

Social–Ecological Factors Influencing Mosquito Presence in Livestock Areas: Implications for Vector Control

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ABSTRACT

Malaria elimination strategies have predominantly targeted the domestic sphere, yet persistent transmission in endemic clusters indicates that malaria is embedded within broader socio-ecological relations linking humans, livestock, and the environment. This study analyzes the socio-ecological dynamics of malaria transmission in an endemic area of Purworejo District, Indonesia, integrating entomological, spatial, and qualitative approaches. A mixed-methods design combined spatial mapping, a quasi-experimental time-series intervention through the installation of long-lasting insecticidal nets (LLINs) in livestock shelters, repeated mosquito collections, and in-depth interviews with livestock owners. The intervention reduced *Anopheles* spp. density by 75.44% overall and 98.71% indoors. Mixed linear model analysis confirmed that time, species, location, and their interactions significantly shaped mosquito abundance ($p < 0.001$), indicating that vector control outcomes are contextually embedded. Post-intervention stability suggests the formation of a new ecological equilibrium at a lower density. Qualitative findings show that reduced mosquito nuisance and improved livestock comfort reshaped community perceptions and strengthened willingness to participate in malaria control. The study reframes livestock shelters as critical yet overlooked transmission nodes and positions malaria control as a socio-ecological transformation rather than a purely technical intervention.

Keywords: Long-lasting insecticidal nets (LLINs); Livestock shelters; Malaria; Socio-ecological approach; Spatial analysis.

INTRODUCTION

Since 2015, global malaria control efforts have achieved significant reductions in both case incidence and mortality rates. Approximately 660 million lives are estimated to have been saved, accompanied by a 75% decline

in incidence across 106 countries over a 15-year period (UN News Centre, 2015). These accomplishments reflect the success of combined technical interventions, strengthened health systems, and sustained global financial support. However, the COVID-19 pandemic was subsequently identified as a major disruptive event, exerting widespread effects on the continuity and sustainability of malaria elimination programs across diverse regional and national contexts.

Data from the World Health Organization (WHO) indicate that malaria-related deaths reached 619,000 in 2021, only slightly lower than the 625,000 deaths reported in the first year of the pandemic, and still higher than the pre-pandemic figure of 568,000 deaths recorded in 2019. A similar increase was observed in global malaria cases, rising from 232 million in 2019 to 245 million in 2020, and further to 247 million in 2021 (The Global Fund, 2023). As of 2022, malaria remained endemic in 84 countries, although 42 countries had achieved elimination status by June 2023 (WHO, 2022). This pattern suggests that malaria elimination is not merely a technical endeavor but a complex process deeply shaped by social, environmental, and institutional dynamics.

Indonesia has also committed to achieving malaria elimination by 2030 through the Ministry of Health. Nationally, most regions have been classified as non-endemic or low-endemic areas. However, the spatial distribution of malaria cases continues to reveal sharp inequalities. The national malaria burden remains heavily concentrated in eastern Indonesia, particularly in Papua Province, which recorded the highest morbidity rate at 222.99 per 1,000 population in 2024 and accounted for approximately 89% of total national cases. Significant contributions were also reported from West Papua and East Nusa Tenggara (Kementrian Kesehatan, 2024). This pattern indicates that malaria elimination in Indonesia is uneven and highly contingent upon local contexts.

On the island of Java, of 128 districts/cities, only about 5% remain classified as low endemic. As of 2023, Purworejo District was reported as the only area on Java that had not yet achieved malaria elimination. This situation became increasingly complex, given that the district had previously maintained zero cases for 32 consecutive months and was preparing for elimination verification in 2022. However, in June 2021, 69 indigenous malaria cases were reported, which subsequently increased to 534. The most substantial increase occurred in the Banyuasin Primary Health Center catchment area, dominated by indigenous *Plasmodium falciparum* cases, including a 7.4% gametocyte rate. Kemejing Village recorded the highest prevalence, with clustered transmission patterns concentrated in Krajan hamlet (Puskesmas Banyuasin Purworejo, 2021).

This clustered transmission pattern suggests the presence of a localized malaria transmission system shaped by interactions among vectors, environmental conditions, and community social practices. To date, vector control strategies in Indonesia have largely focused on household-level interventions, primarily through the distribution of long-lasting insecticidal nets (LLINs) and the implementation of indoor residual spraying (IRS) (Unwin *et al.*, 2023). While these interventions have been technically effective in reducing indoor vector density, their long-term effectiveness is strongly influenced by levels of community adherence.

Several studies report that LLIN utilization rates remain relatively low, ranging from 15–50% across various countries and approximately 47% in Indonesia. Discomfort, heat during sleep, and low perceived risk of malaria transmission outside the home have been identified as major barriers to consistent net use (Marina *et al.*, 2023). These findings indicate that technically focused, household-centered interventions have not fully addressed the social and cultural determinants shaping patterns of malaria exposure in the daily lives of rural communities.

From a socio-ecological perspective, malaria transmission can be understood as the outcome of dynamic interactions among vectors, environmental landscapes, and community social practices in the use of living spaces. Physical environments such as community-managed forests, small water bodies, and domestic spaces constitute interconnected components of the vector's ecological system. These spaces should not be viewed merely as passive backdrops, but as social arenas in which economic activities, cultural practices, and human–environment relations are enacted. Accordingly, malaria control within a socio-ecological framework is positioned as a process of transforming relationships among humans, environments, and vectors, rather than simply reducing mosquito populations.

A reorientation of community perceptions is therefore identified as a crucial factor in expanding the understanding that malaria control is not solely the responsibility of the health sector. Cross-sectoral engagement, including the livestock sector, alongside active community participation, is considered essential for developing sustainable control strategies. One cross-sectoral intervention that warrants greater attention is the installation of long-lasting insecticidal nets in livestock shelters, particularly when the benefits of such interventions are directly observable to community members (Zhou *et al.*, 2024).

Anopheles spp. have been identified as zoophilic, with strong attraction to odors and carbon dioxide produced by livestock (Jobe *et al.*, 2023). Several studies report that mosquito density around livestock shelters ranges between 65–80%, higher than indoor densities, which range from 44–70% (Mayagaya *et al.*, 2015). Livestock shelters have also been described as preferred resting sites for mosquitoes, with populations reaching up to 4.4 times higher than those found in human dwellings (Khan, 2022). These findings indicate that livestock shelters function as critical nodes within the vector's ecological system.

In Purworejo District, primary malaria vectors such as *Anopheles balabacensis*, *Anopheles maculatus*, and *Anopheles vagus* are frequently detected around livestock shelters, demonstrating consistent zoophilic behavior (Putranto, Handoyo and Sumanto, 2020). The region's geographical characteristics—surrounded by community forests and small river streams—create humid microenvironments that support breeding sites and extend vector longevity. This configuration illustrates a socio-ecological transmission pathway in which malaria vectors move from breeding sites to livestock shelters as concentration points before eventually entering human living spaces (Hunter *et al.*, 2025).

Community behavioral factors further reinforce this transmission pathway. Routine nighttime activities by livestock owners, such as feeding and guarding animals, are often triggered by livestock restlessness due to mosquito and insect bites. Human presence in livestock shelters during peak *Anopheles spp.* activity periods increase the intensity of human–vector contact outside the home (Esayas *et al.*, 2024). Within rural socio-economic structures, livestock are positioned as primary household assets that receive prioritized care, often at the expense of individual health protection. This condition aligns with social health scholarship, demonstrating that local economic practices shape patterns of exposure to environmentally mediated diseases (Makhanthisa *et al.*, 2022).

These socio-ecological conditions suggest that malaria control strategies targeting the environmental node of livestock shelters are more contextually grounded than interventions focused solely on domestic spaces. The installation of LLINs in livestock shelters, therefore, has the potential to address existing strategic gaps—not only by reducing mosquito and other insect densities, but also by enhancing livestock comfort, which carries positive economic implications for rural households.

This study examined the effect of installing long-lasting insecticide-treated nets (LLINs) in livestock shelters on *Anopheles spp.* density around the shelters and in human dwellings. By integrating vector dynamics, environmental landscapes, and community social practices within a socio-ecological framework, this research seeks to provide empirical contributions to the development of malaria control strategies that are more holistic, culturally contextualized, and sustainable.

The findings are also expected to be replicable in other endemic areas with similar social and ecological characteristics, thereby accelerating malaria elimination efforts at both national and global levels.

METHODOLOGY

Study Design

This study employed a mixed-methods design integrating a quantitative quasi-experimental time-series approach with qualitative inquiry. The design enabled a comprehensive examination of malaria vector dynamics within a socio-ecological system linking breeding sites, livestock shelters, human dwellings, and community practices (Mwalugelo *et al.*, 2024).

The research was conducted in Kemejing Village, Purworejo District. The district's highest malaria-prevalence area, with Krajan hamlet accounting for 57% of reported cases. All livestock owners were included in the intervention (n = 20 at baseline; n = 17 in August; n = 14 in October due to livestock sales).

Intervention and Entomological Procedures

The intervention consisted of installing long-lasting insecticidal nets (LLINs) in livestock shelters. Mosquito collections followed the WHO (World Health Organization, 2013) guidelines using the all-night human landing catch method (18:00–06:00), with 40-minute collection periods in livestock shelters and 10–20 minutes inside houses.

Measurements were conducted at four time points:

Baseline (June 21, 2024); LLINs installation (June 22, 2024); One month before peak transmission (August 5, 2024); One month after peak transmission (October 14, 2024).

Mosquitoes were collected hourly, stored in humidified paper cups, transported from 20 collection points to a central catching station, and identified by species.

Spatial and Statistical Analysis

Environmental mapping included livestock shelter distribution, malaria case households, vegetation, river streams, and other ecological determinants within a 400-meter radius of malaria case residences using GPS. Spatial analysis was conducted in QGIS.

The dependent variable was mosquito abundance (*Anopheles spp.* and non-*Anopheles spp.*). Independent variables included time, collection location (livestock pens vs. house), and species. Data were analyzed using linear mixed models with Maximum Likelihood (ML) or Restricted Maximum Likelihood (REML) estimation to account for repeated measures and attrition. Residual normality was assessed using histograms, normal probability plots, skewness, and kurtosis; natural log transformation was applied when required.

Qualitative Component

In-depth interviews with purposively selected livestock owners explored perceived changes following LLIN installation, including reductions in indoor mosquito numbers, changes in livestock behavior at night, and willingness to participate in malaria control (Niyonsaba *et al.*, 2026). Field observations documented daily and nighttime activities in livestock shelters and community acceptance of the intervention.

Qualitative data were analyzed thematically through verbatim transcription, iterative reading, open coding, and theme development. Three principal themes emerged: perceived reduction in indoor mosquito density and malaria risk; improved livestock comfort; and community willingness to engage in malaria control.

Data Integration

Quantitative spatial and entomological findings were integrated with qualitative themes to construct a holistic socio-ecological interpretation of malaria transmission pathways. This approach situates LLIN installation not only as a biological vector-control intervention but as a relational intervention reshaping interactions among environment, livestock, and community practices.

RESULT AND DISCUSSION

The mosquito collection sites and the situation of the study area were spatially mapped as follows:



Figure1. Spatial Map of Research Locations

The spatial map of malaria endemicity in Dukuh Krajan, Kemejing Village, illustrates malaria cases (yellow symbols), livestock shelters (blue dots), vector breeding sites (green dots), and community forest vegetation cover (dark green areas), which maintains high humidity and supports the development of *Anopheles* spp. as malaria vectors as well as other mosquito species.

The clustered distribution of malaria cases in the study area indicates that transmission does not occur evenly across geographic space, but is concentrated in areas with specific environmental characteristics. The identification of spatial clusters has become an important approach in malaria epidemiology to delineate transmission hotspots. Global studies suggest that detecting spatial clusters can provide strategic insights for more effective local interventions by linking malaria case patterns to local ecological and anthropogenic factors.

Mapping of transmission clusters demonstrates that vegetation cover surrounding human habitats and semi-domestic spaces is associated with heterogeneity in malaria transmission risk. Moist and heterogeneous vegetation creates microenvironments that support the development of *Anopheles* spp. larvae, enhance the quality of breeding sites, and prolong adult mosquito survival, thereby sustaining vector populations in specific areas (Debebe *et al.*, 2020). In addition, secondary forests and shrublands contribute to vector distribution and abundance by providing optimal shade and humidity, which correlate with increased incidence in local hotspots within endemic regions (Mohammed *et al.*, 2025).

Dense and ecologically heterogeneous vegetation is frequently associated with resting sites for *Anopheles* mosquitoes, particularly *An. balabacensis* and *An. maculatus*, as well as with small surface water accumulations that serve as potential breeding sites. Furthermore, studies conducted in Africa have demonstrated a strong association between surrounding vegetation and an increased likelihood of *Anopheles* larval presence, especially when vegetation is located near temporary or permanent water bodies (Ndiaye *et al.*, 2025).

Mosquito Collection

Malaria epidemiological data were used as the basis for determining the timing of mosquito collection, with the collection results presented as follows:

Table 1. Number of Mosquitoes Caught According to Time of Capture

Locus	Time			% Reduction
	June	Augustus	October	
Home:				
<i>Anopheles spp.</i>	78	4	1	98,71
Non <i>Anopheles spp.</i>	13	18	13	0
Livestock pens				
<i>Anopheles spp.</i>	146	50	54	63,01
Non <i>Anopheles spp.</i>	830	54	133	83,97
Total:				
<i>Anopheles spp.</i>	224	54	55	75,44
Non <i>Anopheles spp.</i>	843	122	146	82,68

The reduction of *Anopheles spp.* mosquitoes were 98.71% indoors and 63.01% in livestock shelters, while the reduction of non-*Anopheles spp.* mosquitoes reached 83.97% in livestock shelters and 81.16% overall.

The reduction of *Anopheles spp.* populations indoors following the installation of long-lasting insecticidal nets (LLINs) in livestock shelters indicates a significant impact on the malaria transmission pathway. Biologically, post-mating female mosquitoes seek blood meals in response to gradients of CO₂ and host-derived volatile compounds, which are stronger in large livestock and thus attract zoophilic or opportunistic vectors before they reach humans (Gueye *et al.*, 2023). The installation of LLINs in animal pens serves as both a physical barrier and a mechanism to increase adult mosquito mortality during the host-seeking phase, thereby disrupting the transmission pathway from breeding sites to human settlements and drastically reducing mosquito-human contact (>98% indoors). A similar approach using ivermectin administration to livestock has also been reported to increase mortality in *Anopheles arabiensis* for several weeks after blood feeding, with implications for reducing vector populations by nearly 50% before they bite humans (Sagna *et al.*, 2023).

Statistical Analysis

Statistical analysis was performed using ratio data (number of mosquitoes captured), applying the appropriate test assumptions. The results of the analysis are presented as follows:

Table 2. Statistical Analysis Results

No.	Influence on dependent variables	Types of Analysis	Value	Kesimpulan
1.	Capture time	Mixed model linear	0,000	Ha: Accepted
2.	Species <i>Anopheles spp.</i>	Mixed model linear	0,000	Ha: Accepted
3.	Location of the catch	Mixed model linear	0,000	Ha: Accepted
4.	Interaction of time, species and location	Mixed model linear	0,000	Ha: Accepted

The mixed linear model analysis showed that variations in mosquito abundance were significantly influenced by time, species, collection site, and their three-way interaction ($p < 0.001$), indicating that the intervention effects were context-dependent and specific to specific socio-ecological settings. The post hoc test results are presented as follows:

Table 3. Further test results

No.	Variablel	Variablel	Mean difference	p	Kesimpulan
1.	Varies according to the time of arrest	June (before)	0,275	0,000	Ha: Accepted
		Augustus	0,241	0,000	Ha: Accepted
		October	-0,034	0,604	Ha: Rejected
2.	Varies by location:				
	House	Livestock Pens	-0,259	0,000	Ha: Accepted

The post hoc test indicated that mosquito abundance in the pre-intervention period differed significantly from the post-intervention period, while no significant differences were observed among the post-intervention periods. These findings suggest that the intervention effect occurred relatively rapidly and subsequently reached a plateau effect.

Moreover, the significant differences between collection sites confirm that livestock shelters remained the primary space of mosquito concentration, despite the overall population decline. This finding highlights an important contribution of the study: uncovering a neglected link in malaria transmission that has been overlooked due to the dominance of vector control approaches focused primarily on domestic spaces, while disregarding the livestock shelter environment.

The entomological data generated in this study indicate that after a sharp decline in *Anopheles* spp. populations following the installation of insecticide-treated nets in livestock shelters, mosquito numbers tended to stabilize in August and October and were not statistically significantly different from the preceding month. This stability should be interpreted as a consequence of the primary intervention effect rather than merely as a seasonal phenomenon. Thus, the stability of mosquito abundance in August and October represents part of the medium-term post-intervention effect, in which the intervention suppressed the vector population to a relatively low level and maintained stability through sustained mortality. This condition is consistent with vector population dynamics theory, which suggests that after strong control pressure, a new steady state may be established, resulting in month-to-month population variations that are not statistically significant (Afagbedzi, Alhassan, and Guure, 2022).

In addition to the quantitative findings on changes in vector density, this study was complemented by an exploration of social and ecological dimensions through in-depth interviews with community members, particularly livestock owners involved in installing insecticide-treated nets in animal shelters. Qualitative analysis was conducted using the socio-ecological model framework to understand community perceptions, experiences, and responses to the intervention within the context of daily life, and to provide contextual meaning that enriches the quantitative findings.

The analysis was developed around three major themes: (1) whether the long-term installation of insecticide-treated nets in livestock shelters could reduce mosquitoes inside houses; (2) whether livestock became calmer at night; and (3) whether the community was willing to participate in malaria control efforts. The findings are presented as follows:

Theme 1: Most informants reported that after the installation of insecticide-treated nets in livestock shelters, the number of mosquitoes entering their homes noticeably decreased. The reduction in mosquito nuisance was particularly felt at night during resting hours, which had previously been frequently disturbed by mosquito bites. This perception suggests an indirect protective effect of the intervention in livestock shelters on the residential environment.

"Before using the netting in the livestock shelter, many mosquitoes still entered the house. After it was installed, there were rarely any inside the house." (Informant 7)

Theme 2: At the livestock environment level, informants reported observable changes in animal behavior following the intervention. The animals appeared calmer at night and no longer exhibited the restlessness previously associated with mosquito and other insect disturbances. This condition strengthened community acceptance of the intervention, as its benefits were directly experienced in daily livestock management activities.

"At night, the atmosphere in the shelter is no longer as noisy as before. Previously, the cattle often vocalized due to disturbances from insect or mosquito bites, whereas now they appear calmer and more comfortable." (Informant 9)

Theme 3: The in-depth interviews also revealed increased awareness and willingness among community members to engage in community-based malaria control. Informants' perceptions were divided. Those who owned cattle or goats with relatively large shelters tended to express willingness to independently procure insecticide-treated nets after the study, as the intervention was perceived as easy to implement, non-disruptive to livestock activities, and directly beneficial to both the family and the animals. In contrast, those who owned only a few goats reported limited capacity to do so due to economic constraints.

The interview findings illustrate this perspective:

"The installation of these nets has proven to reduce the number of mosquitoes both in the house and in the shelter. At home, I can sleep soundly, and the risk of mosquito bites from malaria is reduced, while in the shelter, my cattle are no longer restless at night, so they eat more and gain weight faster. Therefore, if I have to buy it myself, I am willing, but where can I buy it and how much does it cost?" (Informant 2)

The implementation of vector control interventions that reduce mosquito populations in both houses and livestock shelters represents not only an ecological change but also a process of social transformation occurring across multiple levels, as described in the Social Ecological Model (SEM) framework. The reduction in mosquito density within domestic and semi-domestic spaces reshapes everyday experiences, risk perceptions, and household

health practices. From a cultural analysis perspective, environmental change is not neutral; rather, it produces new meanings within human–environment–animal relationships, while simultaneously influencing the social construction of comfort, safety, and community health (Susilowati *et al.*, 2025).

The SEM emphasizes that health behaviors are shaped through dynamic interactions among individual, interpersonal, community, and structural factors. Therefore, positive ecological changes can reinforce self-directed vector control practices by fostering collective norms, internalizing perceived benefits, and reconfiguring everyday social practices. In this context, malaria elimination is not merely a technical matter, but also a process of social change rooted in the transformation of meaning structures and cultural practices at the community level (Isnaeni, Musthofa, and Indraswari, 2025).

Within the framework of the Health Belief Model (HBM), the direct experience of reduced mosquito nuisance and increased livestock calmness functions as cues to action, strengthening perceived benefits while lowering psychological barriers to preventive behavior. The intervention is thus perceived not merely as a health obligation, but also as a practical strategy that enhances comfort and livestock productivity, thereby reinforcing social acceptance through a community-based approach (Alamer, 2024) (Firdaus *et al.*, 2025).

From a One Health perspective, these cross-species and cross-ecosystem benefits demonstrate that reducing vector populations yields co-benefits for both human and animal health, which, in turn, encourage sustained adoption. Nevertheless, successful community participation remains influenced by structural factors and the availability of adequate resource support (Niyonsaba *et al.*, 2026).

CONCLUSION

This study affirms that the persistence of malaria is not solely driven by the biological characteristics of the vector, but by a socio-ecological configuration that sustains transmission pathways through breeding sites, resting sites in humid vegetation, and livestock shelters as nodes of mosquito concentration. These ecological pathways have largely been overlooked, as control approaches have predominantly focused on domestic spaces.

The installation of long-lasting insecticidal nets (LLINs) in livestock shelters has been shown to significantly reduce vector density and to interrupt the movement of mosquitoes from breeding habitats to human settlements. Beyond its entomological impact, this intervention also triggered changes in community perceptions through directly experienced benefits, reduced mosquito nuisance, and improved livestock comfort, which strengthened willingness to participate in malaria control efforts. Thus, malaria control should be positioned as an integrated socio-ecological strategy rather than as a stand-alone technical intervention.

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