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INFLUENCE OF BIOCLIMATIC CONDITIONS ON REPORTED UNCOMPLICATED AND SEVERE MALARIA CASES IN THE SECOND DISTRICT OF COTONOU, BENIN

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ABSTRACT

Malaria remains a major public health concern in Benin, and its seasonal pattern may be influenced by local climate. This study examined associations between bioclimatic conditions and reported uncomplicated and severe malaria cases in the second district of Cotonou. Monthly temperature, relative humidity and rainfall data for 1995-2024 were obtained from Météo-Bénin, while monthly malaria data for 2005-2024 were obtained from the Littoral Departmental Health Directorate. A field survey involving 142 adults provided contextual information on local vulnerability and adaptation. Two study-specific indicators, an air enthalpy index and an adjusted rainfall-temperature index, were calculated. Monthly patterns were described and exploratory Pearson correlations were estimated using 12 calendar-month observations. The district has a subequatorial climate with two rainy and two dry seasons. Reported uncomplicated malaria cases peaked in July at 2743, whereas severe malaria cases peaked in August at 1050. Rainfall correlated more strongly with uncomplicated malaria ($r=0.419$) than with severe malaria ($r=0.096$). Relative humidity showed correlations of $r=0.641$ with uncomplicated malaria and $r=0.528$ with severe malaria. The adjusted rainfall-temperature index correlated moderately with uncomplicated malaria ($r=0.396$) but only weakly with severe malaria ($r=0.070$). The hypothesis was therefore partially supported: climatic conditions were more closely associated with uncomplicated malaria than with severe disease. Climate-informed surveillance and intensified vector-control activities should be prioritized before and during high-risk rainy months, while the ecological design and absence of population denominators require cautious interpretation.

Keywords: Biometeorology; Disease seasonality; *Plasmodium*; Urban vulnerability; Vector-borne transmission; West Africa

1 INTRODUCTION

Malaria is caused by Plasmodium parasites and transmitted through the bites of infected Anopheles mosquitoes. In 2023, an estimated 263 million malaria cases and 597,000 deaths occurred worldwide, with the overwhelming burden concentrated in the African Region [1]. Climatic conditions affect mosquito survival, breeding-site availability, parasite development and human-vector contact. Rainfall, temperature and relative humidity are therefore important determinants of malaria seasonality, although their effects vary across ecological and urban settings [2].

Benin continues to face a substantial malaria burden. National information indicates that malaria accounts for a large proportion of outpatient consultations and hospital admissions [3]. Cotonou, the economic capital, combines a humid tropical climate, rapid urbanization, shallow groundwater, flood-prone zones and uneven drainage. These conditions can create standing-water habitats that support mosquito breeding [4,5]. Previous research in southern Benin has also reported seasonal links between climate and malaria or other climate-sensitive diseases [6-8].

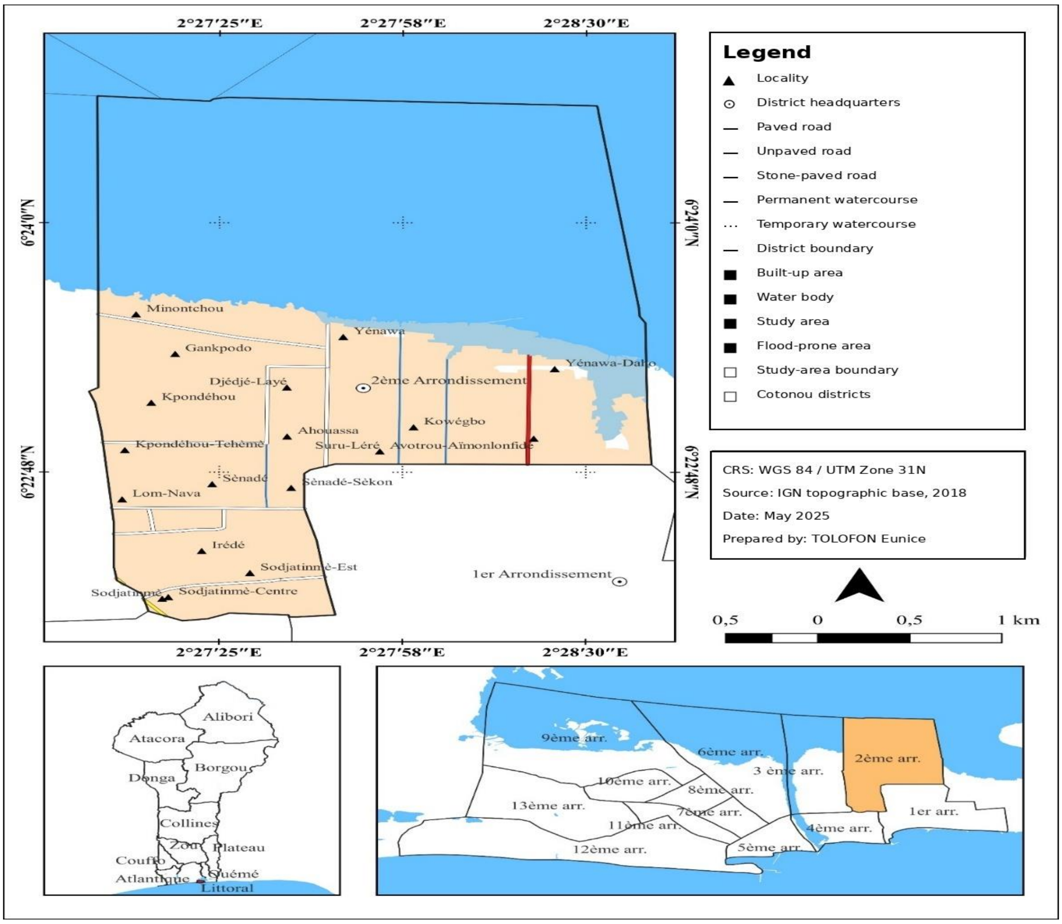
The original manuscript used the term prevalence, although the available epidemiological dataset contained case counts without corresponding population denominators. The outcome is therefore reported here as monthly malaria case counts rather than prevalence. The study aimed to assess how rainfall, temperature and relative humidity, together with two study-specific bioclimatic indicators, were associated with reported uncomplicated and severe malaria cases in the second district of Cotonou. The hypothesis was that rainy, humid and moderately warm periods would be associated with higher malaria case counts, particularly for uncomplicated malaria.

2 MATERIALS AND METHODS

2.1 Study area

The study was conducted in the second district of Cotonou, Benin. Cotonou is divided into 13 districts and 143 urban neighborhoods. The second district contains 13 neighborhoods and lies approximately between 6°22′48″ and 6°24′00″ N and 2°27′25″ and 2°28′30″ E. It is bordered by Lake Nokoué to the north, the third district to the west, the first district to the east and the fourth district to the south.

Figure 1 shows the geographical location of the study area.



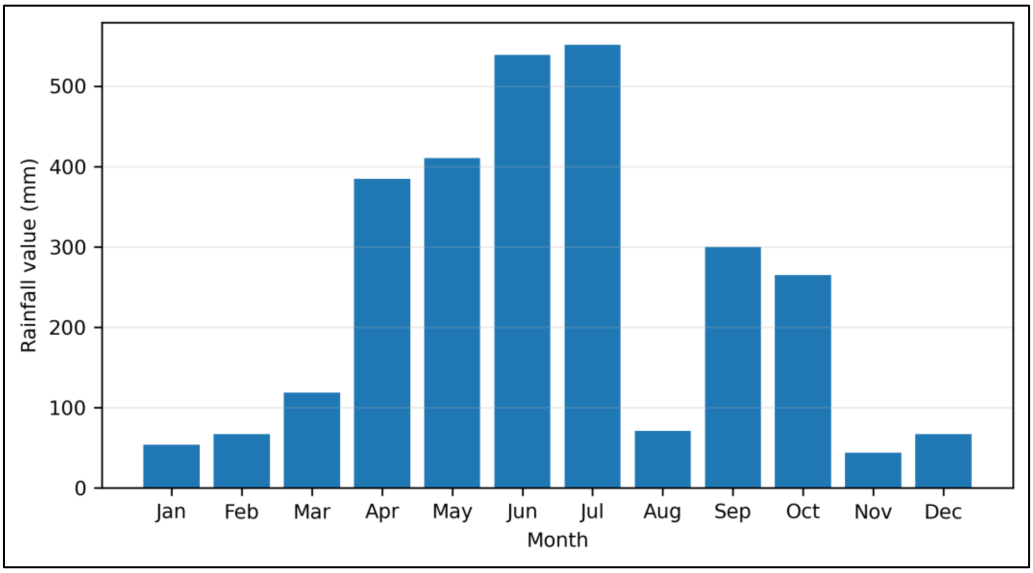
Source: IGN topographic base; map prepared by TOLOFON Eunice, May 2025.

Figure 1: Geographical location of the second district of Cotonou.

The local climate is subequatorial and humid, with a long dry season from November to March, a long rainy season from mid-March to July, a short dry season from mid-July to mid-September and a short rainy season from mid-September to October. Monthly mean temperatures generally range from approximately 27°C to 31°C. Lake Nokoué, the Cotonou lagoon and the Atlantic Ocean influence local hydrology. The fourth national population and housing census reported 61,668 inhabitants in the second district in 2013, including 29,426 men and 32,242 women [5].

2.2 Data sources

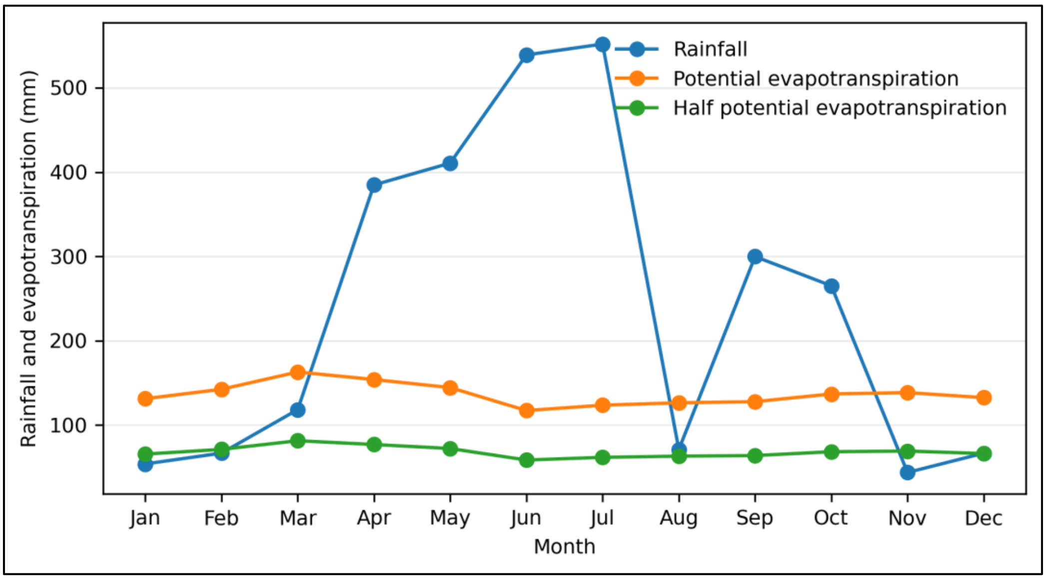
Monthly climate data, including rainfall, temperature and relative humidity, were obtained from the National Meteorological Agency of Benin (Météo-Bénin) for 1995-2024. Monthly uncomplicated and severe malaria case data for 2005-2024 were extracted from the database of the Littoral Departmental Health Directorate. The series used in the original analysis were summarized by calendar month. Raw annual records and population denominators were not available in the submitted manuscript; consequently, the analysis describes seasonal case-count patterns and does not estimate incidence or prevalence.



Data source: Météo-Bénin, 2025.

Figure 2: Monthly rainfall values used in the analysis, second district of Cotonou, 1995-2024

Figure 3 compares rainfall with potential evapotranspiration and half potential evapotranspiration.



Data source: Météo-Bénin, 2025.

Figure 3: Monthly rainfall and potential evapotranspiration in the second district of Cotonou.

The monthly rainfall values used in the source analysis are displayed in Figure 2. Because their sum is not consistent with the annual mean stated in the original draft, the unsupported annual-mean statement was removed rather than altering the supplied values.

2.3 Bioclimatic indicators

Two study-specific indicators were retained from the original analysis. The first was an air enthalpy index intended to combine thermal and humidity conditions:

$$h = c_p T + (R_v T/\varepsilon)RH$$

where h is the air enthalpy index, c_p is the specific heat capacity of dry air, T is air temperature, R_v is the gas constant for water vapor, ε is a thermodynamic ratio and RH is relative humidity. The original computation and cut-offs were not independently validated; the indicator is therefore interpreted comparatively across months rather than as a clinical measure of heat stress.

Table 1: Operational interpretation of air enthalpy values retained from the original study.

Air enthalpy value	Category	Operational interpretation
10-20	Thermal comfort	Pleasant conditions, with little or no thermal stress.
20-40	Moderate heat	Mild heat sensation and possible discomfort.
40-60	High heat	Marked thermal discomfort and moderate heat-stress risk.
>60	Extreme heat	High risk of heat stress and heat-related illness.

The second indicator was the adjusted rainfall-temperature index (ARTI), a normalized composite developed for this study:

$$ARTI = (P/Pmax) \times (T/Topt)$$

where P is monthly rainfall, Pmax is the reference maximum rainfall, T is monthly temperature and Topt is the reference temperature considered favorable for mosquito development, set at 27°C in the original analysis. Higher values indicate a combination of rainfall and temperature considered more favorable for mosquito breeding. The categories in Table 2 are operational thresholds used in the source study and should not be interpreted as externally validated risk cut-offs.

Table 2: Operational interpretation of the adjusted rainfall-temperature index.

ARTI	Risk category	Operational interpretation
0.0-0.2	Low	Climate considered unfavorable for mosquito proliferation.
>0.2-0.5	Moderate	Conditions considered favorable, but without high risk.
>0.5-0.8	High	Conditions considered favorable for mosquito breeding and malaria transmission.
>0.8-1.0	Very high	Conditions considered highly favorable for rapid mosquito proliferation.

2.4 Field survey and sampling

A complementary cross-sectional field survey was conducted among local authorities, health professionals and adult household respondents. Five of the 13 neighborhoods were selected: Gankpodo, Suru-Léré, Kpondéhou, Sènadé Sékou and Yénawa. Household eligibility criteria were adulthood, residence in the study area for at least 10 years and sufficient familiarity with local conditions. The source protocol initially calculated a minimum of 68 households using the Schwartz formula, $n=Z^2pq/i^2$, with p=0.227, q=0.773, Z=1.96 and precision i=0.10. Seventy households were ultimately surveyed.

Table 3: Distribution of surveyed participants by neighborhood.

Neighborhood	Local authorities	Households	Health professionals	Total
Gankpodo	2	14	8	24
Suru-Léré	1	15	58	74
Kpondéhou	1	14	0	15
Sènadé Sékou	1	13	0	14
Yénawa	1	14	0	15
Total	6	70	66	142

The questionnaire addressed knowledge of malaria, perceived periods of occurrence, perceived relationships with rainfall, humidity and temperature, adaptation practices and local vulnerability. Survey information was used to contextualize the environmental analysis; the manuscript did not contain a complete quantitative survey-results dataset, so no unsupported survey percentages were introduced.

2.5 Statistical analysis

Data entry and descriptive processing were performed in Microsoft Excel. Exploratory Pearson correlation coefficients were used to assess linear relationships among the monthly climate variables, the bioclimatic indicators and malaria case counts. The coefficient ranges from -1 to +1; its sign indicates direction and its absolute magnitude indicates strength. For interpretation, $|r|<0.30$ was considered weak, 0.30-0.59 moderate and ≥0.60 strong. Correlation does not establish causality. No p-values or confidence intervals were available, and the effective analysis included only 12 calendar-month observations; the results are therefore descriptive and exploratory.

2.6 Ethical considerations

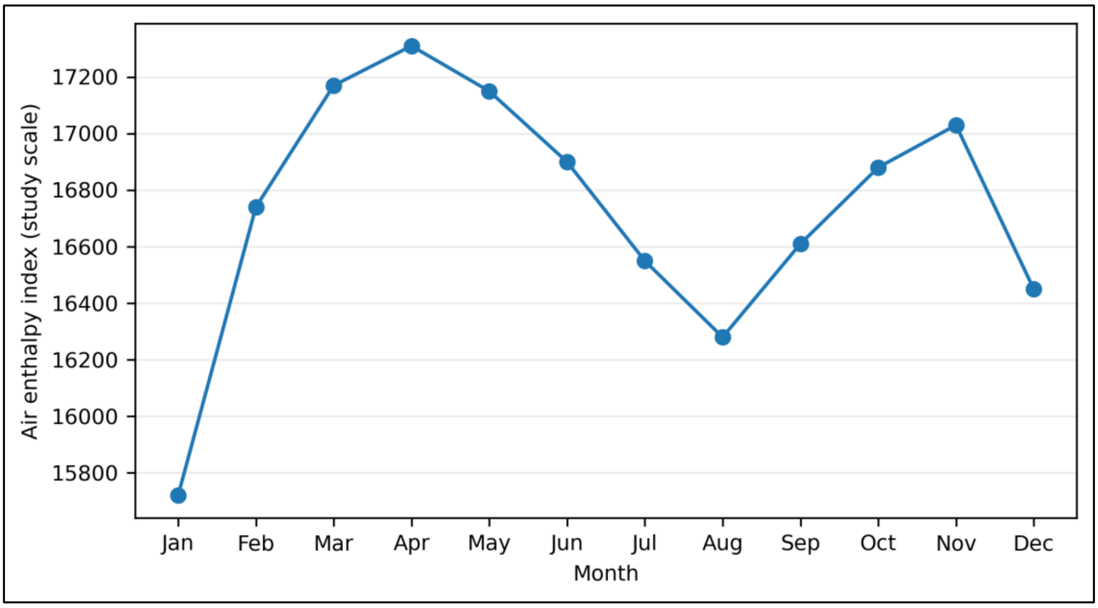
The study did not undergo formal review by an institutional ethics committee. All survey participants were adults, participation was voluntary and informed consent was obtained before data collection. No minors were included. The survey was conducted without collecting identifying information, and responses were treated confidentially. Administrative health and meteorological data were analyzed in aggregated form.

3 RESULTS AND DISCUSSION

3.1 Seasonal bioclimatic patterns

The rainfall and evapotranspiration series indicate two rainy periods and two drier periods. The highest supplied rainfall values occurred in June and July, followed by a secondary rise in September and October. The dry-season months generally showed lower rainfall and relatively higher evapotranspiration. These seasonal conditions can alter the availability and persistence of mosquito breeding sites [13], although heavy rainfall may also flush some habitats and local drainage conditions can modify the relationship.

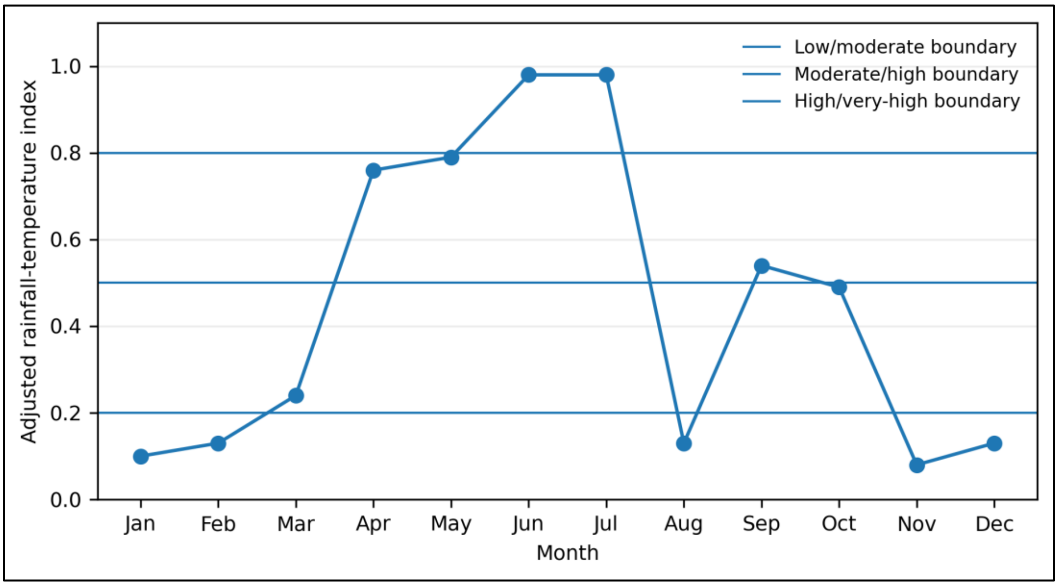
The air enthalpy index varied across the year, with the highest values in March and April and a secondary increase in November. Lower values occurred around August and December (Figure 4). Because this is a study-specific index and its physical calibration is uncertain, its role is interpreted through correlations rather than absolute comfort categories.



Data source: Météo-Bénin; study-specific calculation.

Figure 4: Monthly variation in the air enthalpy index in the second district of Cotonou.

The ARTI increased sharply from March, reached its highest values in June and July, fell in August, and showed a secondary increase in September and October (Figure 5). This pattern largely reflects rainfall because the index is normalized by rainfall and was strongly correlated with rainfall in the source analysis.

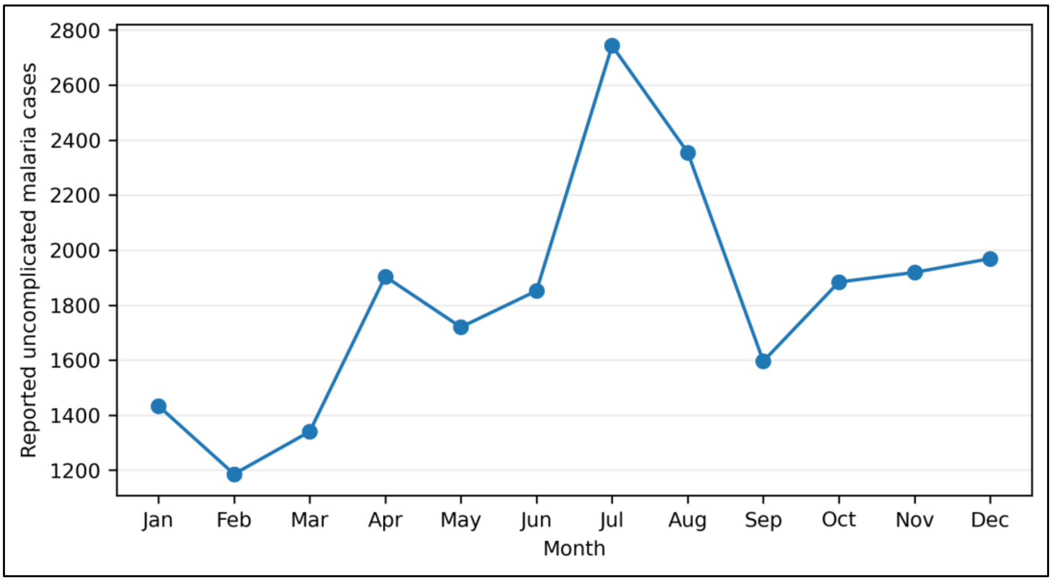


Data source: Météo-Bénin; study-specific calculation.

Figure 5: Monthly variation in the adjusted rainfall-temperature index in the second district of Cotonou.

3.2 Monthly malaria case patterns

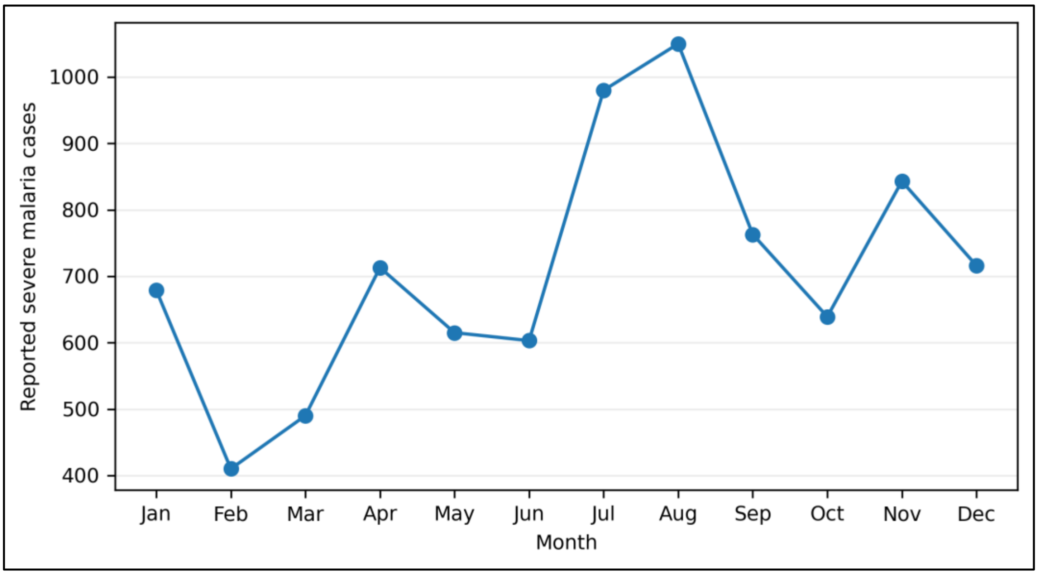
Reported uncomplicated malaria cases varied from 1186 in February to 2743 in July (Figure 6). Counts increased from March to April, remained elevated in June, reached their maximum in July and remained high in August. After a decline in September, counts increased again from October through December. This corrected description differs from the original draft, which incorrectly reported 716 uncomplicated cases in December; the embedded source chart shows 1969 cases.



Data source: Littoral Departmental Health Directorate, 2005-2024 series.

Figure 6: Monthly reported uncomplicated malaria cases in the second district of Cotonou.

Severe malaria cases ranged from 410 in February to 1050 in August (Figure 7). Counts declined from January to February, increased in March and April, remained between 603 and 615 in May and June, and rose sharply in July and August. They subsequently declined in September and October, increased in November and fell again in December. The later peak in severe malaria may be compatible with delays between infection, care seeking and progression, but this ecological dataset cannot test that mechanism.

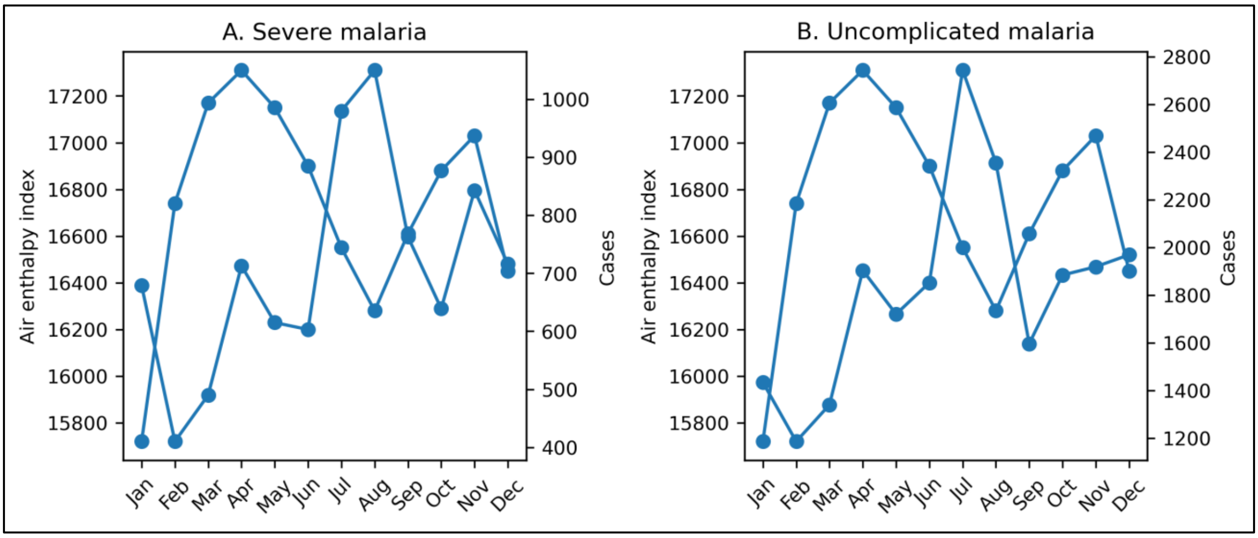


Data source: Littoral Departmental Health Directorate, 2005-2024 series.

Figure 7: Monthly reported severe malaria cases in the second district of Cotonou.

3.3 Correlations between climate and malaria

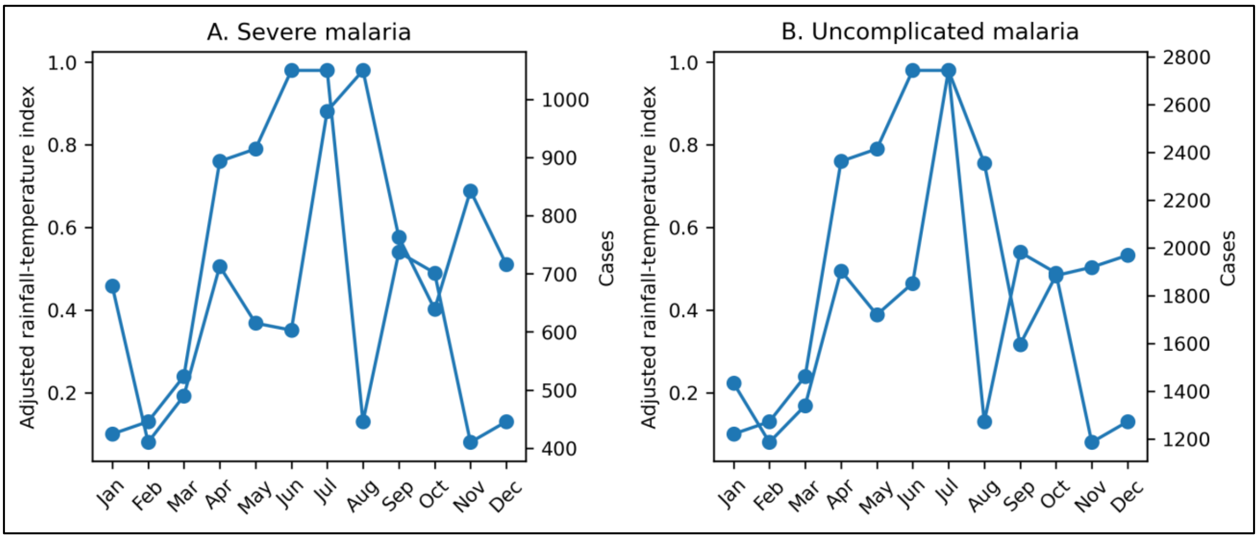
The air enthalpy index showed weak negative correlations with uncomplicated malaria (r=-0.094) and a moderate negative correlation with severe malaria (r=-0.338). Figure 8 illustrates that monthly malaria patterns did not closely track the enthalpy index. This suggests that the composite index, as calculated in the source study, did not capture malaria seasonality as clearly as rainfall or humidity.



Data sources: Météo-Bénin and Littoral Departmental Health Directorate.

Figure 8: Monthly malaria case counts in relation to the air enthalpy index: (A) severe malaria and (B) uncomplicated malaria.

ARTI correlated weakly with severe malaria (r=0.070) and moderately with uncomplicated malaria (r=0.396). The association was therefore more evident for uncomplicated malaria (Figure 9). Because ARTI was almost perfectly correlated with rainfall (r=0.998), it added limited independent information beyond rainfall in this dataset.



Data sources: Météo-Bénin and Littoral Departmental Health Directorate.

Figure 9: Monthly malaria case counts in relation to the adjusted rainfall-temperature index: (A) severe malaria and (B) uncomplicated malaria.

Uncomplicated and severe malaria case counts were strongly correlated with each other (r=0.854), indicating broadly shared seasonality. Relative humidity was strongly correlated with uncomplicated malaria (r=0.641) and moderately correlated with severe malaria (r=0.528). Rainfall showed a moderate correlation with uncomplicated malaria (r=0.419) but only a weak correlation with severe malaria (r=0.096). Temperature was negatively correlated with both outcomes, which may reflect the inverse seasonal relationship between temperature and humidity or rainfall in Cotonou rather than a direct protective effect of warmth.

The observed seasonal pattern is consistent with research from southern Benin reporting climate-sensitive malaria dynamics [6-8,12]. Studies from Bamako and Tourou have likewise emphasized the importance of rainfall, standing water, vegetation and human behavior in mosquito abundance or malaria risk [10,11]. However, severe malaria depends not only on infection pressure but also on host immunity, age, comorbidities, diagnostic delay, treatment access and quality of care. This may explain why the climatic correlations were weaker for severe than for uncomplicated malaria.

The study hypothesis was partially supported. Rainfall and humidity were related more clearly to uncomplicated malaria than to severe malaria, and the study-specific ARTI reflected this difference. The findings support intensified drainage, larval-source management, insecticide-treated-net use, risk communication and health-service preparedness before and during the main rainy season. These actions should be adapted to neighborhood-level flooding and sanitation conditions.

Table 4: Pearson correlation matrix for malaria case counts, bioclimatic indicators and climate variables.

Variable	Air enthalpy	Severe malaria	Uncomplicated malaria	Temperature	Humidity	Rainfall	ARTI
Air enthalpy	1.000	-0.338	-0.094	0.457	0.209	0.363	NA
Severe malaria	-0.338	1.000	0.854	-0.700	0.528	0.096	0.070
Uncomplicated malaria	-0.094	0.854	1.000	-0.645	0.641	0.419	0.396
Temperature	0.457	-0.700	-0.645	1.000	-0.774	-0.348	-0.305
Humidity	0.209	0.528	0.641	-0.774	1.000	0.640	0.615
Rainfall	0.363	0.096	0.419	-0.348	0.639	1.000	0.998
ARTI	NA	0.070	0.396	-0.305	0.615	0.998	1.000

3.4 Study limitations

This study has several limitations. First, the analysis was ecological and based on 12 calendar-month observations, so causal inference and assessment of delayed climate effects were not possible. Second, malaria denominators were unavailable; case counts may reflect population size, care-seeking behavior, diagnostic practices and reporting completeness. Third, the original dataset did not provide statistical uncertainty, annual raw records or complete survey outcomes. Fourth, the rainfall series contained an inconsistency between the plotted monthly values and the annual mean stated in the initial draft; the annual-mean claim was therefore removed. Finally, the air enthalpy and ARTI cut-offs were study-specific and were not externally validated. Future analyses should use monthly time-series regression with lag terms, population denominators, diagnostic-confirmation data and spatially resolved environmental variables.

4 CONCLUSIONS

Reported malaria cases in the second district of Cotonou displayed marked seasonal variation. Uncomplicated malaria peaked in July, whereas severe malaria peaked in August. Rainfall, relative humidity and the adjusted rainfall-temperature index were more closely associated with uncomplicated than with severe malaria, while the air enthalpy index showed weak or inverse relationships. These findings indicate that climate-informed surveillance may help identify periods requiring intensified vector control, community prevention and health-service readiness. Nevertheless, climatic conditions alone do not determine severe disease, and the ecological design, absence of denominators and limitations of the source indicators require cautious interpretation. More robust longitudinal studies should integrate climate lags, environmental sanitation, confirmed malaria diagnoses, access to care and population vulnerability.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The author thanks Météo-Bénin and the Littoral Departmental Health Directorate for facilitating access to aggregated meteorological and epidemiological records, as well as the survey respondents for their participation.

Disclosure of conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Statement of ethical approval

The study protocol involved non-invasive household surveys and secondary analysis of aggregated administrative and meteorological records without individual identifiers. Formal institutional review board clearance was not required for this descriptive study.

Statement of informed consent

Informed consent was obtained from all individual adult participants prior to survey administration. No minors were enrolled.

Authors' contributions

Nouvêwa Patrice Maximilien BOKO conceived and designed the study, performed data acquisition, statistical analyses, and graphical visualizations, and drafted, revised, and approved the final manuscript.

Data availability

Climatic and epidemiological data were obtained from official databases of Météo-Bénin and the Littoral Departmental Health Directorate and are subject to institutional data-sharing policies. The derived monthly analytical matrix is available from the corresponding author upon reasonable request.

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