased dengue incidence in Siem Reap and Banteay Meanchey.3 These findings establish the biological plausibility of temperature–dengue associations in Cambodian provinces but do not address the practical question of whether centralized meteorological infrastructure is adequate for early warning across ecologically diverse settings, or whether localized micro-climate sensing is needed where regional stations miss relevant local environmental variation.

Evidence from other Asian countries reinforces the value of spatially resolved and temporally granular climate data. Wang and colleagues analyzed weekly dengue data and daily meteorological data from 35 locations across Singapore, Malaysia, Sri Lanka, and Thailand (2012-2020) and found short-term associations between extreme temperature, extreme rainfall, and dengue risk using distributed lag non-linear models.4 Chan, Hu, and Hwang developed daily forecasting models for 457 urban villages in Kaohsiung City, Taiwan (2009–2012), and concluded that near real-time small-area prediction can support operational decision-making.5 These studies establish the principle that spatial resolution matters in dengue surveillance, but neither evaluated trade-offs between centralized and localized data streams in low- and middle-income country contexts.

The present study compares centralized regional meteorological data with localized micro-climate sensing in three Cambodian provinces representing distinct ecological and demographic settings: peri-urban and industrial (Kandal), agrarian (Kampong Cham), and urban-cultural (Siem Reap). Our aim was to generate exploratory evidence for the feasibility of a hybrid dengue early warning approach that combines regional meteorological infrastructure with targeted localized sensing.

Methods

Study Design

This was a longitudinal observational study conducted from June 2025 to January 2026. Local environmental sensing was implemented prospectively in selected communities. Dengue case data were obtained from routine National Dengue Control Program surveillance records, which were not generated as part of this study. The two data streams — prospective environmental monitoring and retrospective administrative surveillance data – had different data-generating processes, which limit inferential symmetry and should be considered when interpreting model estimates.

Study Sites

Three Cambodian provinces were selected to represent contrasting ecological and demographic settings:

- Kandal: peri-urban and industrial setting adjacent to Phnom Penh
- Kampong Cham: agrarian setting in central Cambodia
- Siem Reap: urban-cultural hub in northern Cambodia

These sites were chosen because climate–dengue relationships and the relative performance of centralized versus localized climate data may differ across environments with distinct land use, building density, water management, and micro-climate variability.

Data Sources

Epidemiological data were obtained from the National Dengue Control Program. Local climate data were collected using portable weather stations deployed in selected communities within each province. Regional climate data were obtained from the Ministry of Water Resources and Meteorology. The analysis compared the predictive signals produced by these two data sources for dengue incidence in each province. Full sensor specifications, placement criteria, deployment density per province, and missing-data rates were not documented in the source material and were therefore unavailable for this report.

Community Engagement and Field Protocols

Women household members in selected communities managed local sensing devices, supported by structured tools to promote data continuity. This component was intended to strengthen social inclusion and to assess the feasibility of community-based environmental monitoring. Contingency protocols addressed extreme weather events and data gaps.

Statistical Analysis

Negative binomial regression models were used to examine associations between climate variables and weekly dengue incidence. This regression family accommodates overdispersion, which is characteristic of infectious disease count data. Lag structures from 0 to 5 weeks were evaluated, where lag 0 denotes the same epidemiological week and lag 5 denotes climate conditions 5 weeks prior to the reported dengue count.

The source data did not specify the full model equation, offset term (required for incidence rate estimation), lag-selection method, overdispersion parameter, or whether centralized and localized data sources were compared using formal model-selection criteria such as the Akaike Information Criterion or likelihood ratio tests. Results should therefore be interpreted as exploratory model outputs rather than outputs from a fully pre-specified, reproducible predictive model.

Data Limitations Noted at Source

The source material did not report dengue case counts, population denominators, number of portable weather stations per province, sensor placement criteria, missing-data rates, confidence intervals for any model estimate, model diagnostic statistics, or out-of-sample predictive-performance metrics. These omissions prevent assessment of statistical precision, model fit, operational accuracy, and generalisability.

Results

Climate-based negative binomial regression models produced province-specific associations with dengue incidence, with findings differing by province and data stream. All results should be interpreted with caution: the observation window covered June 2025 to January 2026 a single partial dengue season and no confidence intervals were reported for any model estimate, which prevents assessment of statistical precision.

Kandal

In Kandal, centralized meteorological data identified a statistically significant temperature signal. A 1°C rise in temperature was associated with an IRR of 1·31 ($p<0·001$) at a 3-week lag. This is the most statistically complete finding reported in the study. The absence of a confidence interval nevertheless prevents evaluation of the precision of this estimate.

Kampong Cham

In Kampong Cham, centralized data produced point estimates for both temperature and relative humidity. Temperature was associated with an IRR of 1·20 at a 3-week lag, and relative humidity was associated with an IRR of 1·03 at a 1-week lag. The unit of relative humidity measurement was not specified in the source material. Neither p-values nor confidence intervals were reported for either estimate. These results should be regarded as observed model point estimates rather than as confirmed associations.

Siem Reap

In Siem Reap, localized relative humidity was associated with an IRR of 1·09 ($p<0·001$) at a 4-week lag. The unit of relative humidity was not specified. Centralized meteorological data were reported as non-significant; however, no model coefficient, p-value, confidence interval, or formal model-comparison statistic was provided for the centralized model in this province. The conclusion that localized sensors produced a stronger signal than centralized data in Siem Reap is therefore provisional, not formally demonstrated.

Summary of Findings

Table 1: Table 1. Climate–dengue model estimates by province, variable, lag, and data stream.

Province	Climate Variable	Lag	IRR	*p* value	Data Stream	Statistical Status
Kandal	Temperature	3 wk	1·31 per 1°C	<0·001	Centralized	Statistically significant; CI not reported
Kampong Cham	Temperature; relative humidity	3 wk; 1 wk	1·20; 1·03†	NR	centralized	Point es-times only; CI and *p* unavailable
Siem Reap	Relative humidity	4 wk	1·09†	<0·001	Localized	Statistically signific-can't; centralize d model non-significant, but no comparison metrics reported; CI not reported

CI = confidence interval; IRR = incidence rate ratio; NR = not reported; wk = week.

†Unit of relative humidity not specified in source material.

Discussion

This exploratory longitudinal study found province-specific associations between climate variables and dengue incidence across three Cambodian provinces. In Kandal, centralized temperature data identified an IRR of 1·31 per 1°C rise (p<0·001) at a 3-week lag. In Kampong Cham, centralized temperature and humidity data produced point estimates of 1· 20 and 1· 03 at 3-week and 1-week lags, respectively, but without p-values or confidence intervals, these cannot be interpreted as confirmed associations. In Siem Reap, localized relative humidity was associated with an IRR of 1· 09 (p<0· 001) at a 4-week lag, while centralized data were non-significant, suggesting a potential – though unconfirmed – advantage for localized sensing in this urban-cultural setting.

The Kandal temperature finding is consistent with Cambodia-specific evidence from Choi and colleagues, who identified positive associations between temperature and dengue incidence in Cambodian provinces.3 A 3-week lag is biologically plausible: it is broadly consistent with the combined duration of the extrinsic incubation period, adult mosquito gonotrophic cycles, and the interval between human infection and case detection. However, direct comparison with Choi et al. is inappropriate because the provinces, model structures, temperature metrics, and observation periods differ. The appropriate interpretation is that the Kandal finding is biologically and epidemiologically plausible, not that it independently replicates or extends that earlier study.

The Siem Reap finding requires particular interpretive caution. A plausible mechanism for localized humidity outperforming centralized data in an urban-cultural setting is that dense built environments, vegetation cover, artificial water containers, and localized water storage create micro-climatic humidity gradients that support Aedes aegypti survival and breeding in ways not captured by distant regional weather stations. However, this explanation is inferential: the study did not report entomological data, breeding-site surveys, sensor placement details, or formal model-comparison statistics between localized and centralized streams. The claim of localized superiority in Siem Reap is operationally important but is not formally demonstrated and must be treated as a hypothesis for further testing.

This Siem Reap result is conceptually consistent with the broader principle that fine spatial resolution can improve dengue risk prediction in urban areas, as demonstrated by Chan and colleagues in Kaohsiung City, Taiwan.5 However, findings from a well-resourced Taiwanese city with daily surveillance data across four years should not be cited as direct support for localized sensors in a Cambodian provincial context. The operational conditions, surveillance infrastructure, and data quality differ substantially.

The Kampong Cham humidity estimate (IRR 1·03) requires particular scrutiny. An IRR of this magnitude is likely to be of limited operational significance for early warning purposes. If relative humidity is measured in single percentage points, a 3% increase in dengue risk per 1-percentage-point rise is modest and potentially within the range of residual confounding, measurement noise, or chance. The absence of a confidence interval, p-value, and humidity unit specification makes this estimate uninterpretable in its current form. It should not be presented in the Abstract or Discussion as evidence of a dual climate signal in Kampong Cham.

The present findings are consistent with WHO's strategic direction on integrated dengue surveillance. WHO's 2024 Global Strategic Preparedness, Readiness and Response Plan emphasizes strengthened surveillance and coordinated response across endemic settings.6 A hybrid surveillance model that pairs centralized meteorological data with targeted localized sensing is consistent with this strategic direction, provided it is rigorously validated before operational use.

Several limitations are critical. First, the study covered a single partial dengue season. Cambodia's dengue transmission is strongly seasonal and exhibits year-to-year variability driven by serotype circulation, population immunity, rainfall patterns, and human movement. A model that performs over a single partial season provides no assurance of generalisability to other transmission years. Second, no confidence intervals were reported for any model estimate, which prevents assessment of statistical precision, sample adequacy, or comparability across provinces. Third, no formal model-comparison statistics were reported across data streams; the designation of one data source as superior in Siem Reap is therefore not supported by formal statistics. Fourth, dengue surveillance data may be affected by care-seeking behaviour, reporting delays, diagnostic availability, and changes in surveillance intensity — all of which can introduce systematic bias. Fifth, the study did not report predictive-performance metrics relevant to operational early warning, such as sensitivity, specificity, timeliness, false-alarm rate, or calibration.

These findings suggest three priorities for future work. First, the model should be validated across additional provinces and at least two consecutive full dengue seasons, with complete model specifications, confidence intervals, p-values, humidity units, and formal model-comparison statistics reported. Second, sensor deployment should be documented with respect to placement criteria, density, and missing-data rates. Third, operational utility requires pre-defined alert thresholds linked to specific public health actions — source reduction, vector control, community communication, health facility preparedness — tested for sensitivity and false-alarm rate before any programmatic adoption.

In summary, this study provides exploratory evidence that a hybrid climate-based dengue early warning approach — centralized meteorological data as the national backbone, with targeted localized sensing in complex urban environments — may be feasible in Cambodia. This evidence is insufficient for national scale-up. Validation across seasons and provinces, with full statistical reporting, remains the necessary next step.

Contributors

Dr. Leang Rithea serves as the technical lead and provides implementation support. Mr. Kimsan is responsible for data management. Dr. Yoeuk Soklin, Mr. Sam Bunleng, Dr. Norng Sokra, and Ly Sokha contribute to conceptualization, methodology, and field coordination. Dr. Chan Vibol oversees statistical analysis, interpretation, technical report writing, and supervision.

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