Environmental Modelling of Malaria Risk Areas in The Local Governments of Sakété and Ifangni, in Southeastern Benin

Parfait C. Alexis AHOHOUNDO[1], Yémalo ZANNOU[2], Fadélé David KITON[3], Virgile Narcisse Sènan AYIMADE[4]

[1]PhD student in Geography at University of Abomey-Calavi (UAC)/BENIN

[2]Ketou-Adja-Ouèrè-Pobè Health Zone Office, Ministry of Health

[3]University of Abomey-Calavi (UAC) / Multidisciplinary Doctoral School-Space, Culture, and Development

[4]PhD in Geography at the University de Brest (UBO

DOI: https://dx.doi.org/10.47772/IJRISS.2026.10100613

Received: 31 January 2026; Accepted: 06 February 2026; Published: 19 February 2026

ABSTRACT

Malaria remains a major public health challenge in Benin, with transmission strongly influenced by local environmental and climatic conditions. Identifying areas at high risk is essential for guiding targeted interventions. This study aimed to model environmental determinants of malaria risk in the local government areas of Sakété and Ifangni in southeastern Benin. Climatic data (temperature and relative humidity) and remote sensing-derived environmental indices, including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Pond Index (NDPI), were analyzed to assess their association with malaria morbidity. A linear mixed-effects model was used to quantify the contributions of these variables to spatial variations in malaria prevalence. Risk maps were generated by integrating climatic and environmental predictors. Malaria morbidity exhibited a heterogeneous spatial distribution, with higher incidence observed in areas combining favorable climatic conditions and suitable environmental habitats for Anopheles mosquitoes. Temperature and relative humidity were identified as primary climatic determinants, influencing vector survival and parasite development. NDVI and NDPI were positively associated with malaria risk, indicating the importance of vegetation cover and aquatic habitats as breeding sites, while NDWI highlighted the role of soil surface moisture in sustaining larval habitats. The resulting risk map effectively delineated high-risk zones, providing a spatially explicit tool for targeted malaria control.

Environmental modelling combining climatic and remote sensing variables provides valuable insights into spatial patterns of malaria risk. The generated maps can support evidence-based targeting of vector control and public health interventions in southeastern Benin.

Keywords: Malaria risk, Climatic factors, environmental indices, Spatial epidemiology, Sakété and Ifangni

INTRODUCTION

Vector-borne diseases are a major public health issue worldwide (K. Gromek and al., 2020, p. 49). Tropical and subtropical regions are particularly prone to the spread of these diseases, with an almost constant risk of transmission (K. S. Palo and al., 2025, p. 1). In most vulnerable areas, vector-borne diseases, due to their scale, contribute to putting strain on health systems that are already weakened by various contingencies. This is the case with malaria, a parasitic disease that is rampant in regions lacking adequate medical infrastructure (J. O. Dada, 2023, p. 1).

Recent statistics from the World Health Organization indicate that between 2000 and 2024, approximately 2.2 billion cases of malaria and 12.7 million deaths were prevented thanks to initiatives to combat the disease (WHO,

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue I January 2026

2024, p. 2). This progress is the result of a combination of effective interventions and preventive measures (C. Birane and al., 2016, p. 276). According to M. A. Tewara and al. (2018, p. 2), these control measures include rapid diagnosis of cases, the use of insecticide- treated mosquito nets, access to appropriate antimalarial treatments, and targeted awareness campaigns. However, the impact of the disease remains strongly felt in many African regions, where persistent disparities in preventive treatments and essential interventions increase the population's exposure to the risk of malaria.

In Africa, the available literature largely addresses the issue of malaria in general terms, while discussing the multiple factors involved. In this regard, E. U. Alum and al. (2024, p. 8) emphasize the major role of climatic and environmental determinants in amplifying conditions conducive to transmission. Similarly, O. Okunlola and O. Oyeyemi (2019, p. 1) argue that, depending on the nature of the living environment (rural or urban), the type of landscape and ground cover have a decisive influence on the incidence of the disease. Despite the implementation of preventive measures such as insecticide-treated mosquito nets and indoor spraying, the risk of transmission remains much higher in rural areas due to the dense and diverse vector population present (T. Z. Nigussie and al., 2023, p. 2).

In the Republic of Benin, malaria experiences seasonal variations in all regions of the country (R. Aïkpon and al., 2020, p. 2). As pointed out by F. T. Tokponnon and al. (2023, p. 2), this eco-climatic variability leads to heterogeneity in transmission, with significant disparities in malaria risk levels between the south and north of the country (PNLP, 2023, p. 4). Indeed, despite the government's efforts at various levels to combat malaria, high prevalence persists in regions with abundant rainfall and warm temperatures. Consequently, the seasonal agricultural transformations that structure the landscape of the municipalities of Sakété and Ifangni contribute to shaping specific spatial configurations resulting from changes in the natural environment (A. Z. S. Honvo and A. C. Dossou-Yovo, 2021, p. 3). Indeed, the expansion of cultivated areas and the proliferation of micro-developments contribute to the proliferation of microhabitats conducive to the formation of larval breeding sites (A. Sovi and al., 2013, p. 1). This situation not only increases the presence of vectors, but also the exposure of human populations to vector-borne diseases, thus reflecting increased health vulnerability (P. C. A. Ahohoundo and G. Boni, 2024, p. 103).

In the context of this study, spatial modeling of malaria-related health risks based on the integration of geographical and environmental determinants is a fundamental lever of health geography, in that it provides a better understanding, identifies vulnerable areas, and guides prevention and intervention strategies tailored to local contexts.

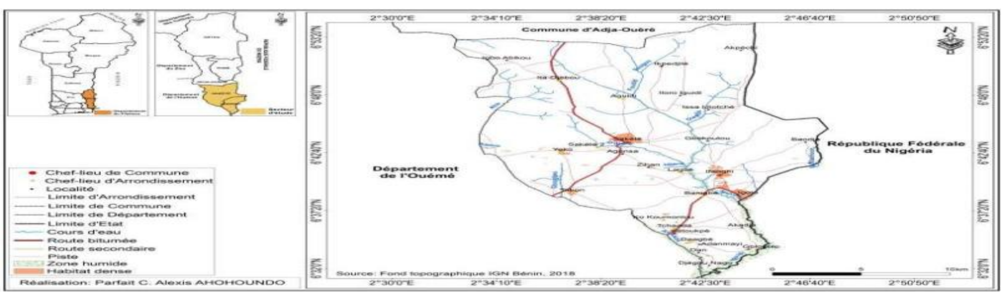
MATERIALS AND METHODS

Description of the research environment

The study area covers the municipalities of Sakété and Ifangni, one of the health zones in the Plateau department in southeastern Benin. It lies between 6°30' and 6°53' north latitude and between 2°32' and 2°47' east longitude. It covers an area of 654 km^2 and shares its administrative boundaries with the

municipality of Adja-Ouèrè to the north, the municipality of Adjarra to the south, the department of Ouémé to the west, and approximately 51 km of border with the Federal Republic of Nigeria to the east (Figure 1).

Figure 1: Geographic location of the Sakété-Ifangni health zone



The landscape of these two municipalities is characterized by vegetation consisting mainly of wooded savannas and shrublands, remnants of sacred forests, oil palm plantations (Elaeis guineensis), and fallow shrublands (L. Fagbohoun and al., 2014, p. 57). This vegetation cover, on fairly well-drained land conducive to the creation of Anopheles microhabitats, provides important refuges for mosquitoes. These breeding grounds and the presence of the vector, combined with the scattered human population in the numerous hamlets, determine the level of transmission and the risk of contracting malaria in the municipalities of Sakété and Ifangni.

MATERIALS AND METHODS

Study data

Conducting this study required the mobilization of several data sets from various sources. Table I shows the types of data used.

Table I: Characteristics of the data used

N°	Type of data	Nature	Source	Usefulness
1	Epidemiological	Incidental cases of malaria	Health zone	Cumulative malaria incidence
2	Climatic	Precipitation, temperature and relative humidity	Météo-Bénin	Local rainfall, temperature and humidity conditions
3	Satellite	Landsat 8 images collection SRTM image	USGS	NDVI, NDWI and NDPI Hypsometric factor
4	Spatial	Administrative boundaries	IGN	Thematic mapping

Sources: SNIGS Sakété-Ifangni, Météo-Bénin et INStaD, 2013 - 2022; IGN, 2018

This dataset has been processed purely for cartographic and statistical purposes.

Data processing and analysis methods

Data processing

Malaria cases from 2013 to 2022 were used to calculate the cumulative incidence of the disease in the local government of Sakété and Ifangni. The formula is as follows:

$$\textbf{\textit{Incid cuml}} = \frac{\textit{number of incidents of malaria in a given period}}{\textit{Population at risk}} * \mathbf{1000} \quad (1)$$

The average morbidity indicator for the decade was calculated and spatialized in the form of a histogram for each district of the two municipalities. Climate data (rainfall, temperature, and humidity) were interpolated using the kriging method. In addition, three indices (NDVI, NDWI, and NDPI) were generated to characterize vegetation cover, soil moisture, and the presence of water bodies, respectively, based on analysis of spectral bands from Landsat 8 satellite imagery (Table II).

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue I January 2026

Table II: Spectral indices of vegetation, soil moisture, and ponds

Indices	Titles	Formula	Sources
NDVI	Normalized Difference Vegetation Index	(NIR-R) / (PIR+R)	C. Tucker (1979)
NDWI	Normalized Difference Water Index	(NIR-SWIR1) / (PIR+MIR1)	B. C. Gao (1996)
NDPI	Normalized Difference Pond Index	(G-SWIR1) / (G+SWIR1)	J. P. Lacaux and al. (2007)

NIR: Near Infrared - **R**: Red - **SWIR**: Mid Infrared - **G**: Green

Source: Results of documentary research, 2023

These radiometric indices are generated using Google Earth Engine (GEE) technology from a programming language written as a script in the code editor (Photo 1).

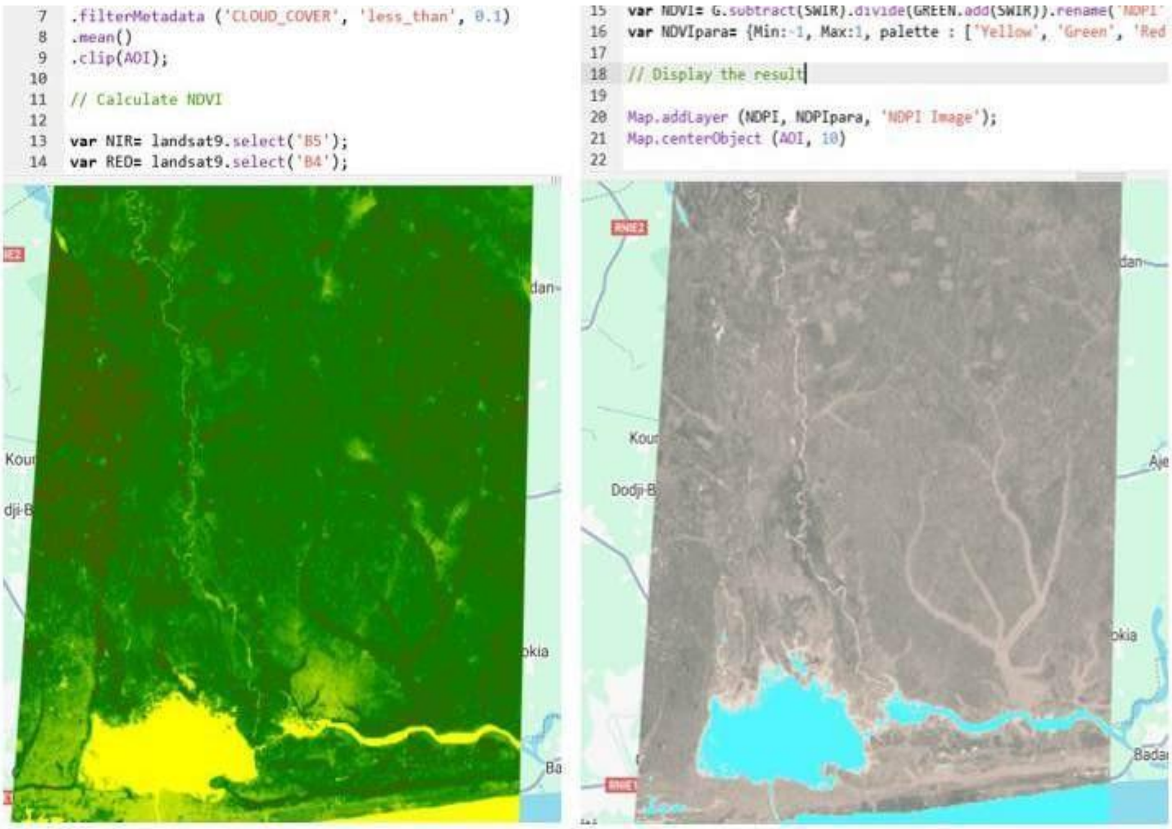


Photo 1: NDVI and NDPI derived from the GEE platform

Statistical analysis of data

After these pre-processing operations, localized average statistics for climate parameters and environmental indices were calculated by district. The effect of rainfall, temperature, relative humidity, NDVI, NDPI, NDWI, and altitude on malaria morbidity was assessed using a linear fixed-effects model implemented in R (lm function). Adjusted means were estimated using the lsmeans function (Russell, 2016). All analyses were performed using R version 4.1.3 (R Core Team, 2022).

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue I January 2026

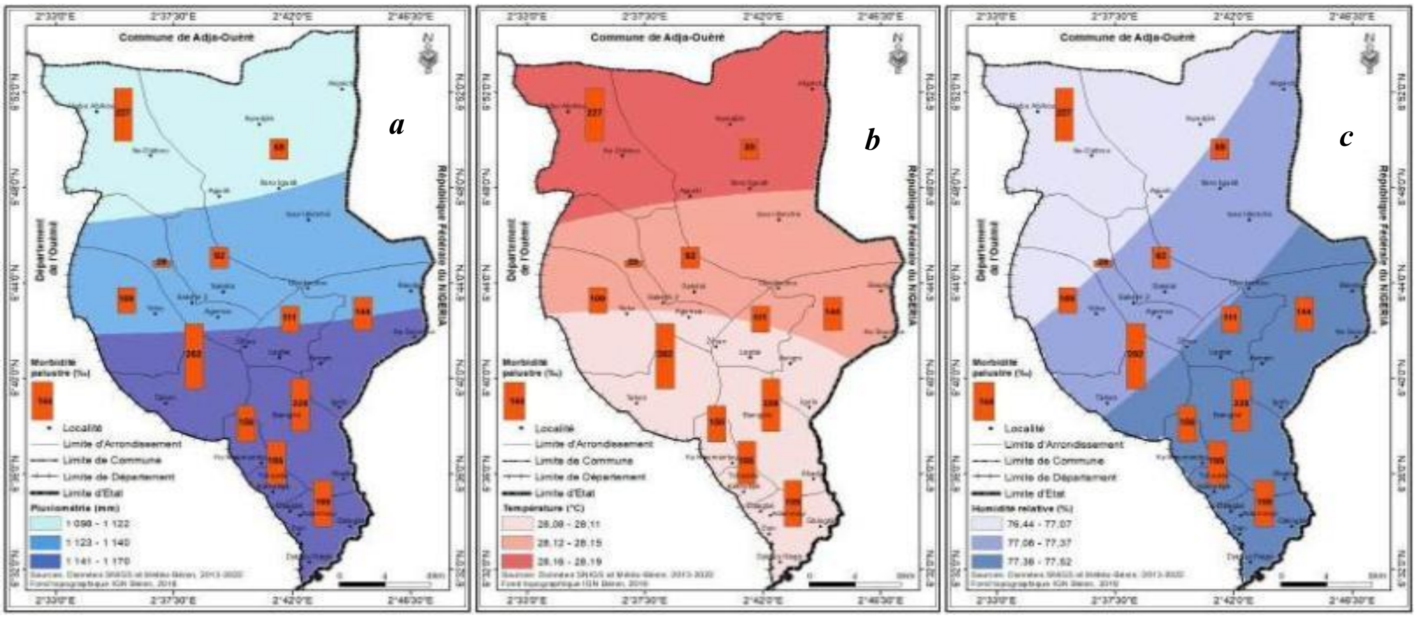
The 30 m spatial resolution grid files for the various parameters were then integrated into a GIS to produce thematic maps using ArcGIS 10.8 software.

RESULTS

Variation in malaria morbidity according to local climatic conditions

The spatial distribution of local climatic conditions, particularly precipitation, temperature, and relative humidity in the local governments of Sakété and Ifangni provides a better understanding of the spatial dynamics of malaria morbidity (Figure 2).

Figure 2: Variation in malaria morbidity according to precipitation (a), temperature (b), and relative humidity (c) in the Sakété-Ifangni health zone



The analysis of Figure 2 highlights marked spatial heterogeneity in malaria risk, closely associated with the distribution of local climate parameters in the municipalities of Sakété and Ifangni. Areas with high rainfall like Takon, Ko-Koumolou, Tchaada, Daagbé, and Banigbé (Figure 2a) have the highest cumulative incidence rates, reaching up to 197 per 1,000, while districts with low rainfall (Sakété 2 and Aguidi) have significantly lower rates, around 58 cases per 1,000 inhabitants. Nevertheless, the district of Ita-Djèbou stands out for its high morbidity despite moderate rainfall, suggesting that rainfall variability favors the persistence of stable larval habitats and heterogeneous spatial transmission of malaria. A similar association is observed with relative humidity (Figure 2c), with the highest annual values (≈ 77.45%) coinciding with areas of high malaria incidence (150–282‰), reflecting its role in vector survival and the intensification of local transmission. Furthermore, areas characterized by moderate to relatively low temperatures have more intense transmission (Figure 2b), with morbidity increasing as air temperature decreases, particularly in the most endemic districts of the Sakété-Ifangni health zone. These results confirm the decisive influence of climatic conditions on vector dynamics and

the spatial structuring of malaria risk. Beyond these climatic factors, other geo-environmental determinants also contribute to the spatial differentiation of malaria risk at the local level.

3.2. Variation in malaria morbidity in relation to local geo-environmental conditions

As with the local climate, it is essential to take into account a range of geo-environmental conditions in order to understand the spread of malaria in the health zone (Figure 3).

Figure 3: Variation in malaria morbidity with altitude (a), NDVI (b), NDWI (c), and NDPI (d) in the SakétéIfangni health zone

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue I January 2026

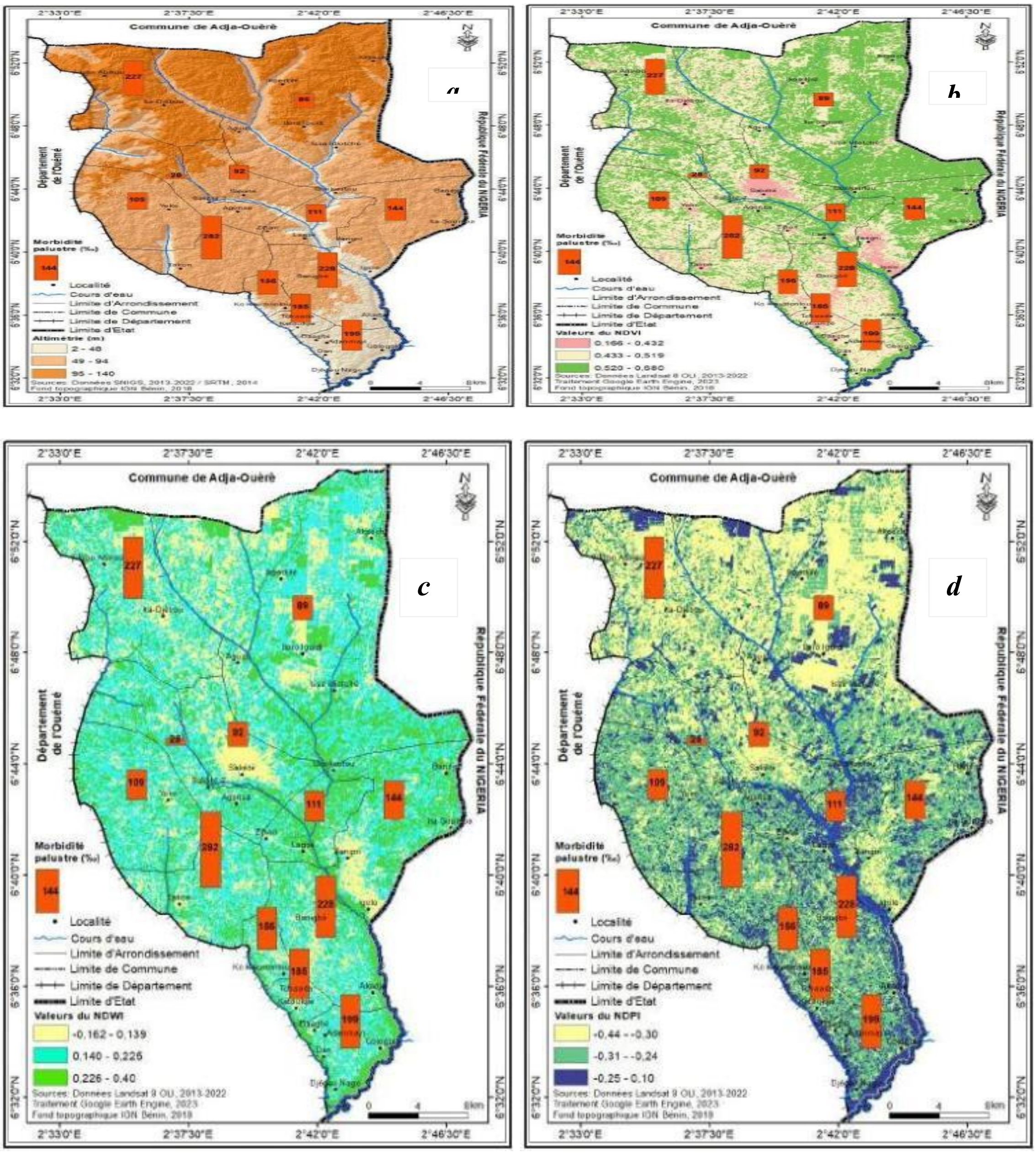


Figure 3 highlights significant variations in malaria incidence based on geo-environmental parameters in the municipalities of Sakété and Ifangni. These parameters include altitude, vegetation cover intensity, surface soil moisture, and the presence of ponds or swampy areas. The Figure 3a reveals an inverse relationship between altitude and malaria risk: low-altitude areas appear particularly vulnerable, notably the districts of Takon, Banigbé, Ita-Djèbou, Ko-Koumonlou, Tchaada, and Daagbé. These areas, which constitute natural outlets, offer favorable conditions for vector reproduction, leading to a high incidence of malaria. Figure 3b illustrates the relationship between morbidity and vegetation cover intensity. The locality of Aguidi stands out for its low incidence despite homogeneous vegetation cover, suggesting a limited influence of this factor. Conversely, endemic areas have moderately high NDVI values (0.43 - 0.52), reflecting anthropogenic pressure on the landscape. This configuration favors the creation of new larval habitats and increases the risk of malaria. The NDWI analysis (Figure 3c) indicates moderate moisture levels (0.14 - 0.225) across the entire territory. Certain areas, such as Ita-Djèbou, Banigbé, and Takon, characterized by an average NDWI greater than 0.20, have a high incidence. However, the impact of humidity remains heterogeneous, as shown by the relatively low incidence observed in Sakété 2 and Aguidi. These results suggest that the presence of humid environments is a contributing factor, but not a determining one, in the spatial distribution of malaria.

Finally, Figure 3d highlights a concentration of vector niches in the central and southern regions of the study area. Localities characterized by humid environments (average NDPI between -0.31 and 0.10) consistently have an incidence greater than 197‰. The presence of humid valleys, swampy areas, and temporary pools near human settlements thus appears to be a major determinant of malaria transmission.

Influence of environmental conditions on the variability of malaria-related morbidity

The influence of environmental determinants on malaria morbidity was established using a multiple linear fixed-effect model, the results of which are shown in Table III.

Table III: Results of the linear fixed-effect model analysis of environmental determinants

	Coefficient	Standard Error	t statistic	Probability
(Intercept)	-6151.1850	2013.8705	-3.0544	0.0028
Precipitation	0.0382	0.2677	0.1426	0.8868
Temperature	-64.6677	20.4039	-3.1694	**0.0020**
Relative humidity	101.4068	27.2627	3.7196	**0.0003**
NDPI	1519.3630	542.4303	2.8010	**0.0060**
NDVI	1160.3480	475.1692	2.4420	**0.0162**
NDWI	-1622.8160	662.3883	-2.4499	**0.0158**
Altitude	0.00221	0.01501	0.01677	0.8969

Source: Data processing, September 2024

The examination of Table III highlights a significant structuring of malaria morbidity by a set of climatic and environmental factors, reflecting the central role of microclimatic conditions and landscape dynamics in malaria transmission. Among the variables included in the model, temperature, relative humidity, and several remote sensing indices (NDPI, NDVI, and NDWI) have a statistically significant influence on the spatial distribution of malaria morbidity, confirming the value of an ecosystem-based approach to health risk.

Temperature - a limiting factor in an already hot environment: temperature show a negative and statistically significant effect on malaria morbidity. In the study area, a 1°C increase in the local average temperature leads to an average decrease in malaria morbidity of 64.7 units. In the climatic context of the municipalities of Sakété and Ifangni, this result suggests that thermal conditions frequently exceed the biological optimum, thereby reducing the longevity of adult mosquitoes. This limits the success of

the Plasmodium sporogonic cycle. The regressive effect induced by the intensity of ambient air heat therefore acts as a biological limiting factor for mosquitoes and the parasite. It contributes to significantly attenuating the intensity of malaria transmission.

Relative humidity - a major determinant of persistent risk: the level of water vapor in the air has a highly significant positive effect on malaria morbidity. In the communities studied, which are characterized by high atmospheric humidity due to their proximity to bodies of water, low-lying areas, and dense vegetation, this parameter appears to be a key factor in maintaining transmission. In fact, a 1% increase in relative humidity leads to an average increase of 101.4 units in malaria morbidity. The effect is gradual and highly amplifying, as even small variations in humidity have a significant impact on transmission, which explains why the risk persists even outside of peak rainfall periods.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue I January 2026

Abundance of breeding sites as real malaria risk hotspots: the presence of landscapes dominated by numerous natural water bodies (small ponds, pools, swamps, and wet depressions), combined with the presence of food crop fields, agricultural developments, and plantations, favors the presence and maintenance of vector niches. In the municipalities of Sakété and Ifangni, a variation of one unit in the NDPI is associated with an average increase of 1,519 units in malaria morbidity. Thus, the increase in vector niches actively contributes to the creation of intensive mosquito breeding grounds, which greatly increases the dynamics of malaria transmission.

Vegetation cover enhances vector-favorable microclimates: vegetation cover is known to have a significant positive effect on malaria morbidity. In the municipalities studied, the existence of vegetated areas is associated with shaded, humid microenvironments that are conducive to the survival of adult mosquitoes and protect larval habitats from evaporation. In the municipalities of Sakété and Ifangni, a oneunit variation in vegetation cover intensity (NDVI) leads to an average increase of 1,160 units in malaria morbidity. Thus, denser vegetation cover reinforces microclimates favorable to mosquitoes and leads to a significant increase in malaria morbidity in the municipalities of Sakété and Ifangni.

Soil moisture influences the stability of temporary stagnant waters: the nature of the soil and its degree of surface water retention are also telling indicators of the creation and potential presence of Anopheles breeding sites in a region. In Sakété and Ifangni, a one-unit increase in NDWI is associated with an average decrease of 1,623 units in malaria morbidity, indicating that shallow, fragmented, or temporary water bodies are less favorable for Anopheles larval development. This highlights the role of diffuse and unstable breeding sites, often linked to human activities and agricultural landscapes, in malaria transmission dynamics.

In light of the various aspects mentioned above, the model equation is as follows:

This equation is implemented in the ArcGIS GIS calculator to generate the risk map (Figure 4).

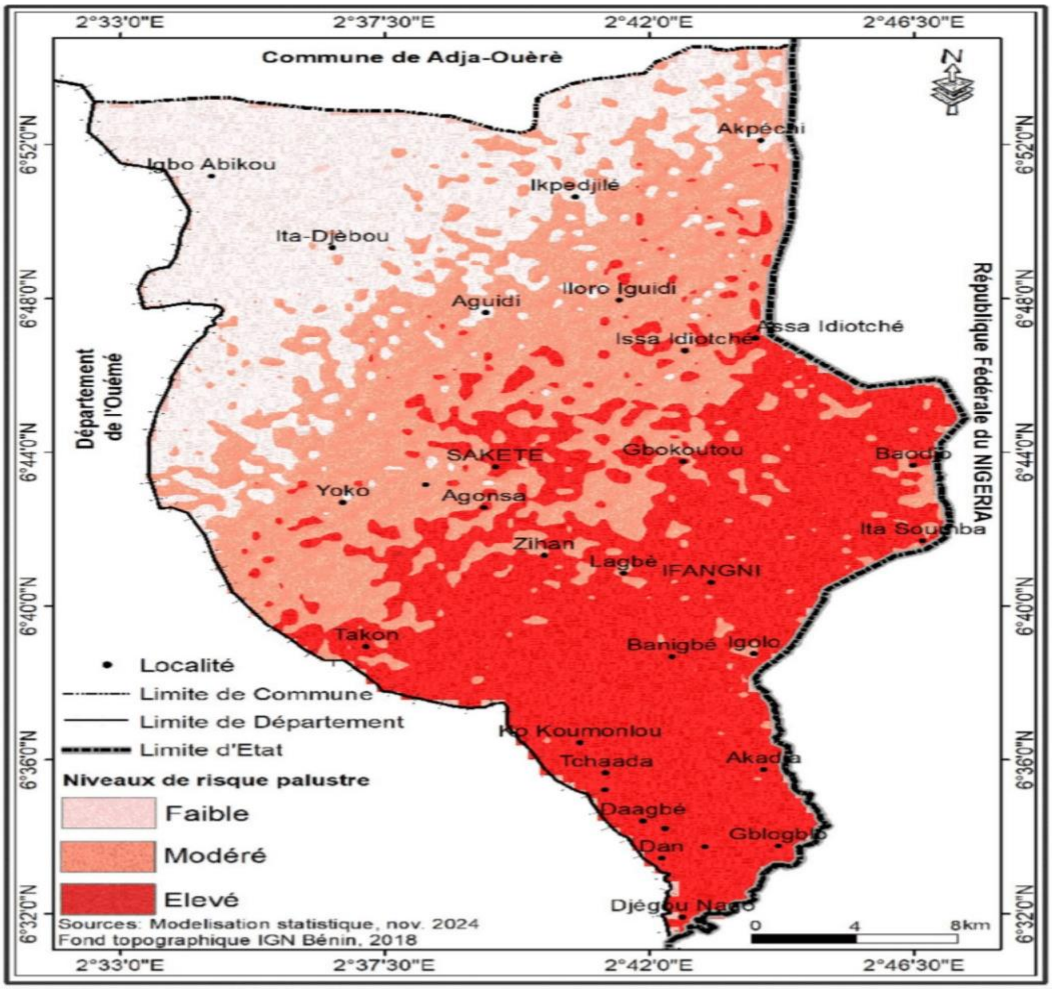


Figure 4: Variation of malaria environmental areas risk in the Sakété-Ifangni health zone

Figure 4 highlights significant spatial heterogeneity in malaria risk in the municipalities of Sakété and Ifangni, reflecting uneven distribution of malaria morbidity at the sub-municipal level. It distinguishes three levels of risk (low, moderate, and high), revealing a clear territorial structure of climate- environmental risk related to malaria.

High-risk areas cover an area of 264.41 km^2 and are mainly concentrated in the municipality of Ifangni, particularly around the towns of Zian, Lagbè, Banigbé, Igolo, Akada, Gblogblo and Djègou Nago. That is the similar realty at Ko-Koumolou, Tchaada and Daagbé. The high-risk area observed in the south of the municipality of Sakété covers mainly the towns of Takon, Sakété, and Agossa. This spatial concentration of high risk suggests the presence of environmental and landscape conditions that are particularly favorable to malaria transmission. These areas correspond to territories with high levels of interaction between human activities, agricultural land use and local hydrological dynamics, increasing the population's exposure to the vector. They are mainly the result of high relative humidity, intensively farmed agricultural landscapes and dense vegetation that promotes humid microclimates, not to mention the coexistence of vulnerable populations with numerous temporary and anthropogenic larval breeding sites.

The moderate-risk areas are mainly concentrated over a large part of the municipality of Sakété. They cover an area of 225.05 km^2. They include localities such as Sakété-centre, Agonsa, Yoko and part of Gbokoutou and surrounding areas. These areas constitute a transition zone, where factors conducive to transmission are present but less intensely combined. The risk of malaria appears to be latent but unstable, likely to increase to a high level depending on seasonal variations (rainfall, humidity) or changes in land use. These areas play a key role in the spatial spread of risk, serving as relay zones between areas of high transmission and areas of lower exposure.

Low-risk areas are mainly located in the north and northwest, on the edge of the municipality of Adja- Ouèrè, mainly around localities such as Igbo-Abikou, Ita-Djèbou, and Ikpédjilé. They cover an area of 164.54 km^2. These areas appear to be less conducive to transmission, probably due to relatively less humid microclimatic conditions and a spatial organization that limits the proximity between human habitats and larval breeding sites. These are areas where the environmental determinants of malaria are present but insufficiently combined to generate high morbidity.

DISCUSSION

The results of this study highlight the pivotal role of local climatic factors in shaping the spatial distribution of malaria morbidity within the local government areas of Sakété and Ifangni. Air temperature and relative humidity emerged as the main climatic indicators of malaria infection risk, confirming that transmission is strongly conditioned by the thermo-hygrometric characteristics of the environment. High relative humidity promotes the survival and longevity of Anopheles mosquitoes, while temperature simultaneously influences larval development, adult mosquito survival, and the extrinsic incubation period of the parasite. The combination of these parameters creates climatic windows favorable for transmission, explaining the observed spatial concentration of cases in certain areas. These findings are consistent with previous studies conducted in West and Central Africa, notably those by D. Ekpa and al. (2023, p.5) in Nigeria, Ita and al. (2017, p.169), and Mordecai and al. (2013, p.28), which demonstrated the existence of an optimal temperature and humidity threshold for malaria transmission. They also corroborate observations by F. K. Médéou (2015, p.88) in Benin and Y. Djamé and al. (2018, p.222) in Togo, emphasizing that spatial and seasonal variations in climatic parameters represent major determinants of malaria dynamics in humid tropical contexts.

Beyond climatic conditions, remote sensing data revealed the significant influence of landscape environmental components on malaria risk. The positive association between malaria morbidity and the Normalized Difference Vegetation Index (NDVI) as well as the presence of water bodies and wetlands (NDPI) underscores the central role of landscape structures in creating favorable breeding habitats. Dense vegetation contributes to the formation of shaded, humid microclimates, while ponds, marshes, and irrigated areas provide optimal sites for mosquito reproduction and resting. These results are in line with the findings of C. Prussing and al. (2019, p.4), who reported strong associations between Anopheles larval habitats and water bodies in modified landscapes, and with Ceccato and al. (2005), who highlighted the role of irrigated perimeters in the dynamics of Anopheles gambiae s.l. populations. The analysis also revealed a significant relationship with the Normalized Difference Water Index (NDWI), which showed the highest contribution in the model. This relationship reflects the complex interactions between surface hydrology and vector ecology, as soil moisture can indicate both the presence of water collections favorable to larval development and hydrological conditions that modulate habitat stability.

Similar findings have been reported by R. Sauerborn and al. (2012, p.42-43) in Burkina Faso and Y. G. Yang and al. (2006, p.88-90), confirming the relevance of satellite-derived indices for the spatial characterization of vector-borne disease risk.

The combined effect of climatic and landscape variables results in a diversified environmental risk for malaria across the territories of Sakété and Ifangni. The resulting risk map provides a spatial synthesis of the eco-epidemiological mechanisms identified through statistical analyses. It reveals a clear structuring of risk, with high-probability areas corresponding to sectors characterized by a favorable combination of thermo-hygrometric conditions, dense vegetation cover, and the presence of wet habitats. This mapping allows for the visualization of converging risk factors and the identification of potential persistent transmission foci, reflecting the ecological stability of vector habitats. As such, the risk map functions not merely as a descriptive tool but as an analytical and operational instrument to support decision-making for targeted vector control interventions. It offers a solid basis for spatially guided surveillance, prevention, and malaria control measures at the local scale, consistent with integrated public health approaches grounded in spatial analysis. By demonstrating the complementarity of climatic data, remote sensing indices, and risk mapping, this study reinforces the value of geospatial methods for a nuanced and operational understanding of malaria dynamics in tropical territories.

CONCLUSION

In the local government areas of Sakété and Ifangni, malaria morbidity results from a complex interplay of microclimatic and landscape factors, which play a decisive role in shaping transmission patterns. Temperature emerges as a key regulatory factor, while the combined presence of vegetation cover and natural or anthropogenic water bodies in the immediate vicinity of villages serves as a primary driver for the proliferation of Anopheles breeding sites, indirectly promoting increased transmission of malaria. The spatialized approach adopted in this study thus enables more precise identification of high-risk areas and facilitates targeted public health interventions that account for local ecological specificities.

From a health geography perspective, these findings collectively demonstrate that malaria morbidity in the landscapes of Sakété and Ifangni arises from intricate interactions between climatic factors, environmental dynamics, and land-use patterns. This underscores the need to integrate high-resolution environmental indicators into malaria surveillance and control strategies to better capture local ecological determinants and optimize intervention planning.

REFERENCES

1. Ahohoundo P. C. A., Boni G. (2024): Analyse spatiale de la morbidité palustre dans la zone sanitaire Sakété-Ifangni, au sud-est du Bénin. Revue IJPSAT, Vol. 45, N° 1, juin 2024, pp. 273–287.
2. Ahohoundo Parfait Cossi Alexis, Boni Gratien (2024): Évolution temporelle de l'incidence du paludisme dans la zone sanitaire Sakété-Ifangni: influence du climat local et des mesures de prévention. Revue Afrique Science, 24(5), mai 2024, pp. 93–107.
3. Aïkpon R., Missihoun A., Lokossou A., Aïkpon G., Salifou S., Dansi A., Agbangla C. (2020): Hétérogénéité génétique et résistance des vecteurs du paludisme (Anopheles gambiae s.l) aux insecticides en zone cotonnière au Bénin. Int. J. Biol. Chem. Sci., 14(8), 2724–2736. ISSN 1997-342X (Online), ISSN 1991-8631 (Print).
4. Alum E. U., Ugwu O., Egba S. I., Uti Daniel E., Benedict A. N. (2024): Climate variability and malaria transmission: unraveling the complex relationship. INOSR Scientific Research, 11, pp. 16–22. https://doi.org/10.59298/INOSRSR/2024/1.1.21622
5. Birane Cissé, Niang Diène Aminata, Ndiaye Jean Louis, Dione Jaques André, Christopher Bryant, Quensière Jacques, Alioune Kane, Ousmane Faye (2016): Facteurs de risque environnementaux de la

persistance du paludisme dans la banlieue de Dakar (Guédiawaye-Pikine). International Journal of Innovation and Applied Studies, Vol. 15, n° 2, pp. 275–290. ISSRJ-ISSN 2028-93. http://www.ijias.issr-journals.org/

6. Ceccato P., Connor S. J., Jeanne I., Thomson M. C. (2005): Application of remote sensing to the mapping of irrigated areas and malaria risk in West Africa. International Journal of Health Geographics, 4(1), 84–95. https://doi.org/10.1186/1476-072X-4-84
7. Djamé Y., Kpatcha T., Ahouangon S. (2018): Climatic determinants of malaria transmission in the Oti Prefecture, northern Togo. Malaria Journal, 17(1), 222. https://doi.org/10.1186/s12936-018-2380x
8. Ekpa D. E., Oyetunde A., Nwosu I. (2023): Spatial distribution of malaria morbidity and its climatic correlates in Ondo State, Nigeria. Malaria Journal, 22(1), 5. https://doi.org/10.1186/s12936-02304567-2
9. Fagbohoun L., Gbaguidi F., Ayédoun M., Mathe C., Moudachirou M., Vieillescazes C. (2014): Étude ethnobotanique et phytochimique des plantes tinctoriales, sources de colorants naturels et matériaux résineux traditionnels du Bénin dans le domaine artisanal (Ifangni/Bénin). Ethnopharmacologia, n° 52, décembre 2014, pp. 56–66.
10. Gao B. (1996): NDWI – a normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment, 58(3), pp. 257–266. https://doi.org/10.1016/S0034-4257(96)00067-3
11. Gromek K., Gameiro T., Catarino L., Serrano R., Silva O. (2020): Botanical quality control of Terminalia albida leaf. Planta Med, 36–49. DOI: 10.1055/s-0034-1394913
12. Honvo S. Z. A., Dossou-Yovo A. (2021): Mutations socio-spatiales et extension urbaine au sud du Plateau de Sakété (Sud-Est du Bénin). International Journal of Progressive Sciences and Technologies (IJPSAT), Vol. 28, N° 1, August 2021, pp. 01–16.
13. Ita I., Nwankwo U., Okeke C. (2017): Temperature and humidity effects on Anopheles vector survival and malaria transmission in West Africa. Parasites & Vectors, 10(1), 169. https://doi.org/10.1186/s13071-017-2145-6
14. Kabaria C. W., Mbogo C., Snow R. W. (2016): The effect of vector longevity on malaria transmission dynamics in endemic settings. Parasites & Vectors, 9(1), 8. https://doi.org/10.1186/s13071-016-1305-x
15. Lacaux Jean-Pierre, Tourre Yves, Vignolles Cécile, Ndione Jacques André, Lafaye Murielle (2007): Classification of ponds from high-spatial resolution remote sensing: application to Rift Valley Fever epidemics in Senegal. Remote Sensing of Environment, 106, 66–74. http://dx.doi.org/10.1016/j.rse.2006.07.012
16. Médéou F. K. (2015): Influence of local climatic variability on malaria prevalence in the Collines region, Benin. African Journal of Environmental Science and Technology, 9(2), 88–97.
17. Mordecai A. E., Cohen J. M., Evans M. V., Gudapati P., Johnson L. R., Lippi C. A., Murdock C. C. (2013): Optimal temperature for malaria transmission is dramatically lower than previously predicted. Ecology Letters, 16(1), 22–30. https://doi.org/10.1111/ele.12015
18. Nigussie T. Z., Zewotir T., Muluneh E. K. (2023): Seasonal and spatial variations of malaria transmissions in northwest Ethiopia: evaluating climate and environmental effects using generalized additive model. Heliyon, 9, e15252. https://doi.org/10.1016/j.heliyon.2023.e15252
19. Okunlola O. A., Oyeyemi O. T. (2019): Spatio-temporal analysis of association between incidence of malaria and environmental predictors of malaria transmission in Nigeria. Scientific Reports, 9, 17500. https://doi.org/10.1038/s41598-019-53814-x
20. Palo S. K., Panda P. P., Parida D., Malick S. T., Pati S. (2025): Remote sensing and GIS-based study to predict risk zones for mosquito-borne diseases in Cuttack district, Odisha, India. GeoHealth, 9, e2023GH001007.
21. PNLP (2023): Réunion sous-régionale des programmes paludisme et des partenaires d'Afrique de l'Ouest et du centre. Document de communication, Roll Back Malaria, Abidjan, 22 p.
22. Prussing C., Vasquez C., Rodriguez H. (2019): Landscape and water body associations with Anopheles darlingi larval habitats in rural Amazonian villages. Acta Tropica, 192, 4–12. https://doi.org/10.1016/j.actatropica.2018.09.004
23. Russel S. (2004): The economic burden of illness for households in developing countries: a review of studies focusing on malaria, tuberculosis, and HIV/AIDS. American Journal of Tropical Medicine and Hygiene, 71(suppl 2), pp. 147–155. https://doi.org/10.4269/ajtmh.2004.71.147

24. Sauerborn R., Schroeder D., Becher H. (2012): Soil moisture and vector breeding: implications for malaria transmission in Nouna, Burkina Faso. Tropical Medicine & International Health, 17(1), 42–43. https://doi.org/10.1111/j.1365-3156.2011.02925.x
25. Sovi A., Govoétchan R., Tokponnon F., Hounkonnou H., Aïkpon R., Agossa F., Gnanguenon V., Salako A., Agossou C., Ossè R., Oké M., Gbénou D., Massougbodji A., Akogbéto M. (2013): Impact of land-use on malaria transmission in the Plateau region, southeastern Benin. Parasites & Vectors, 6, article number 352. https://doi.org/10.1186/1756-3305-6-352
26. Tewara M. A., Mbah-Fongkimeh P. N., Dayimu A., Kang F., Xue F. (2018): Small-area spatial statistical analysis of malaria clusters and hotspots in Cameroon, 2000–2015. BMC Infectious Diseases, 18. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6286522/
27. Tokponnon T. F., Ossè R., Padonou G. G., Affoukou C. D., Sidick A., Sewade W., Fassinou A., Koukpo C., Akinro B., Messenger L., Okê M., Tchévoédé A., Ogouyemi-Hounto A., Gazard K. D., Akogbéto M. (2023): Entomological characteristics of malaria transmission across Benin: an essential element for improved deployment of vector control interventions. Insects, 14(1), 52. https://doi.org/10.3390/insects14010052
28. Tucker C. (1979): Remote sensing of leaf water content in the near infrared. US National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md, NASA-TM-80291, mis en ligne le 30 novembre 1995, consulté le 20 juillet 2019. https://ntrs.nasa.gov/search.jsp?R=19820049362
29. Yang Y. G., Li X. H., Xu Z. Q. (2006): Predicting intermediate host habitats for schistosomiasis using NDVI and soil moisture indices. International Journal of Remote Sensing, 27(1), 88–90. https://doi.org/10.1080/01431160512331303245