

IMPACT OF ENVIRONMENTAL RISK FACTORS ON MALARIA INCIDENCE IN POST-COAL MINING LANDS: “SPATIAL ANALYSIS IN KUTAI KERTANEGARA”

ANDI ANWAR^{1,2}, A. ARSUNAN ARSIN², LALU MUHAMMAD SALEH²,
ANWAR DAUD², AGUS BINTARA BIRAWIDA², NATANIEL
DENGAN³, BAHARUDDIN⁴, ANWAR MALLONGI⁵

¹ FACULTY OF PUBLIC HEALTH, MULAWARMAN UNIVERSITY, SAMARINDA, INDONESIA

² FACULTY OF PUBLIC HEALTH, HASANUDDIN UNIVERSITY, MAKASSAR, INDONESIA

³ FACULTY OF ENGINEERING, MULAWARMAN UNIVERSITY, SAMARINDA, INDONESIA

⁴ FACULTY OF FORESTRY, HASANUDDIN UNIVERSITY, MAKASSAR, INDONESIA

Abstract

Introduction . Malaria remains a global health problem, especially in tropical areas such as Indonesia. Coal mining activities exacerbate the risk of transmission because they create ex-mining land that is prone to waterlogging and high humidity. This transmission is still high in areas with ecosystems that have changed due to human activities. This phenomenon requires a comprehensive approach.

Objectives . This study aims to identify environmental risk factors in ex-coal mining land that contribute to the incidence of malaria in Kutai Kertanegara Regency, East Kalimantan.

Methods. This study applied a case-control design (1:2) with a total of 41 malaria cases and 82 controls. Data collection was carried out through interviews, field observations, and spatial mapping using Geographic Information Systems. The variables analyzed included demographic factors, housing characteristics, distance from house to mining void, humidity, and preventive behavior. The chi-square test and binary logistic regression were used to determine the relationship between risk factors and malaria incidence.

Results. The results showed that high humidity (OR=33.65) and close distance from house to mining void (OR=13.89) were the main predictors of transmission. Other factors such as semi-permanent housing type (OR=28.75), night-going habits (OR=16.45), and non-compliance with mosquito net use (OR=14.11) also significantly increased the risk. The age group above 25 years and mining workers and forest encroachers had higher vulnerability compared to other groups. These findings are relevant for malaria elimination efforts in Indonesia.

Conclusion . Environmental, demographic, and behavioral factors together influence the incidence of malaria in ex-coal mining areas. Malaria control interventions need to focus on mosquito habitat management, improving housing quality, and behavioral education for high-risk workers. This integrated approach is expected to reduce malaria transmission sustainably.

Keywords: malaria, spatial analysis, environmental risk factors, post-mining areas, GIS

I. INTRODUCTION

Malaria is one of the infectious diseases that is still a global health challenge, especially in tropical and subtropical regions. This disease is caused by the Plasmodium parasite which is transmitted through the bite of a female Anopheles mosquito . Based on the World Health Organization report (WHO, 2023) , although global efforts in malaria control have shown some success, the disease remains a serious threat in many developing countries, especially those with environmental conditions that support the life cycle of malaria vectors. WHO noted that in 2022, there were more than 249 million cases of malaria globally, with the majority of cases occurring in Africa, Southeast Asia, and South America.

Environmental factors play an important role in the spread of malaria. Landscape changes due to human activities such as deforestation, agriculture, urbanization, and mining have been shown to affect the ecological dynamics of malaria vector mosquitoes (Kweka et al., 2016) (Laporta et al., 2013) These activities can create conditions that support mosquito breeding, such as increased amounts of stagnant water and changes in temperature and microhumidity that can accelerate the vector life cycle (Burkett-Cadena & Vittor, 2018) . Hydrological changes due to deforestation and land conversion also contribute to increased malaria incidence in various tropical regions, especially in areas with high humidity and adequate rainfall for mosquito breeding (Castro et al., 2019) .

One of the human activities that has a significant impact on the environment is coal mining. Former coal mining areas often experience ecological degradation that can increase the risk of spreading vector-based diseases. The mining process often causes extensive deforestation, loss of natural vegetation, and changes in water flow patterns that lead to the formation of puddles in previously dry areas (Thakur et al., 2024). Puddles formed in post-mining areas can be potential habitats for *Anopheles* mosquitoes, which are the main vectors of malaria (Rojas et al., 2023). Studies in various countries have shown that post-mining areas have higher rates of malaria cases compared to areas that have not experienced similar ecological changes (Nabila et al., 2024).

Post-mining land also often experiences changes in soil structure and topography that affect the distribution of water pools, humidity patterns, and the presence of vegetation that can support the development of malaria vectors. In addition, the presence of mine workers who migrate from various regions can also increase the risk of malaria transmission, both through increased human-vector contact and through the entry of individuals who have been infected with *Plasmodium* from other endemic areas (Hasyim et al., 2018a). Previous studies have shown that areas with mining activities have higher rates of malaria infection compared to surrounding areas that are not affected by mining activities (Glendening et al., 2024). Therefore, understanding the environmental factors that contribute to the incidence of malaria in ex-mining land is crucial in efforts to mitigate and control this disease.

Spatial analysis approaches are a very important tool in understanding the relationship between environmental factors and malaria incidence in ex-coal mining areas. Spatial analysis allows the identification of the spatial distribution of malaria incidence and risk factors that contribute to its spread, including the distribution of water bodies, land cover changes, rainfall, humidity, and topographic conditions (Weiss et al., 2019). Geographic Information System (GIS) technology and spatial modeling have been used in various malaria epidemiology studies to map high-risk areas and support decision-making in public health interventions (Bhatt et al., 2015).

In the context of this study, a spatial analysis approach is used to identify environmental risk factors that contribute to malaria incidence in post-coal mining areas. This study will explore the relationship between various environmental parameters and malaria incidence using a GIS-based approach and ecological modeling. The results of this study are expected to provide more accurate information on the spatial distribution of malaria and the factors that contribute to its spread in post-mining areas. Thus, this study is expected to contribute to the development of more effective malaria risk mitigation strategies, especially in post-mining areas that have a high level of vulnerability to this disease.

A better understanding of environmental risk factors contributing to malaria incidence will be very useful in planning public health interventions. By using a spatial data-based approach, it is hoped that malaria prevention and control strategies can be more targeted and efficient. Therefore, this study not only has implications in the fields of epidemiology and public health, but can also be a basis for formulating more sustainable post-mining land management policies based on environmental health principles.

II. MATERIALS AND METHODS

2.1. Research location

This study was conducted in Kutai Kartanegara Regency, East Kalimantan, focusing on communities living around former coal mining pits. East Kalimantan has around 1,735 former mining pits, with 49% spread in Kutai Kartanegara, 20% in Samarinda, and 19% in East Kutai. Kutai Kartanegara Regency also ranks third in the number of malaria cases in the province, indicating a potential link between post-mining landscapes and vector-borne disease risk.

2.2. Design, population and data collection

This study used a case-control design to analyze the relationship between environmental risk factors and malaria incidence in ex-coal mining areas. The case group consisted of individuals diagnosed with malaria based on medical examination results, while the control group consisted of individuals who had no history of malaria in the last 12 months and lived in the same area as the case group. The case-control ratio used was 1:2 to increase the statistical power of the study. The study area was selected based on the intensity of previous mining activities, the presence of air habitats, and the incidence of malaria in recent years. This study took place from February 2024 to July 2024.

The population in this study included all residents living around the former coal mining area. The study sample consisted of 41 individuals as the case group and 82 individuals as the control group selected using the purposive sampling method. The inclusion criteria for the case group included individuals who had been diagnosed with malaria based on a medical examination and had resided in the study area for at least the last six months. Meanwhile, the control group consisted of individuals who had no history of malaria in the last 12 months and lived in the same area. Data collection was conducted through structured interviews, field observations, and spatial mapping using drones. Malaria epidemiology data were obtained from medical records of local health facilities and the national malaria surveillance system. Structured interviews were used to identify environmental factors and individual habits that could potentially increase exposure to malaria vectors. Measurement parameters included the presence and distribution of former coal mining areas studied through field surveys and satellite imagery analysis, as well as rainfall and humidity data obtained from local meteorological stations. Land cover and land use change data were obtained from Landsat 9

satellite imagery and SHP Rupa Bumi Indonesia (RBI), while elevation and topography information were analyzed using the Digital Elevation Model (DEM). All spatial data were analyzed using Geographic Information System (GIS) technology to understand the spatial pattern of malaria incidence.

Topographic maps of the area were created using 8-meter resolution DEM data, revealing elevation variations across the study area. Topographic analysis showed that malaria cases tended to be distributed in areas with elevations below 50 meters above sea level, indicating a relationship between topography and disease distribution. Land cover data were obtained from Landsat 8 imagery and RBI information, which were broken down into several types of land use such as open land, wetlands, arable land, artificial surfaces, agricultural/plantation areas, and water.

2.3. Data analysis

The collected data were analyzed using descriptive, spatial, and statistical approaches to identify environmental risk factors for malaria incidence. Descriptive analysis was conducted to describe the distribution of cases and controls based on demographic, environmental, and epidemiological factors. Comparison of environmental parameters between case and control groups was conducted to identify significant differences in risk factors, a case-control ratio of 1:2 allows for efficient comparison by pairing each case with two controls, increasing statistical power and increasing the precision of estimates (Haley & Huber, 2023).

Spatial analysis in this study was conducted using Landsat 8, Sentinel-2, and Google Earth Engine satellite imagery. ArcGIS software was used to identify the relationship between the distribution of malaria cases and environmental factors. In addition, an entomological survey was conducted by sampling mosquito larvae at various points of former coal mining land inundation that had been identified during the field survey.

Statistical analysis was performed using Chi-square test and Binary Logistic Regression to test the relationship between environmental variables and malaria incidence, while binary logistic regression was applied to identify environmental factors that have a significant influence on malaria incidence. In addition, Odds Ratio (OR) calculations were performed to assess the magnitude of risk posed by environmental factors on malaria incidence. All statistical analyses were performed using SPSS version 26 software.

III. RESULTS

3.1. Univariate Analysis

The results of univariate analysis showed that the majority of malaria sufferers came from the age group >25 years (80%), while the group <25 years was only 20%. The proportion of adults in the control group was higher (95% in control I and 98% in control II). In terms of gender, men dominated the case group (95%), compared to women (5%), indicating that men are more susceptible to malaria due to higher mobility and outdoor activities. Respondents who worked as forest encroachers (51%) and miners (17.2%) had a higher prevalence of malaria compared to other occupational groups. In addition, as many as 80% of malaria sufferers lived in semi-permanent houses, which have lower protection against mosquitoes than stilt houses or permanent houses.

Table 1. Respondent Characteristics Based on Age, Gender, Occupation and Type of House

No	Respondent Characteristics	Case		Control I		Control II		Amount	
		f	%	f	%	f	%	f	%
1	Age								
	<25	8	20	2	5	1	2	11	9
	≥25	33	80	39	95	40	98	112	91
2	Gender								
	Woman	2	5	8	20	8	20	18	15
	Man	39	95	33	80	33	80	105	85
3	Work								
	Housewife	0	0	1	2.4	1	2.4	2	1.6
	Students	1	2.4	0	0	0	0	1	0.8
	Mine Worker	7	17.2	6	14.6	15	36.6	28	22.8
	Forest Encroacher	21	51	9	22	8	19.5	38	30.9
	civil servant	0	0	0	0	1	2.4	1	0.8
	Farmer	3	7.3	8	19.5	6	14.6	17	13.8
	Planter	7	17.2	17	41.5	10	24.5	34	27.7
Fisherman	2	4.9	0	0	0	0	2	1.6	
4	Type of House								
	House on stilts	4	10	4	10	5	12	13	10.5

Semi Permanent House	33	80	32	78	32	78	97	79
Permanent Home	4	10	5	12	4	10	13	10.5

Source; Primary Data 2024

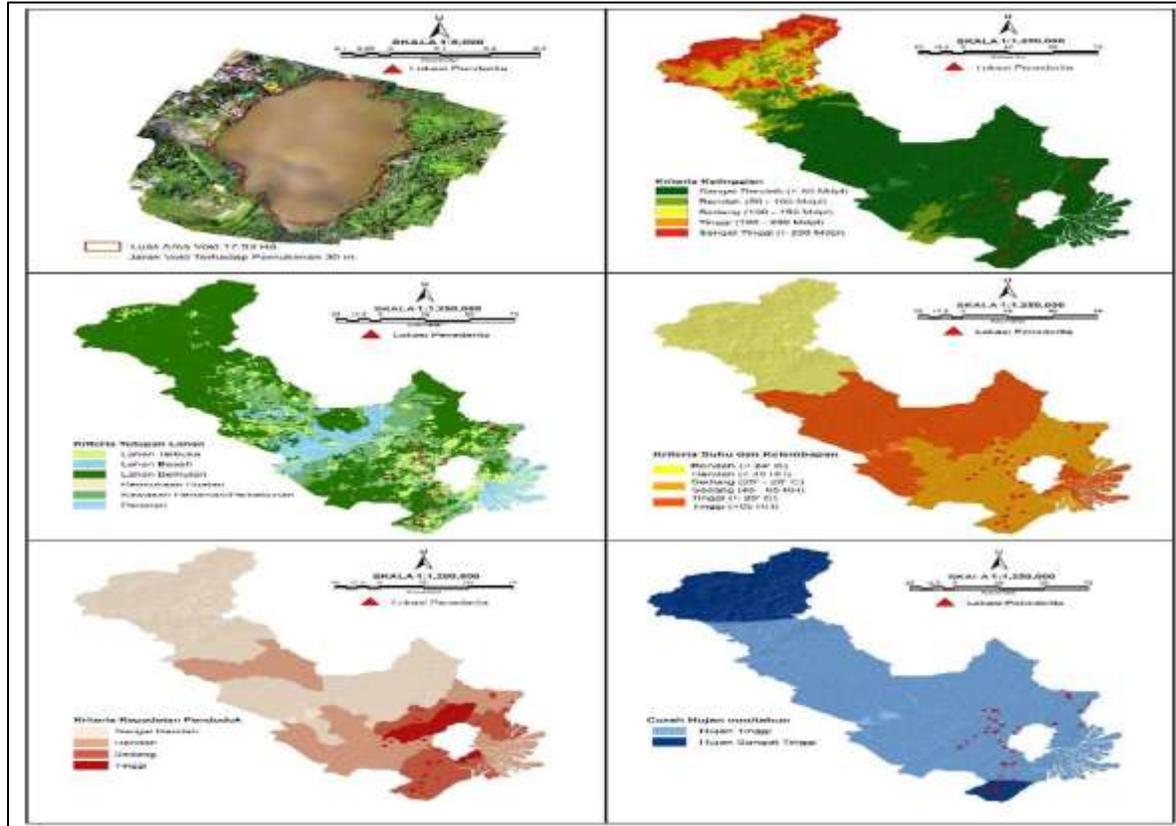


Figure 1. Overlay map of house distance with voids, topography, land cover, temperature and humidity, population density, and rainfall.

In terms of environmental factors, malaria cases were spread across 12 sub-districts with the highest incidence in Samboja Sub-district (13 cases) and the lowest in Loa Kulu, Muara Badak, Marangkayu, and Sebulu Sub-districts (1 case each). The temperature ranged from 28–29°C, with moderate to high humidity (60–80 RH) which supports mosquito breeding. Areas with high rainfall showed higher malaria incidence rates compared to areas with very high rainfall. The study area was dominated by lowlands with land cover in the form of forests and former mining voids which are potential habitats for Anopheles mosquitoes. Houses that are closer to mining voids have a higher risk of contracting malaria. Population density varies, with fairly dense areas having higher malaria incidence rates than less dense areas. The survey results show that the minimum distance between the empty area of the former mine and settlements is 30 meters, with an area reaching 17.93 hectares, which has the potential to become a habitat for malaria vectors. Malaria cases are spread across 13 sub-districts, especially in the lowlands (<50 masl). Land cover is dominated by forests, agricultural and plantation lands, and open land, which contributes to the presence of stagnant water as a breeding ground for mosquitoes. Temperature and humidity vary, with the lowest temperature <25°C and the highest >29°C, and humidity ranging from <60% to >80% Rh. However, most malaria cases are found at moderate temperatures (25–28°C) with humidity of 61–79% Rh, which are optimal conditions for vector development. Population density in malaria case areas is dominated by moderate (31.7%) and high (39%) densities, which contribute to increased interactions between humans and mosquitoes. The distribution of malaria cases is also related to rainfall, with a wider distribution in areas with high (87.8%) and very high (12.2%) rainfall. High rainfall supports the formation of water bodies, while extreme rainfall can inhibit vector growth. (can be seen in the map overlay figure 1).

3.2. Bivariate Analysis

The results of the bivariate analysis showed that several factors had a significant relationship with the incidence of malaria. Statistical tests showed that age ($p = 0.001$), gender ($p = 0.041$), occupation ($p = 0.000$), humidity ($p = 0.000$), distance from home to the mine void ($p = 0.000$), type of house ($p = 0.000$), use of mosquito repellent ($p = 0.034$), use

of mosquito nets ($p = 0.000$), and nighttime habits ($p = 0.000$) had a significant relationship with the incidence of malaria.

Table 2. Recapitulation of risk factor analysis for malaria incidents in Kutai Kertanegara Regency

No	variable	P-Value	OR (95%CI)
1	Age	0.001	7.150 (2.112- 24.203)
2	Gender	0.041	4,086 (1,137- 14.68)
3	Work	0.000	4.154 (1.472- 11,726)
4	Temperature	1,000	1,000 (0.418- 2.394)
5	Humidity	0.000	33,648 (9,102-124,394)
6	Topography	1,000	1,000 (1,000-1,000)
7	Rainfall	1,000	1,000 (0.369- 2.708)
8	Distance from Home	0.000	13,886 (4,904-39,318)
9	Type of House	0.000	28,750 (4,164-198,484)
10	Anti Mosquito	0.034	3.456 (1.206-9.903)
11	Population density	1,000	1,000 (0.191-5.241)
12	Use of Mosquito Nets	0.000	14,109 (5,442-36,581)
13	Out at Night	0.000	16,454 (6,512-41,575)

Source: Primary Data, 2024

3.3. Multivariate Analysis

The results of the multivariate analysis identified dominant risk factors that increased the likelihood of malaria. Significant contributing factors included high humidity (OR = 33.648; $p = 0.000$), type of house (OR = 28.750; $p = 0.000$), habit of going out at night (OR = 16.454; $p = 0.000$), use of mosquito nets (OR = 14.109; $p = 0.000$), distance from the house to the mine void (OR = 13.886; $p = 0.000$), occupation (OR = 4.154; $p = 0.000$), and use of mosquito repellent (OR = 3.456; $p = 0.034$).

3.4. Ethics Statement

This study has obtained approval from the Research Ethics Committee of the Faculty of Health, Hasanuddin University with recommendation number 292/UN4.14.1/TP.01.02/2024 on January 29, 2024. Each participant was given information regarding the purpose and procedures of the study before giving written consent to participate. Participant data is kept confidential and is only used for scientific analysis purposes. Entomological surveys were conducted by following research protocols established by relevant institutions to ensure the security and accuracy of the data obtained.

IV. DISCUSSION

The results of this study confirm that demographic factors, type of work, environmental conditions, and individual behavior contribute significantly to the incidence of malaria in former coal mining areas. The analysis shows that age is the main risk factor, where individuals aged over 25 years have a higher risk than younger age groups (p -value = 0.001, OR = 7.150; CI: 2.112-24.203). This finding is in line with previous studies showing that adults are more susceptible to malaria due to increased outdoor activities, especially in the mining and forest encroachment sectors (Hasyim et al., 2018b) ; (Guntur et al., 2024) . Further research by (Amaral et al., 2024) also shows that workers in the mining sector, which are dominated by men aged 15-29 years, have high mobility and are more often exposed to malaria vectors.

Gender was also shown to play a role in increasing malaria risk, with men having a higher risk than women (p -value = 0.041, OR = 4.086; CI: 1.137-14.68). This is associated with high mobility and men's involvement in outdoor work which increases exposure to malaria vectors (Rahman & Hossain, 2025) ; (Msellemu et al., 2024) . Conversely, women tend to have more indoor activities, which provide more protection from mosquito bites (Seyoum et al., 2012) . The implications of these results indicate the importance of gender-based interventions in malaria control, including the provision of protective equipment and education for male workers in endemic areas.

Type of work is also a major determinant of malaria risk. Workers in the forestry (51%), mining (17.2%), and plantation (17.2%) sectors have a higher risk than workers in other sectors (p -value = 0.000, OR = 4.154; CI: 1.472-11.726). Studies by (Ranjha & Sharma, 2021) and (Boyer et al., 2025) show that workers in forested areas are at higher risk of malaria due to high exposure to Anopheles mosquitoes. In addition, climatic conditions such as high humidity and ambient temperatures that support vector development also contribute to the increase in malaria cases (Kibret et

al., 2019). Therefore, workplace-based malaria prevention policies are needed, such as the distribution of insecticide-treated bed nets and education programs for workers in malaria-prone areas.

Environmental factors also play a crucial role in malaria epidemiology. The results of this study showed that high humidity significantly increased the risk of malaria by 33.64 times (p -value = 0.000, OR = 33.648; CI: 9.102-124.394). Previous studies (Brown et al., 2023) and (Alum et al., 2024) revealed that high humidity supports the mosquito life cycle and increases the resistance of Plasmodium sporogony, which accelerates malaria transmission. In addition, the distance of the house to sources of stagnant water, such as coal mine voids, also contributes to the risk of malaria infection (p -value = 0.000, OR = 13.886; CI: 4.904-39.318), in line with the findings by (Balkew et al., 2021) and (Bhatt et al., 2015) which showed that the presence of stagnant water increases the density of the mosquito vector population. Therefore, environmental mitigation strategies such as drainage engineering and reclamation of former mining land are important steps in controlling malaria.

House structure also contributes to malaria risk. Individuals living in semi-permanent houses are more susceptible to infection than those living in permanent houses or stilt houses (p -value = 0.000, OR = 28.750; CI: 4.164-198.484). The results of the study (Liu et al., 2014) showed an association between malaria incidence and housing quality with the association concentrated among the best quality houses, other studies have shown that housing quality affects malaria incidence, with houses with solid walls and windows covered with mosquito nets can significantly reduce the risk of infection (Tusting et al., 2017) and (Getawen et al., 2018). More specifically, improving the quality of houses by increasing safe ventilation and installing mosquito nets (Endo & Eltahir, 2016). Environmental-based interventions such as improving housing quality and planning the layout of settlements around mining areas need to be part of the malaria control strategy.

In addition to environmental and socio-demographic factors, individual behavior also plays an important role in the incidence of malaria. The habit of going out at night increases the risk of infection by 16.45 times (p -value = 0.000, OR = 16.454; CI: 6.512-41.575). Previous studies by (Soe et al., 2017) and (Namango et al., 2024) which found that the habit of going out at night has a significant effect on the risk of malaria showed that outdoor activities at night increase the risk of malaria, considering that peak mosquito activity occurs between 19:00-23:00 and 01:00-03:00 (Mukisa et al., 2024). Given the importance of these aspects, behavioral-based intervention efforts such as the use of protective clothing and insecticide spraying need to be strengthened to reduce exposure to malaria vectors.

The use of mosquito nets has been shown to be an effective prevention method, where individuals who do not use mosquito nets have a 14.10 times higher risk of contracting malaria than those who sleep with mosquito nets (p -value = 0.000, OR = 14.109; CI: 5.442-36.581). A study (Levens, 2024) showed that Long Lasting Insecticidal Nets (LLIN) significantly reduce malaria transmission, by providing physical and chemical protection against mosquitoes. A study (Epstein et al., 2024) also showed that the distribution of new generation LLINs can reduce malaria incidence by up to 23% in the first year in endemic areas. It is very important that the massive distribution of mosquito nets and education on their use must be an integral part of community-based malaria control strategies.

Overall, this study confirms that malaria control requires a multidisciplinary approach that includes environmental factors, individual behavior, and evidence-based health policies. Integration of environmental mitigation strategies, behavioral interventions, and strengthening of health surveillance systems in endemic areas is essential to achieve more effective and sustainable malaria control.

While this study provides valuable insights, there are some limitations that need to be considered. Potential recall bias from participants may affect the accuracy of information related to environmental risk factors. In addition, limited satellite image resolution may affect the accuracy of detecting small changes in standing water that play a role in the development of vector mosquitoes. The potential for underreporting of malaria epidemiological data is also a challenge, especially in remote areas with limited health surveillance systems. Future research is recommended to use a combination of high-resolution mapping technology and field data collection to improve the accuracy of environmental risk monitoring for malaria incidence.

V. CONCLUSION

This study confirms that malaria incidence is influenced by complex interactions between demographic, occupational, environmental, and individual behavioral factors. The results showed that individuals aged over 25 years were at higher risk of malaria, which was associated with increased outdoor activity and involvement in high-risk occupations. In addition, men were more susceptible to malaria infection than women, mainly due to their high mobility and exposure to the outdoor environment.

The type of work is also a determining factor in malaria incidence, with workers in the forestry, mining, and plantation sectors showing higher levels of risk. Work environments that support the breeding of vector mosquitoes, such as the presence of stagnant water and high humidity, contribute to increased malaria transmission. Other environmental factors, such as humidity and proximity to sources of stagnant water, further exacerbate the risk of transmission. The

study also confirmed that inadequate housing conditions, such as semi-permanent houses without adequate structural protection, increase the risk of malaria infection.

From a behavioral perspective, the habit of going out at night significantly increases exposure to mosquito vector bites. In addition, low compliance in the use of insecticide-treated bed nets is associated with increased malaria incidence. Therefore, a behavioral change-based approach is an important component of prevention strategies, including education on self-protection and optimization of bed net use.

The implications of this study emphasize the need for a multidisciplinary approach to malaria control that involves demographic, environmental, occupational, and individual behavioral interventions. Effective strategies that can be implemented include environmental management to reduce vector habitat, widespread distribution of insecticide-treated bed nets, and educational campaigns targeting high-risk groups. With an evidence-based approach and integrated mitigation strategies, sustainable malaria control can be achieved, supporting malaria elimination efforts in the long term.

REFERENCE

1. Alum, EU, Ugwu, OP-C., Egba, SI, Uti, DE, & Alum, BN (2024). Climate Variability and Malaria Transmission: Unraveling the Complex Relationship. *INOSR Scientific Research* , 11 (2), 16–22. <https://doi.org/10.59298/INOSRSR/2024/1.1.21622>
2. Amaral, PST, Garcia, KKS, Suárez-Mutis, MC, Coelho, RR, Galardo, AK, Murta, F., Moresco, GG, Siqueira, AM, & Gurgel-Gonçalves, R. (2024). Malaria in areas under mining activity in the Amazon: A review. *Revista Da Sociedade Brasileira de Medicina Tropical* , 57 . <https://doi.org/10.1590/0037-8682-0551-2023>
3. Balkew, M., Mumba, P., Yohannes, G., Abiy, E., Getachew, D., Yared, S., Worku, A., Gebresilassie, A., Tadesse, FG, Girma, E., Esayas, E., Ashine, T., Yewhalaw, D., Chibsa, S., Teka, H., Murphy, M., Yoshimizu, M., Dengela, D., Zohdy, S., & Irish, S. (2021). An update on the distribution, bionomics, and insecticide susceptibility of *Anopheles stephensi* in Ethiopia, 2018–2020. *Malaria Journal* , 20 (1). <https://doi.org/10.1186/s12936-021-03801-3>
4. Bhatt, S., Weiss, DJ, Cameron, E., Bisanzio, D., Mappin, B., Dalrymple, U., Battle, KE, Moyes, CL, Henry, A., Eckhoff, PA, Wenger, EA, Briët, O., Penny, MA, Smith, TA, Bennett, A., Yukich, J., Eisele, TP, Griffin, JT, Fergus, CA, ... Gething, PW (2015). The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015. *Nature* , 526 (7572), 207–211. <https://doi.org/10.1038/nature15535>
5. Boyer, S., Doeurk, B., Rakotonirina, A., Chy, S., Vong, C., Piv, E., Tat, B., Ea, M., Chhin, C., Phen, S., Kloeung, N., Ke, S., Popovici, J., Piola, P., Witkowski, B., Maquart, P.-O., & Vantaux, A. (2025). *Anopheles* mosquitoes in Monduliri forest, Cambodia: abundance, distribution, seasonal patterns and *Plasmodium* prevalence. *Malaria Journal* , 24 (1), 6. <https://doi.org/10.1186/s12936-024-05166-9>
6. Brown, J., Pascual, M., Wimberly, M., Johnson, L., & Murdock, C. (2023). Humidity - The Overlooked Variable in Thermal Biology of Mosquito-Borne Disease . <https://doi.org/10.22541/au.168053633.38060615/v1>
7. Burkett-Cadena, N.D., & Vittor, A.Y. (2018). Deforestation and vector-borne disease: Forest conversion favors important mosquito vectors of human pathogens. *Basic and Applied Ecology* , 26 , 101–110. <https://doi.org/10.1016/j.baae.2017.09.012>
8. Castro, M.C., Baeza, A., Codeço, C.T., Cucunubá, Z.M., Dal'Asta, A.P., De Leo, G.A., Dobson, A.P., Carrasco-Escobar, G., Lana, R.M., Lowe, R., Monteiro, AMV, Pascual, M., & Santos-Vega, M. (2019). Development, environmental degradation, and disease spread in the Brazilian Amazon. *PLOS Biology* , 17 (11), e3000526. <https://doi.org/10.1371/journal.pbio.3000526>
9. Endo, N., & Eltahir, EAB (2016). Environmental determinants of malaria transmission in African villages. *Malaria Journal* , 15 (1), 578. <https://doi.org/10.1186/s12936-016-1633-7>
10. Epstein, A., Gonahasa, S., Namuganga, J.F., Nassali, M., Maiteki-Sebuguzi, C., Nabende, I., Snyman, K., Nankabirwa, J.I., Opigo, J., Donnelly, M.J., Staedke, S.G., Kanya, M.R., & Dorsey, G. (2024). Evaluating the impact of two next generation long-lasting insecticidal nets on malaria incidence in Uganda: an interrupted time series analysis using routine health facility data . <https://doi.org/10.1101/2024.10.03.24314858>
11. Getawen, S. K., Ashine, T., Masseur, F., Woldeyes, D., & Lindtjörn, B. (2018). Exploring the impact of house screening intervention on entomological indices and incidence of malaria in Arba Minch town, southwest Ethiopia: A randomized control trial. *Acta Tropica* , 181 , 84–94. <https://doi.org/10.1016/j.actatropica.2018.02.009>
12. Glendening, N., Haileselassie, W., Lee, M.-C., Taye, B., Alemu, Y., Belachew, A., Deressa, W., Yan, G., & Parker, D.M. (2024). A cross-sectional study investigating malaria prevalence and associated predictors of infection among migrants to a newly established gold mining settlement in the Gambella Region of Ethiopia. *Malaria Journal* , 23 (1), 292. <https://doi.org/10.1186/s12936-024-05117-4>
13. Guntur, R.D., Pahnuel, J.R., Ginting, K.B., Bria, Y.P., Kusumaningrum, D., & Islam, F.M.A. (2024). Malaria prevalence and its associated factors amongst rural adults: Cross-sectional study in East Nusa Tenggara Province Indonesia . <https://doi.org/10.1101/2024.09.11.24313521>

14. Haley, K. E., & Huber, K. E. (2023). Case-control study. In *Translational Radiation Oncology* (pp. 223–229). Elsevier. <https://doi.org/10.1016/B978-0-323-88423-5.00091-1>
15. Hashim, H., Nursafingi, A., Haque, U., Montag, D., Groneberg, D.A., Dhimal, M., Kuch, U., & Müller, R. (2018a). Spatial modeling of malaria cases associated with environmental factors in South Sumatra, Indonesia. *Malaria Journal* , 17 (87), 1–15. <https://doi.org/10.1186/s12936-018-2230-8>
16. Hashim, H., Nursafingi, A., Haque, U., Montag, D., Groneberg, D.A., Dhimal, M., Kuch, U., & Müller, R. (2018b). Spatial modeling of malaria cases associated with environmental factors in South Sumatra, Indonesia. *Malaria Journal* , 17 (1), 87. <https://doi.org/10.1186/s12936-018-2230-8>
17. Kibret, S., Lautze, J., McCartney, M., Nhamo, L., & Yan, G. (2019). Malaria around large dams in Africa: Effect of environmental and transmission endemicity factors. *Malaria Journal* , 18 (303), 1–12. <https://doi.org/10.1186/s12936-019-2933-5>
18. Kweka, E. J., Kimaro, E. E., & Munga, S. (2016). Effect of Deforestation and Land Use Changes on Mosquito Productivity and Development in Western Kenya Highlands: Implications for Malaria Risk. *Frontiers in Public Health* , 4 . <https://doi.org/10.3389/fpubh.2016.00238>
19. Laporta, GZ, Prado, PIKL de, Kraenkel, RA, Coutinho, RM, & Sallum, MAM (2013). Biodiversity Can Help Prevent Malaria Outbreaks in Tropical Forests. *PLoS Neglected Tropical Diseases* , 7 (3), e2139. <https://doi.org/10.1371/journal.pntd.0002139>
20. Levens, W. (2024). Modeling the Combined Use of Long-Lasting Insecticidal Nets and Insecticides Zoophylaxis Against the Resilience of Anopheles Arabiensis for Effective Malaria Control. *Tanzania Journal of Science* , 50 (1), 134–146. <https://doi.org/10.4314/tjs.v50i1.11>
21. Liu, J.X., Bousema, T., Zelman, B., Gesase, S., Hashim, R., Maxwell, C., Chandramohan, D., & Gosling, R. (2014). Is Housing Quality Associated with Malaria Incidence among Young Children and Mosquito Vector Numbers? Evidence from Korogwe, Tanzania. *PLoS ONE* , 9 (2), e87358. <https://doi.org/10.1371/journal.pone.0087358>
22. Msellemu, D., Tanner, M., Yadav, R., & Moore, S. J. (2024). Occupational exposure to malaria, leishmaniasis and arbovirus vectors in endemic regions: A systematic review. *Current Research in Parasitology & Vector-Borne Diseases* , 6 , 100185. <https://doi.org/10.1016/j.crpvbd.2024.100185>
23. Mukisa, M.C., Kassano, J.J., Mwalugelo, Y.A., Ntege, C., Kahamba, N.F., Finda, M.F., Msugupakulya, BJ, Ngowo, H.S., & Okumu, F.O. (2024). Analysis of the 24-Hour Biting Patterns and Human Exposures to Malaria Vectors in South-Eastern Tanzania . <https://doi.org/10.21203/rs.3.rs-4844193/v1>
24. Nabila, S.A., Sunarsih, E., & Novrikasari, N. (2024). Determinants of the Dynamics of Malaria Infection Transmission in Mining Areas: Literature Review. *Indonesian Health Promotion Publication Media (MPPKI)* , 7 (10), 2397–2408. <https://doi.org/10.56338/mppki.v7i10.5923>
25. Namango, IH, Moore, SJ, Marshall, C., Saddler, A., Kaftan, D., Tenywa, FC, Makungwa, N., Limwagu, AJ, Mapua, S., Odufuwa, OG, Ligema, G., Ngonyani, H., Matanila, I., Bharmal, J., Moore, J., Finda, M., Okumu, F., Hetzel, M. W., & Ross, A. (2024). A matter of timing: Biting by malaria-infected Anopheles mosquitoes and the use of interventions during the night in rural south-eastern Tanzania. *PLOS Global Public Health* , 4 (12), e0003864. <https://doi.org/10.1371/journal.pgph.0003864>
26. Rahman, A., & Hossain, M. M. (2025). Malaria and Environmental Determinants in Bangladesh: Implications for Occupational Health and Disease Control . <https://doi.org/10.20944/preprints202501.1485.v1>
27. Ranjha, R., & Sharma, A. (2021). Forest malaria: the prevailing obstacle for malaria control and elimination in India. *BMJ Global Health* , 6 (5), e005391. <https://doi.org/10.1136/bmjgh-2021-005391>
28. Rojas, M.A., Velasco, M.C., Ahumada, M., Chaparro, P., Yasnot, M.F., & Orjuela, L.I. (2023). Anopheles species associated with malaria transmission in gold-mining areas of northwest Colombia . <https://doi.org/10.21203/rs.3.rs-3466655/v1>
29. Seyoum, A., Sikaala, C.H., Chanda, J., Chinula, D., Ntamatungiro, A.J., Hawela, M., Miller, J.M., Russell, T.L., Briët, O.J.T., & Killeen, G.F. (2012). Human exposure to anopheline mosquitoes occurs primarily indoors, even for users of insecticide-treated nets in Luangwa Valley, South-east Zambia. *Parasites & Vectors* , 5 (1), 101. <https://doi.org/10.1186/1756-3305-5-101>
30. Soe, HZ, Thi, A., & Aye, NN (2017). Socioeconomic and behavioral determinants of malaria among the migrants in gold mining, rubber and oil palm plantation areas in Myanmar. *Infectious Diseases of Poverty* , 6 (1), 142. <https://doi.org/10.1186/s40249-017-0355-6>
31. Thakur, T.K., Swamy, S.L., Dutta, J., Thakur, A., Mishra, A., Sarangi, PK, Kumar, A., Almutairi, B.O., & Kumar, R. (2024). Assessment of land use dynamics and vulnerability to land degradation in coal-mined landscapes of central India: implications for ecorestoration strategies. *Frontiers in Environmental Science* , 12 . <https://doi.org/10.3389/fenvs.2024.1419041>
32. Tusting, L.S., Bottomley, C., Gibson, H., Kleinschmidt, I., Tatem, A.J., Lindsay, S.W., & Gething, P.W. (2017). Housing Improvements and Malaria Risk in Sub-Saharan Africa: A Multi-Country Analysis of Survey Data. *PLOS*

Medicine , 14 (2), e1002234. <https://doi.org/10.1371/journal.pmed.1002234>

33. Weiss, DJ, Lucas, TCD, Nguyen, M., Nandi, AK, Bisanzio, D., Battle, KE, Cameron, E., Twohig, KA, Pfeffer, DA, Rozier, JA, Gibson, HS, Rao, PC, Casey, D., Bertozzi-Villa, A., Collins, EL, Dalrymple, U., Gray, N., Harris, JR, Howes, RE, ... Gething, PW (2019). Mapping the global prevalence, incidence, and mortality of *Plasmodium falciparum*, 2000–17: a spatial and temporal modeling study. *The Lancet* , 394 (10195), 322–331. [https://doi.org/10.1016/S0140-6736\(19\)31097-9](https://doi.org/10.1016/S0140-6736(19)31097-9)

34. WHO. (2023). World malaria World malaria report report .

<https://www.wipo.int/amc/en/mediation/%0Ahttps://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2023>