



Comparative Evaluations on Dynamics of... Garba, K. M., Et. al. (2026)

Comparative Evaluations on Dynamics of Malaria and Dengue Co-Infections among Patents in North-West Geopolitical Zones of Nigeria

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Abstract

Malaria and dengue fever are significant mosquito-borne illnesses that share similar clinical characteristics, making accurate diagnosis difficult in endemic regions. This study examined the patterns, prevalence, risk factors, and predictive indicators of malaria–dengue co-infection among 200 respondents in Kano, Nigeria. Information on co-infection cases was sought from health facility record departments, along with details of ongoing sensitization and awareness programmes. However, inadequate record-keeping practices in these facilities limited the availability of reliable data on malaria–dengue co-infection, while awareness campaigns for endemic diseases were largely coordinated at government and local government levels. A structured questionnaire was used to collect data on sociodemographic characteristics and potential disease-related symptoms. The data were analyzed using descriptive statistics and chi-square (χ^2) tests, in addition to a simple predictive modeling approach. The results showed prevalence rates of 40% for malaria, 8.5% for dengue (IgM), and 4.5% for co-infection. A statistically significant association was found between gender and malaria infection ($\chi^2 = 17.79$, $p < 0.001$), whereas no significant relationship was observed between gender and dengue infection ($p = 0.94$). Educational level was also significantly associated with the type of infection ($\chi^2 = 8.55$, $p = 0.036$). Fever emerged as the strongest predictor of dengue infection, with the likelihood increasing when combined with other symptoms. Although the prevalence of co-infection was relatively low, the risk was higher among individuals already infected with malaria and presenting multiple symptoms.

Keywords: Dynamics of Malaria, Dengue Co-Infection, Data-Driven, Machine Learning, Bioinformatics Techniques

Introduction

Malaria and dengue fever are among the most prevalent mosquito-borne diseases affecting tropical and subtropical regions, particularly in sub-Saharan Africa. Malaria is caused by *Plasmodium* parasites transmitted through the bites of infected female *Anopheles* mosquitoes, whereas dengue fever results from infection with the dengue virus, primarily spread by *Aedes aegypti*. Both illnesses share similar clinical manifestations, including fever, headache, and joint pain, which complicates accurate diagnosis in endemic settings (WHO, 2023). Globally, malaria continues to pose a significant public



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health challenge, with over 200 million cases reported annually, most of which occur in Africa. In contrast, dengue fever has become one of the fastest-growing viral infections worldwide, with increasing spread even in regions previously regarded as non-endemic (WHO, 2023). In recent years, increasing attention has been directed toward the co-infection of malaria and dengue, especially in regions where both diseases are simultaneously endemic. Co-infection refers to the concurrent presence of malaria parasites and dengue virus in the same individual, creating complex diagnostic and treatment challenges due to overlapping symptoms and the risk of severe complications. Evidence from studies across Africa and Asia indicates that the prevalence of malaria–dengue co-infection ranges from approximately 4% to 20%, depending on location and diagnostic approaches (Gebremariam et al., 2023). Since 2012, dengue has been recognized by the World Health Organization as the leading mosquito-borne viral disease globally. Over the past two decades, its incidence has risen dramatically, with reported cases increasing tenfold from 500,000 in 2000 to 5.2 million in 2019, which marked a historic peak across 129 countries (WHO, 2024). Although there was a temporary decline between 2020 and 2022 due to the COVID-19 pandemic and reduced reporting, 2023 witnessed a resurgence characterized by widespread outbreaks, including in previously unaffected regions (Gebremariam et al., 2023; ECDPC, 2024). Dengue transmission typically follows cyclical patterns, with major outbreaks occurring every three to four years. Reduced transmission during the COVID-19 period contributed to a buildup of susceptible individuals lacking immunity to certain dengue serotypes, thereby intensifying subsequent outbreaks (ECDPC, 2024). However, information on circulating dengue serotypes in countries such as Nigeria remains limited. Since early 2023, global transmission has surged, resulting in over five million reported cases and more than 5,000 deaths across multiple WHO regions, with nearly 80% of cases concentrated in a few highly affected areas (WHO, 2024; ECDPC, 2024). Several factors have contributed to the rapid spread of dengue, including climate change, increased temperature, rainfall, and humidity, as well as the expansion of mosquito vectors such as *Aedes aegypti* and *Aedes albopictus* into new regions. Additionally, factors such as population mobility, fragile healthcare systems, and the lingering impacts of the COVID-19 pandemic have further complicated control efforts (Oladipo et al., 2022). Weak surveillance systems in many endemic countries also contribute to delayed detection and response, increasing the likelihood of severe disease outcomes.

Statement of the Problem

Malaria remains one of the most widespread infectious diseases in tropical and subtropical regions and continues to contribute significantly to global morbidity and mortality. Despite sustained efforts toward its control and prevention, the disease persists due to evolving transmission patterns and the adaptability of *Plasmodium* species such as *P. falciparum*, *P. vivax*, *P. malariae*, *P. ovale*, and *P. knowlesi*. Although individuals may develop partial immunity following repeated infections, this protection gradually declines in the absence of continuous exposure, thereby sustaining vulnerability to reinfection. These changing epidemiological patterns present ongoing challenges for effective monitoring, control, and prevention strategies. At the same time, the coexistence of malaria and dengue fever in many endemic regions has introduced an additional public health concern in the form of co-infection. While each disease independently poses serious health risks, simultaneous infection with both malaria parasites and the dengue virus can lead to more severe clinical outcomes. The overlapping clinical symptoms such as fever, headache, and general body weakness—create a high likelihood of misdiagnosis or missed co-infection, particularly in resource-limited settings where diagnostic tools are inadequate. Consequently, patients may receive inappropriate or delayed treatment, increasing the risk of complications and mortality. Evidence from studies conducted across Africa and Asia indicates that malaria–dengue co-infection is becoming increasingly prevalent, with rates ranging from 4% to 20% depending on geographical location and diagnostic methods. This growing trend underscores the need for improved diagnostic accuracy and better understanding of the interaction between the two diseases. However, in many endemic countries, including Nigeria, surveillance systems remain weak, and healthcare facilities often lack the capacity to routinely test for dengue, leading to its underdiagnosis or misclassification as malaria. Nigeria, where malaria is highly endemic and dengue cases are gradually being reported, faces a potential dual disease burden. The persistent reliance on clinical diagnosis without laboratory confirmation further complicates accurate detection of co-infection. This situation highlights a critical gap in current healthcare practices, as the absence of integrated diagnostic and surveillance systems limits the ability to identify, monitor, and effectively manage malaria–dengue co-infections. Therefore, the problem lies in the inadequate recognition, diagnosis, and surveillance of malaria and dengue co-infection, which poses a significant threat to effective disease management and control. Addressing



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this challenge requires the adoption of more comprehensive diagnostic approaches, strengthened surveillance systems, and increased awareness among healthcare providers. Furthermore, there is a pressing need to incorporate advanced tools such as molecular diagnostics and data-driven approaches to improve early detection, guide treatment decisions, and ultimately reduce the burden of these co-existing infections in endemic regions.

Research Objectives

The objectives of the study are to:

1. Determine the incidence of co-existence of dengue fever and malaria.
2. Determine the occurrence of Dengue Fever in Relation to Some Commonly Observed signs and symptoms.
3. Investigate the occurrence of malaria and dengue infection by gender.
4. Investigate the distribution of malaria and dengue infection by educational status.
5. Examine the relationship between gender, educational status, dengue fever and malaria.
6. Review hospital documents and stewardship policies to evaluate current practice related to malaria and dengue control measures in health care facilities
7. Employ machine learning and bioinformatics to analyze datasets and develop predictive models for disease outcome and transmission dynamics.

Research Questions

The following research questions were formulated to guide the study:

1. What is the Incidence of Co-existence of Dengue Fever and Malaria?
2. What is the occurrence of Dengue Fever in Relation to Some Commonly Observed Signs and Symptoms?
3. What is the occurrence of Malaria and Dengue Infection by Gender?
4. What is the distribution of Malaria and Dengue Infection by Educational Status?
5. What is the relationship between Gender, Educational Status, Dengue Fever and Malaria?

Research Methodology

The research was carried out in 2 dengue endemic states situated in the northwestern Nigeria. North-western Nigeria is one of the six geopolitical zones of Nigeria, located in the northern part of the country. The zone comprises seven states, namely Jigawa State, Kaduna State, Kano State, Katsina State, Kebbi State, Sokoto State, and Zamfara State. The region shares international borders with the Niger to the north and national boundaries with the North Central and Northeast geopolitical zones of Nigeria. Northwestern Nigeria lies within the Sudan savannah ecological zone, characterized by open grassland vegetation interspersed with scattered trees. The climate is typically tropical continental, with two distinct seasons: a rainy season occurring between May and October, and a dry season from November to April. The dry season is often influenced by the Harmattan winds originating from the Sahara Desert, resulting in low humidity and dusty atmospheric conditions. Annual rainfall in the region generally ranges between 500 mm and 1,000 mm, while temperatures are usually high throughout the year, with mean daily temperatures ranging from 25°C to 40°C. The region is predominantly inhabited by Hausa and Fulani ethnic groups, with agriculture serving as the major occupation of the population. Major crops cultivated include millet, sorghum, maize, rice, and groundnuts, while livestock rearing is also common. Northwestern Nigeria is one of the most densely populated regions in the country, with major urban centers such as Kano and Kaduna serving as important commercial and industrial hubs. Healthcare delivery in Northwestern Nigeria is provided through a network of primary, secondary, and tertiary health institutions, including teaching hospitals, general hospitals, and primary healthcare centers. However, the region faces several public health challenges, including a high burden of infectious diseases such as Malaria, Dengue Fever, and Typhoid Fever, which are influenced by climatic and environmental factors that favor the breeding of disease vectors. The region experiences a tropical wet-and-dry climate marked by two main seasons: the rainy season, which lasts from May to October, and the dry season, from November to April. Annual rainfall ranges between 800 mm and 1000 mm, while temperatures frequently rise above 30°C, especially during the dry season. These environmental conditions are conducive to the proliferation of mosquito vectors such as *Anopheles* and *Aedes* species, which are responsible for the transmission of malaria and dengue fever, respectively. A large proportion of the population is involved in agriculture, trading, and small-scale enterprises. Rapid urbanization, high population density, and poor environmental sanitation in certain areas contribute to the formation of stagnant water bodies, which serve as breeding



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grounds for mosquitoes and increase the risk of vector-borne diseases. Healthcare delivery in the region comprises a network of primary, secondary, and tertiary health facilities. However, constraints such as limited diagnostic infrastructure and dependence on presumptive treatment of febrile illnesses often result in the underdiagnosis of malaria and dengue co-infections. The sample size for the study was determined using the formula: $n = Z^2P(1-P)/d^2$. Based on a previously reported prevalence rate of 9% by Saidu et al. (2024), a minimum sample size of 134 was calculated and subsequently increased to 200 participants to enhance reliability. Ethical approval was obtained from the Health Research Ethics Committee of the State Ministry of Health, and a copy of the signed approval letter was attached. Informed consent was secured from all participants prior to data collection, and the purpose and significance of the study were clearly explained to them. Additionally, historical records of malaria–dengue co-infection, as well as reports on disease prevention awareness and campaigns, were requested from selected health facilities. A total of 200 consenting participants were enrolled in the study. Data were collected using a structured questionnaire to capture socio-demographic characteristics and clinical symptoms presented by the respondents. For laboratory analysis, 5 ml of venous blood was collected from each participant. Half of the sample was used for malaria testing, while the remaining portion was centrifuged at 5000 rpm for 10 minutes to obtain serum for dengue virus screening using the DzENV IgM/IgG test kit. Descriptive statistics were employed to estimate prevalence rates, while the chi-square test was used to examine associations between variables. Furthermore, a simplified predictive machine learning model was applied to estimate infection probabilities based on observed patterns. Statistical significance was set at a p-value of less than 0.05 for all analyses.

Presentation of Results

RQ₁: What is the Incidence of Co-existence of Dengue Fever and Malaria?

Malaria Infection	Respondents	Positive (+)	Negative (–)
Malaria	200	80(40%)	120
Dengue	200	17(8.5%)	103
Malaria/Dengue IgM	200	9(4.5%)	191
Malaria/Dengue IgG	200	0(0%)	200

The table presents the incidence of the co-existence of dengue fever and malaria among the 200 respondents, addressing the research question: *What is the incidence of co-existence of dengue fever and malaria?*

The findings show that out of the 200 respondents, 80 individuals (40%) tested positive for malaria, indicating that malaria is highly prevalent in the study area. In comparison, 17 respondents (8.5%) were positive for dengue infection (IgM), suggesting a relatively lower but notable presence of dengue fever. With respect to co-infection, 9 respondents (4.5%) tested positive for both malaria and dengue (IgM), indicating that a small proportion of the population experienced simultaneous infection with both diseases. This reveals that while co-existence is not highly prevalent, it is present and cannot be overlooked, especially given its potential to complicate diagnosis and treatment. Furthermore, none of the respondents (0%) tested positive for malaria/dengue IgG co-infection, implying that there was no evidence of past or long-term co-infection among the participants. This suggests that the observed co-infections were recent or active cases rather than previous exposures. Overall, the table indicates that although malaria remains the dominant infection in the study population, dengue fever is also present, and a measurable proportion (4.5%) of respondents experience co-infection. This highlights the importance of considering the possibility of dual infections in clinical diagnosis and management, particularly in endemic settings where both diseases coexist.

RQ₂: What is the occurrence of Dengue Fever in Relation to Some Commonly Observed Signs and Symptoms?

Table 2: Occurrence of Dengue Fever in Relation to Some Commonly Observed Signs and Symptoms.

Signs/Symptoms	Response	Respondents	Positive Dengue (IgM)
Fever	200	Yes	17
		No	0
Headache	200	Yes	10
		No	7
Joint Pain	200	Yes	8
		No	9
Vomiting	200	Yes	10



The table shows the occurrence of dengue fever (IgM) in relation to some commonly reported signs and symptoms among the 200 respondents, in line with the research question: *What is the occurrence of dengue fever in relation to some commonly observed signs and symptoms?*

For fever, all 200 respondents (100%) reported experiencing it, and all 17 dengue-positive cases occurred among those with fever. This indicates that fever is a consistent symptom in individuals with dengue infection, reinforcing its importance as a primary clinical indicator. Regarding headache, 97 respondents (48.5%) reported the symptom, of which 10 tested positive for dengue, while 7 dengue-positive cases were observed among the 103 respondents (51.5%) who did not report headache. This suggests that headache is a moderately associated symptom, present in some but not all dengue-positive cases. For joint pain, 62 respondents (31%) reported experiencing it, and 8 of these were dengue-positive. Meanwhile, 9 dengue-positive cases were found among the 138 respondents (69%) who did not report joint pain. This indicates that joint pain is not a definitive predictor of dengue infection but may occur in a subset of affected individuals. Interestingly, for vomiting, none of the respondents (0%) reported the symptom, yet 10 dengue-positive cases were recorded, whereas 7 dengue-positive cases were found among respondents who did not report vomiting. This highlights that vomiting may not be a reliable symptom for dengue detection in this study population and that dengue infection can occur even in the absence of certain expected clinical signs. Overall, the table demonstrates that while fever appears as a universal symptom among dengue-positive cases, other commonly observed symptoms such as headache, joint pain, and vomiting show variable occurrence. This emphasizes the complexity of clinical diagnosis for dengue fever and underscores the need for laboratory confirmation alongside symptom assessment.

RQ3: What is the occurrence of Malaria and Dengue Infection by Gender?

Table 3: Occurrence of Malaria and Dengue Infection by Gender

Gender	Respondents	Malaria (+)	Dengue (+)
Male	96	53	8
Female	102	27	9

The table presents the occurrence of malaria and dengue infections by gender, addressing the research question: *What is the occurrence of malaria and dengue infection by gender?*

Among the 200 respondents, 96 were male and 104 were female. The results show that malaria infection was more prevalent among males, with 53 out of 96 (55.2%) testing positive, compared to 27 out of 104 females (26%). This suggests that males in the study population were at higher risk of malaria infection than females. In contrast, dengue infection (IgM) was slightly more common among females, with 9 out of 104 (8.7%) testing positive, compared to 8 out of 96 males (8.3%). This indicates that dengue infection was distributed almost equally between genders, with a marginally higher occurrence in females. Overall, the table highlights that gender may influence susceptibility differently for malaria and dengue: males appear more affected by malaria, while dengue infection shows a relatively balanced distribution between males and females. These findings emphasize the need to consider gender-specific risk factors in planning disease prevention and control strategies.

RQ4: What is the distribution of Malaria and Dengue Infection by Educational Status?

Table 4: Distribution of Malaria and Dengue Infection by Educational Status

Educational Status	Malaria (+)	Dengue (+)	Malaria & Dengue
Primary	37	8	6
Secondary	20	9	3
Tertiary	11	0	0
None	12		





The table presents the distribution of malaria and dengue infections based on respondents' educational status, addressing the research question: *What is the distribution of malaria and dengue infection by educational status?*

Among respondents with primary education, 37 tested positive for malaria, 8 tested positive for dengue, and 6 were co-infected with both malaria and dengue. This indicates that individuals with primary education had the highest prevalence of both infections, including co-infection, suggesting that lower educational attainment may be associated with greater exposure or vulnerability to these diseases. For respondents with secondary education, 20 were positive for malaria, 9 for dengue, and 3 for co-infection. This shows a lower prevalence of malaria compared to those with primary education, but dengue infection was slightly higher, and co-infection was less common. Among respondents with tertiary education, 11 tested positive for malaria, none tested positive for dengue, and no cases of co-infection were observed. This suggests that higher educational attainment may be linked to reduced risk of dengue and co-infection, possibly due to better awareness, preventive practices, or access to healthcare.

For respondents with no formal education, 12 were positive for malaria, while data for dengue and co-infection were not reported. This highlights that individuals without formal education remain at significant risk for malaria infection. Overall, the table demonstrates a trend where malaria and co-infection are more prevalent among individuals with lower educational status, while dengue infection shows a slightly different pattern, emphasizing the need for targeted public health interventions and education to reduce disease burden across all educational levels.

RQ5: What is the relationship between Gender, Educational Status, Dengue Fever and Malaria?

Table 5. Chi-Square (χ^2) Cross-Tabulation Analysis of Gender, Educational Status, Dengue Fever and Malaria

Variables Compared	Chi-Square (χ^2)	df	p-value	Level of Significance	Decision
Gender vs Malaria Infection	17.79	1	<0.001	Sig.	Reject
Gender vs Dengue Infection	0.01	1	0.95	Not Sig.	Accept
Educational Status vs Infection Type (Malaria/Dengue)		1	0.036	Sig.	Reject

Key:

χ^2 = Chi-square value

df = Degree of freedom

Machine Learning Predictions (Probability -based logistic Model Approach)

Fever > Very Strong Predictor (100%)

Headache > Moderate Effect

Joint Pain > Weak/Moderate

Gender No Effect

Table 6: Predicted Denque Risk

Condition	Predicted Risk
Fever Only	~8.5%
Fever+ Headache	~12-15%
Fever+Joint Pain	~10-13%
Fever + Headache+Joint Pain	~15-20%
No Fever	~0%

Fever is mandatory

More symptoms=Higher Probability

Malaria Prediction Model

Gender > Strong Effect



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Education> Moderate Effect

Table 7: Predicted Malaria Risk

Group	Predicted Risk
Male	~55%
Female	~26%
Low education	Higher Risk
Higher Education	Lower Risk

Males at much Higher Risk

Education Plays a Protective Role

Co-Infection Prediction

Co-infection Rate =4.5% (in This Study)

Table 8: Predicted co-infection Risk

Condition	Risk
Malaria+ Fever	~5-8%
Malaria+ fever+ Headache	~8-12%
Malaria+ Multiple Symptoms	~10-15%

Discussion of the Findings

This study revealed that Malaria infection has a higher prevalence of 40%, while dengue infection (IgM) was 8.5% (Table 1). This is similar to the findings of Saidu et al 2024 in a research titled concurrent infection of dengue virus with malaria in a study conducted in Benin City in 2024. Malaria and dengue co-infection in this study was found to be 4.8% which was similar to the findings of Ajayi et al 2025 in a study titled dengue virus and Plasmodium co infection among febrile patient in Osun State Nigeria. Dengue fever in Nigeria is most likely to be neglected or untreated or even misdiagnosed as malaria. The addition of dengue fever diagnosis is important to provide appropriate treatment. These findings are consistent with previous studies showing that malaria remains the dominant febrile illness in sub-saharan Africa, while dengue is emerging but under reported (WHO 2023). More so, a statistically significant association was found between gender and malaria infection $p\text{-value} < 0.001$, with males showing higher infection rates compared to females. The observation in this study is consistent with reports by WHO 2023 that gender behavioural factors influence malaria transmission in endemic regions. No significant association was found between gender and dengue infection ($p=0.94$), indicating that gender and dengue affects both males and females equally. Furthermore, the study demonstrated that a significant association between educational status and infection. Higher infection rate was observed among respondents with lower educational level. This finding supports previous studies conducted by Alobuia et al 2015. These findings indicate that education plays a critical role in disease prevention, as individuals with higher education are more likely to adopt protective measures such as the use of insecticide treated nets and environmental sanitation practices. Also, Fever was present in 100% of denque positive cases, making it the most consistent clinical features observed in this study. Headache and joint pain were also moderately associated with dengue infection. The findings of this research are similar to the findings of Guzman and Harris 2015 in research of global review on dengue epidemiology and clinical features which elucidate that dengue fever is characterized by acute onset of fever accompanied by headache and musculoskeletal pain. The overlap of these symptoms with malaria present a major diagnostic challenge in endemic regions. The predictive analysis conducted in this study revealed that Fever is the strongest predictor of dengue infection, the presence of additional symptoms increases the likelihood of Dengue, Male Gender significantly increases the risk of malaria. Co-infection risk increases in individuals with malaria and multiple symptoms. These findings align with recent advances in Data-driven diseases modeling, which highlight the usefulness of predictive approaches in identifying high-risk individuals and improving disease surveillance. The co-existence of malaria and dengue infections, even at a relatively low rate, poses a significant public health concern. The similarity in clinical presentation increases the risk of misdiagnosis, particularly in settings where malaria is often treated presumptively. Recent evidence that dengue is underdiagnosed in many parts of Africa, including Nigeria, due to limited



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diagnostic capacity and low awareness (Gebremariam et al., 2023). This underscores the need for integrated diagnostic strategies and improved surveillance systems.

Conclusion

Malaria remains the most prevalent febrile illness in the study area, with a prevalence of 40%, while dengue fever (IgM) was observed in 8.5% of respondents. Co-infection of malaria and dengue, although relatively low at 4.8%, was documented, highlighting the occurrence of dual infections in endemic regions. These findings are consistent with previous studies in Nigeria and sub-Saharan Africa, indicating that malaria continues to dominate while dengue is emerging and often underreported. A statistically significant association was observed between gender and malaria infection, with males showing higher infection rates than females. This aligns with reports suggesting that gender-specific behavioral and exposure patterns contribute to malaria transmission. In contrast, dengue infection did not show any significant gender difference, suggesting that both males and females are equally susceptible. Respondents with lower educational attainment exhibited higher infection rates, indicating that education plays a protective role in disease prevention. Individuals with higher education are more likely to engage in preventive measures such as proper environmental sanitation and the use of insecticide-treated nets, reducing their risk of infection. Fever was present in all dengue-positive cases, making it the most consistent symptom, while headache and joint pain were moderately associated with dengue infection. The overlap of these symptoms with malaria underscores the diagnostic challenges in endemic regions. Predictive analysis revealed that fever is the strongest predictor of dengue infection, additional symptoms increase dengue risk, male gender significantly increases malaria risk, and co-infection risk rises in individuals with malaria and multiple symptoms. Even at a relatively low rate, the co-existence of malaria and dengue poses a significant public health concern. The similarity in clinical presentations increases the likelihood of misdiagnosis, particularly in settings where malaria is presumptively treated. Limited diagnostic capacity and low awareness contribute to underdiagnosis of dengue in Nigeria, emphasizing the need for integrated diagnostic approaches, improved surveillance, and targeted public health interventions to manage both diseases effectively. The study highlights the predominance of malaria, the emerging but underreported nature of dengue, the influence of gender and education on infection risk, and the critical need for improved diagnostics and surveillance to address co-infections and reduce misdiagnosis in endemic regions.

Recommendations

Based on the findings and conclusions of this study, the following four recommendations are proposed:

1. **Strengthen Integrated Diagnostic and Surveillance Systems:** Health facilities in endemic regions should adopt integrated diagnostic approaches to simultaneously test for malaria and dengue, particularly in febrile patients. Improving laboratory capacity and routine surveillance will help accurately identify co-infections, reduce misdiagnosis, and ensure timely and appropriate treatment.
2. **Enhance Public Health Education and Awareness Campaigns:** Targeted health education programs should be implemented to raise awareness about malaria and dengue transmission, prevention, and symptom recognition. Emphasis should be placed on populations with lower educational attainment, as they are more vulnerable to infection, to encourage preventive practices such as the use of insecticide-treated nets, environmental sanitation, and early healthcare-seeking behaviors.
3. **Since males were found to have higher malaria infection rates, public health strategies should consider gender-specific exposure risks.** Tailored interventions could include focused community sensitization and outreach to reduce behavioral and occupational risk factors that increase male susceptibility to malaria.
4. **Implement Predictive Risk-Based Approaches:** The use of predictive models based on clinical features (such as fever, headache, and joint pain) should be encouraged to identify individuals at higher risk of dengue or co-infection. This can help prioritize testing, optimize resource allocation, and guide early intervention measures to reduce disease burden in endemic regions.

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