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Behavioral and Environmental Risk Factors of Malaria Incidence: A Spatial Analysis in a Rural Endemic Area of Eastern Indonesia

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ABSTRACT: Malaria remains a significant public health problem in East Sumba Regency, particularly in rural areas with ecological conditions favorable for *Anopheles* vector breeding. This study aimed to analyze the relationship between behavioral and household environmental risk factors and malaria incidence and to map the spatial distribution of cases in Mau Bokul Village. An analytical observational study with a cross-sectional design was conducted among 194 respondents during August–September 2025. Data were obtained through microscopic examination of thick blood smears, structured questionnaire interviews, and geographic coordinate mapping using Avenza Maps. Statistical analysis used Fisher's Exact Test, while spatial analysis applied buffering and overlay techniques. The prevalence of malaria was 4.1% (8 cases). Significant associations were found between malaria incidence and not using bed nets ($p < 0.001$), nighttime outdoor activities ($p < 0.001$), sleeping outdoors ($p < 0.001$), non-permanent house walls ($p = 0.001$), absence of window screens ($p = 0.028$), and proximity to rivers ($p = 0.001$). Spatial analysis demonstrated clustering of cases within a 500-meter buffer radius from the river. These findings indicate that sleeping outdoors and residence near river areas were the most strongly associated factors with malaria incidence. The study provides spatial evidence that malaria transmission in rural endemic settings tends to cluster around river buffer zones, emphasizing the importance of integrating GIS-based surveillance with environmental management and behavior-focused interventions to support malaria control and elimination strategies in similar endemic regions.

KEYWORDS: Behavioral Risk Factors, Geographic Information System, Malaria, Rural Endemic Area, Spatial Analysis, Vector-Borne Disease

INTRODUCTION

Malaria has re-emerged as a major global public health threat, particularly in tropical and subtropical regions, and continues to impose a substantial burden on health systems worldwide.[1] The disease is caused by Plasmodium parasites and is transmitted to humans through the bites of infected female Anopheles mosquitoes.[1] Despite sustained global control efforts, malaria transmission persists, with an estimated 263 million cases reported worldwide in 2023, underscoring the ongoing challenges to elimination.[2]

In Indonesia, the epidemiological profile of malaria is characterized by marked spatial heterogeneity. While western regions have recorded a decline in malaria incidence, sustained transmission remains evident in eastern provinces, including Papua, Maluku, and East Nusa Tenggara (NTT).[3] Within NTT, East Sumba Regency continues to be a key contributor to the provincial malaria burden, reporting 5,537 cases in 2022.[4] Mau Bokul Village, located in Pandawai District, spans an area of approximately 101.6 km² and is characterized by irrigated rice fields and river networks that provide suitable breeding habitats for Anopheles mosquitoes.[4] Given the mobility of malaria vectors, with reported flight ranges of up to 2–3 km, such ecological conditions increase the vulnerability of the area to sustained local transmission.[14,15]

Malaria transmission reflects a complex interaction among host, parasite, and environmental determinants, as conceptualized within the epidemiological triad.[5] Human behavioral factors—including engagement in nighttime outdoor activities and the consistent use of insecticide-treated bed nets—play a critical role in modulating exposure risk and shaping local transmission dynamics.[5] Evidence from ecologically comparable settings, such as Amfoang Barat Daya and West Sumba, demonstrates that environmental characteristics, particularly proximity to vector breeding habitats, alongside behavioral practices, notably bed net utilization, are significantly associated with malaria incidence.[6,7]

Because malaria transmission often occurs in focal rather than uniformly distributed patterns, conventional epidemiological approaches alone may be insufficient to fully capture spatial heterogeneity in risk. The integration of Geographic Information Systems (GIS) enables visualization of case distribution and quantitative assessment of spatial relationships between households and environmental risk features.[8] Such spatial analyses facilitate the identification of clusters and micro-foci, thereby supporting more precise and context-specific malaria prevention and control strategies.[6]

Given the high transmission potential in Mau Bokul Village, this study aims to investigate behavioral and household environmental risk factors associated with malaria incidence and to describe the spatial distribution of cases at the village level. Although numerous studies have assessed behavioral and environmental correlates of malaria transmission, spatially explicit analyses that integrate household-level risk factors with geographic proximity to potential vector breeding sites remain limited in rural endemic settings of Eastern Indonesia.[9,10] This evidence gap constrains the development of geographically targeted interventions in contexts where malaria transmission is focal rather than diffuse. By combining epidemiological risk factor analysis with GIS-based spatial mapping, this study seeks to identify village-level malaria transmission hotspots and to generate localized evidence to inform targeted environmental management and behavior-focused strategies for malaria control and elimination.

METHODS

Study design and setting

We conducted an analytical observational study with a cross-sectional design, integrating quantitative analysis with spatial epidemiology. The study took place in Mau Bokul Village, Pandawai District, East Sumba Regency, Indonesia, from August to September 2025. The site was purposively selected as a malaria-endemic hotspot with ecological conditions favorable to Anopheles breeding.

Population, sampling, and sample size

The target population comprised all residents of Mau Bokul Village. Participants were recruited using consecutive sampling. Inclusion criteria were residency in the village for at least six months and provision of written informed consent; individuals residing for less than six months or declining consent were excluded. A minimum sample size of 194 respondents was determined using proportion-based calculations.

Data collection

Data were obtained through laboratory examinations, structured interviews, direct observations, and spatial surveys. Peripheral blood was collected to prepare thick blood smears, stained with 3% Giemsa, and examined under light microscopy at (times 1000) magnification to detect Plasmodium. Results were verified by cross-checking with experienced laboratory analysts. Structured questionnaires and observation checklists captured sociodemographic characteristics; malaria prevention behaviors (e.g., bed net use, nighttime outdoor activities, mosquito repellent use); and household physical features (e.g., wall type, ventilation, ceiling presence). For the spatial survey, household coordinates for both malaria-positive and -negative respondents, as well as distances to environmental features (rivers, bushes, livestock enclosures), were recorded in the field using Avenza Maps.

Variables and measures

The primary outcome was malaria positivity by microscopy. Explanatory variables included behavioral factors and household environmental characteristics, alongside spatial proximity to putative vector habitats.

Statistical analysis

Univariate analyses described participant characteristics and study variables. Bivariate associations between putative risk factors and malaria incidence were assessed using Fisher's Exact Test (two-tailed, (alpha = 0.05)) due to sparse contingency table cells that violated Chi-square assumptions. Multivariate logistic regression was not undertaken because the small number of confirmed cases limited model stability and posed a high risk of overfitting.

Spatial analysis

Spatial analyses were performed in a geographic information system (GIS) environment. Buffer radii of 100 m, 500 m, and 2000 m were generated around potential vector breeding sites, followed by overlay analyses to delineate risk zonation and visualize

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clustering near vector habitats. All spatial data were referenced to the World Geodetic System 1984 (WGS 84). Avenza Maps was used solely for field georeferencing and coordinate acquisition; buffer generation and map visualization were conducted in GIS software. Hamlet boundaries were digitized to estimate areal extent; reported hectare values represent author calculations and may differ from administrative statistics due to boundary delineation and map projection. For manuscript presentation, map titles, legends, and annotations were standardized in English.

Administrative boundaries at the hamlet level and base map layers were derived from the Rupa Bumi Indonesia (RBI) topographic map at a scale of 1:25,000, produced by the Geospatial Information Agency of Indonesia (Badan Informasi Geospasial, BIG). The RBI dataset represents the official national geospatial reference for administrative boundaries in Indonesia and was used to ensure spatial accuracy and consistency in the geographic analysis. These data were integrated with household coordinate data and environmental layers during spatial processing and visualization.

Ethics

The study received ethical approval from the Faculty of Medicine and Veterinary Medicine, Universitas Nusa Cendana (approval No. 00000000000FKKH). Written informed consent was obtained from all participants, and confidentiality was strictly maintained.

RESULTS

This study enrolled 194 permanent residents of Mau Bokul Village. Univariate analysis indicated that most participants were of productive age (≥15 years), and females constituted the majority. Overall, 59.3% reported occupations associated with higher mosquito exposure, including farming and fishing.

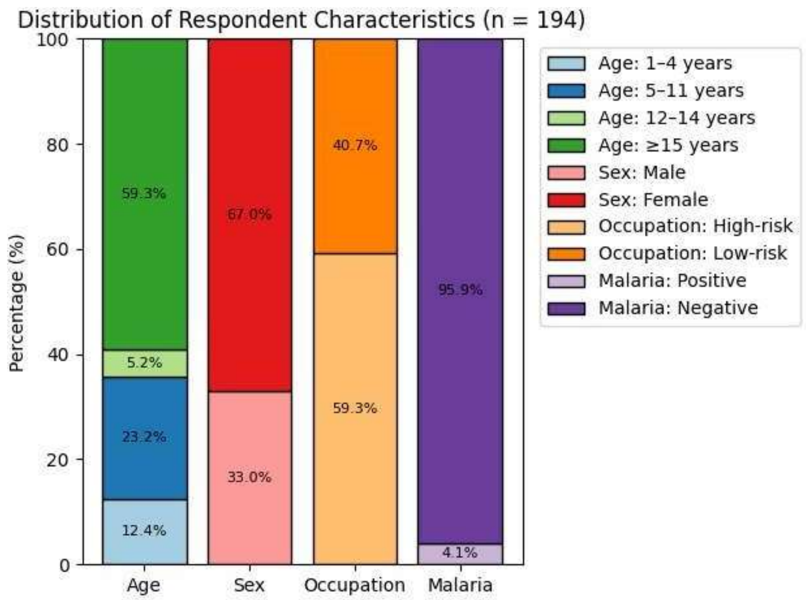

Figure 1. Distribution of respondent characteristics in Mau Bokul Village presented as a 100% stacked bar chart (n = 194).

Each bar represents one aspect (age group, sex, occupational risk, and malaria incidence). Colors indicate categories within each aspect, and the percentages shown inside each segment represent the proportion of respondents in that category.

Bivariate analysis using Fisher's Exact Test demonstrated that several behavioral and environmental factors were significantly associated with malaria incidence ($p < 0.05$). Behavioral factors showing significant associations included sleeping outdoors, lack of bed nets, nighttime outdoor activities, absence of mosquito repellent use, and not wearing protective clothing at night. In addition, household environmental characteristics such as non-permanent wall materials and the absence of window screens were also significantly associated with malaria incidence. Among outdoor environmental variables, proximity to rivers showed a strong association with malaria incidence, whereas the presence of livestock, water puddles, and rice fields did not demonstrate statistically significant relationships. The complete results are shown in Table 1.

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Table 1. Association Between Behavioral and Environmental Factors and Malaria Incidence

Variable	Category	Malaria Positive n (%)	Malaria Negative n (%)	P value*	OR	95% CI
Behavioral Factors						
Sleeping outdoors	Yes	7 (3.6)	44 (22.7)	<0.001	22.59	2.70–188.66
	No	1 (0.5)	142 (73.2)			
Bed nets	Yes	0 (0.0)	140 (72.2)	<0.001	—†	—
	No	8 (4.1)	46 (23.7)			
Nighttime outdoor activities	Yes	8 (4.1)	68 (35.1)	<0.001	—†	—
	No	0 (0.0)	118 (60.8)			
Mosquito repellent use	Yes	0 (0.0)	79 (40.7)	0.022	—†	—
	No	8 (4.1)	107 (55.2)			
Protective clothing at night	Yes	0 (0.0)	78 (40.2)	0.022	—†	—
	No	8 (4.1)	108 (55.7)			
Household Environmental Factors						
Permanent house walls	Yes	0 (0.0)	80 (41.2)	0.001	—†	—
	No	8 (4.1)	106 (54.6)			
Window screens	Yes	0 (0.0)	71 (36.6)	0.028	—†	—
	No	8 (4.1)	115 (59.3)			
Ceiling	Yes	0 (0.0)	53 (27.3)	0.110	—	—
	No	8 (4.1)	133 (68.6)			
Outdoor Environmental Factors						
Proximity to river	Yes	6 (3.1)	36 (18.6)	0.001	12.50	2.42–64.51
	No	2 (1.0)	150 (77.3)			
Livestock near house	Yes	6 (3.1)	91 (46.9)	0.279	3.13	0.61–15.92
	No	2 (1.0)	95 (49.0)			
Water puddles	Yes	6 (3.1)	50 (25.8)	1.000	0.90	0.17–4.64
	No	2 (1.0)	136 (70.0)			
Rice fields	Yes	0 (0.0)	17 (8.8)	1.000	—	—
	No	8 (4.1)	169 (87.1)			

* Fisher's Exact Test
† OR not calculated due to zero cell counts

Spatial analysis was conducted to examine the geographic distribution and clustering of malaria cases in relation to environmental features. Participatory mapping combined with GIS-based visualization revealed that malaria cases were not randomly distributed but instead formed spatial clusters within specific ecological settings.

Figure 2. Map of the study location in Mau Bokul Village, Pandawai District, East Sumba Regency. The map was created by the authors using original spatial data

Spatial visualization indicated a non-random distribution of malaria cases, with distinct clustering patterns. Positive households were concentrated near putative vector habitats, particularly in bush-covered areas and along river corridors. In both hamlets, these clusters overlapped with zones of dense vegetation and livestock enclosures, highlighting the close interface between human activity and high-risk environments. River-buffer analysis corroborated these patterns: all eight positive cases were located within 500 meters of the river, with the majority situated within 100 meters of the riverbank. These findings implicate the r iparian zone as an active transmission area, likely driven by slow-moving or stagnant water bodies that provide suitable breeding sites for Anopheles mosquitoes during the dry season. The mapped areal extent of Mau Bokul Hamlet was approximately 7,302 ha and Tanarara Hamlet approximately 4,775 ha (author calculation based on digitized boundaries). The larger mapped extent of Mau Bokul implies a wider settlement-environment interface, which may partly explain the more prominent overlap between case points and high-risk land-cover features observed in Figure 3a relative to Figure 3b.

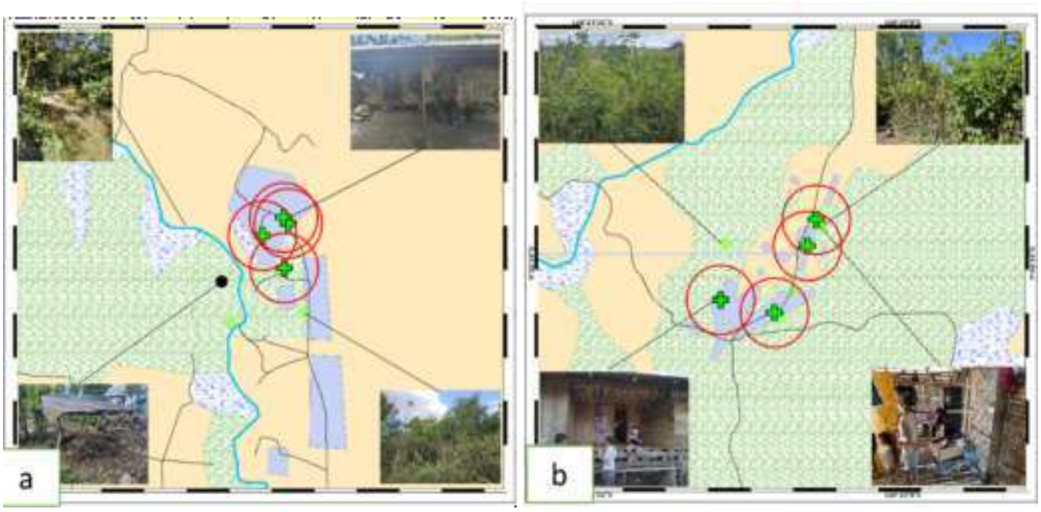

Figure 3. Spatial distribution and clustering of malaria cases based on land cover. (a) Clustered case patterns in Maubokul

Hamlet near the river and livestock enclosures; (b) Case distribution pattern in Tanarara Hamlet. Red circles indicate buffer zones where case points overlap with vector habitats. All positive case points fall within the effective flight radius of the vector from the river. The figure was created by the authors based on original field data.

Vector flight-range zoning with a 2000 m radius—representing the upper bound of Anopheles dispersal—showed that all residences with confirmed cases lay within the vector's movement corridor. Overlay analysis indicated that patient households were aligned along probable mosquito flight paths originating at breeding sites in riverine and forested areas and extending toward residential zones. Although breeding foci were concentrated around the river, transmission risk extended up to 2000 m, consistent with vector mobility. Collectively, these spatial findings suggest that malaria transmission in Mau Bokul Village is focal and strongly conditioned by settlement proximity to water bodies and land-cover types that sustain the mosquito life cycle. The results highlight the necessity of area-based control strategies that explicitly incorporate environmental determinants of risk.

DISCUSSION

Malaria transmission in Mau Bokul Village exhibited a clear spatial pattern rather than a random distribution. Spatial analysis demonstrated that malaria-positive households were clustered within specific areas, particularly in proximity to river corridors. This clustered distribution suggests the presence of focal transmission zones, where environmental conditions favor sustained vector–human contact. Similar spatial clustering of malaria cases has been reported in other endemic areas of eastern Indonesia, where transmission tends to occur in geographically defined pockets shaped by local ecological characteristics.[2,7]

Environmental factors appear to play a central role in shaping the spatial distribution of malaria cases in this study area. The proximity of settlements to rivers emerged as the most prominent environmental determinant. Riverine environments provide suitable breeding habitats for *Anopheles* mosquitoes, especially during periods of reduced water flow that create stagnant pools conducive to larval development. Vegetated areas surrounding rivers further enhance vector survival by providing shade and humidity. The spatial overlap between malaria-positive households, river buffers, and vegetated land cover supports previous findings that identify riparian zones as persistent malaria risk areas in rural endemic settings.[6,8]

Further spatial examination revealed that all malaria-positive households were located within a 2-km radius of river systems, corresponding to the estimated flight range of *Anopheles* mosquitoes.[14,15] This finding indicates that while breeding sites may be concentrated near rivers, the risk of malaria transmission extends beyond immediate riverbanks through mosquito dispersal. Additionally, differences in hamlet size and spatial configuration may contribute to variations in transmission intensity. Mau Bokul Hamlet, which covers a larger area than Tanarara Hamlet, presents more extensive interfaces between human settlements and vector habitats, potentially increasing opportunities for mosquito–human contact and facilitating localized transmission clusters.

Beyond environmental exposure, individual behaviors and household characteristics were found to significantly influence malaria incidence. Sleeping outdoors was strongly associated with malaria positivity, reflecting increased exposure to nocturnally active vectors during peak biting hours. The lack of consistent bed net use further amplified this risk. These behavioral factors are particularly relevant in rural settings where social and occupational activities frequently occur outdoors at night. In addition, housing conditions such as non-permanent wall materials and the absence of window screens may facilitate mosquito entry, increasing indoor exposure. These findings are consistent with previous studies highlighting the combined influence of behavior and housing quality on malaria risk in endemic rural communities.[6,7,10]

Taken together, the findings of this study indicate that malaria transmission in Mau Bokul Village is driven by a synergistic interaction between environmental suitability and human behavior. Spatial proximity to riverine breeding habitats establishes a baseline ecological risk, while individual behaviors and household characteristics modulate exposure within these high-risk zones. This interaction explains why malaria cases remain spatially clustered rather than uniformly distributed across the village. Consequently, the observed malaria prevalence of 4.1% indicates that local transmission persists despite the relatively small number of confirmed cases, a pattern consistent with malaria epidemiology in East Nusa Tenggara where transmission occurs in focal pockets rather than diffusely across communities.[2,7] From a public health perspective, these findings underscore the importance of integrating GIS-based spatial surveillance with behavior-focused interventions and targeted environmental management of river buffer zones to effectively reduce and ultimately interrupt local malaria transmission.[3,8,16]

CONCLUSION

This study indicates that malaria transmission in Mau Bokul Village, East Sumba, is highly focal and mediated by the interplay of high-risk behaviors and environmental conditions favorable to vector breeding. The most salient behavioral determinants were sleeping outdoors and suboptimal use of personal protective measures, while proximity to riverine areas constituted the principal spatial predictor of infection. These results highlight the need to embed spatial analytics within routine malaria surveillance, particularly in rural endemic settings characterized by clustered transmission. Precision interventions—combining behavior change strategies with environmental management targeted to river buffer zones—are warranted to enhance control efforts and accelerate progress toward elimination in comparable endemic contexts.

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