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Spatial variation and multilevel determinants of malaria infection among pregnant women in Sub-Saharan Africa: using malaria indicator surveys

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Abstract

Background Malaria remains a major public health challenge in Sub-Saharan Africa, with pregnant women being particularly vulnerable to its adverse effects, including increased risk of maternal and neonatal mortality. Despite significant efforts to control malaria, high infection rates persist, especially in underserved areas. Existing studies have identified individual-level factors as contributors to malaria infection, yet the influence of community-level factors and spatial variations remain underexplored. This study aimed to investigate the spatial variation and multilevel determinants of malaria infection among pregnant women in Sub-Saharan Africa.

Methods Data from the Malaria Indicator Surveys across 19 Sub-Saharan African countries were used for analysis. The study included a total of 107,712 pregnant women aged 15–49. Spatial autocorrelation was employed to assess the spatial dependency of malaria infection. Kriging interpolation was used to predict malaria infection in the unsampled areas. Factors associated with malaria infection were considered significant at p-values < 0.05. The adjusted odds ratio and confidence intervals were used to interpret the results. A model with the lowest deviance and highest log-likelihood ratio was selected as the best-fit model.

Results The pooled prevalence of malaria among pregnant women was 28.31% (95% CI: 27.47, 29.20). Factors associated with higher odds of malaria infection included advanced maternal age (AOR: 1.19, 95% CI: 1.03, 1.37), no formal education (AOR: 1.52, 95% CI: 1.28, 1.80), non-use of bed nets (AOR: 6.63, 95% CI: 3.20, 13.73), use of untreated bed nets (AOR: 4.16, 95% CI: 3.72, 8.49), no use of indoor residual spraying (AOR: 2.07, 95% CI: 1.63, 2.64), rural residence (AOR: 2.11, 95% CI: 1.64, 2.41), and residing in West Sub-Saharan Africa (AOR: 6.58, 95% CI: 5.67, 7.64) were determinants of malaria infection.

Conclusions This study revealed a high malaria infection rate among pregnant women in Sub-Saharan Africa, with both individual and community-level factors playing a significant role. Health policies should prioritize targeted interventions for pregnant women, especially in rural areas, with an emphasis on increasing bed net use, indoor

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residual spraying, and region-specific strategies, particularly in West Sub-Saharan Africa where malaria clustering is notably high.

Keywords Determinants, Malaria infection, Pregnant women, Sub-Saharan Africa, Spatial analysis

Background

Sub-Saharan Africa (SSA), located south of the Sahara Desert, is a vast and diverse region encompassing 49 countries and covering approximately 9.4 million square miles [1]. Sub-Saharan Africa also faces significant public health challenges, including the high burden of malaria, which contributes to a significant morbidity and mortality [2, 3].

Malaria is a life-threatening disease caused by parasites of the genus Plasmodium, transmitted to humans through the bites of infected female Anopheles mosquitoes, primarily in tropical and subtropical regions [4]. Among the five Plasmodium species that infect humans, *Plasmodium falciparum* and *Plasmodium vivax* pose the greatest threat, with *Plasmodium falciparum* being the most virulent and prevalent [5, 6]. Pregnant women are particularly vulnerable to malaria due to immunological changes during pregnancy and the sequestration of malaria parasites in the placenta, which creates a favorable environment for parasite replication [7].

According to the World Health Organization (WHO), malaria during pregnancy is a significant public health concern, especially in regions with high malaria transmission such as Sub-Saharan Africa [8]. Globally, over 125 million pregnancies are at risk of malaria annually with Sub-Saharan Africa (SSA) bearing the highest burden [9]. Malaria infection in pregnancy can result in severe consequences, including maternal anemia, miscarriage, stillbirth, prematurity, and low birth weight, with *P. falciparum* infections posing the highest risks [10, 11]. WHO estimates that approximately 200,000 newborn deaths annually are directly or indirectly attributed to malaria during pregnancy, largely due to complications such as low birth weight and preterm delivery [12].

In 2022, an estimated 13.3 million pregnant women in Sub-Saharan Africa were infected with malaria infection, resulting in approximately 1.07 million low birth weight deliveries, accounting for around 19% of all low birth weight cases in the region [13]. Furthermore, severe maternal anemia, a frequent complication of malaria in pregnancy, contributes to about 10,000 maternal deaths annually in Africa [14]. Sub-Saharan Africa experiences regional variation in exposure to malaria among pregnant women, with West and Central Africa having the highest prevalence rates of 39.8% and 39.4%, respectively, while East and Southern Africa report relatively lower prevalence rates [15].

To mitigate the impact of malaria during pregnancy, the WHO recommends the widespread use of insecticide-treated nets (ITNs) and the administration of intermittent preventive treatment in pregnancy (IPTp) using sulfadoxine-pyrimethamine [16]. Coverage of these interventions has increased in recent years. Between 2017 and 2018, the proportion of pregnant women in Sub-Saharan Africa receiving three or more doses of IPTp rose from 22 to 31%, while ITN usage among pregnant women and children increased from 26% in 2010 to 61% in 2018 [17, 18]. Despite these efforts, malaria during pregnancy remains a persistent challenge, with intervention coverage and effectiveness varying widely across regions.

The risk of malaria among pregnant women is influenced by multiple demographic, health-related, and behavioral factors, including maternal educational status [19, 20], maternal age [21, 22], antenatal care (ANC) visits [22], parity [19], gravidity [7], gestational age [23], HIV status [24, 25], and the use of insecticide-treated nets (ITNs) [26, 27]. Furthermore, spatial heterogeneity in malaria prevalence underscores the need for targeted approaches to intervention.

Malaria remains a significant public health challenge, particularly among pregnant women in Sub-Saharan Africa, where it contributes to maternal morbidity, adverse pregnancy outcomes, and neonatal mortality. Despite extensive research on malaria epidemiology, there is limited evidence on the spatial distribution of malaria hotspots specifically among pregnant women across SSA. Most studies have focused on general population-level malaria prevalence without identifying high-risk geographical areas or considering the hierarchical nature of individual, household, and community-level determinants in this vulnerable group. To the best of our knowledge, no study has systematically investigated the spatial variation and multilevel determinants of malaria infection among pregnant women using malaria indicator surveys (MIS) across SSA.

Therefore, this study aimed to fill this gap by addressing the following research questions: (1) what are the spatial variations in malaria infection among pregnant women across Sub-Saharan Africa? (2) What are the individual, household, and community-level factors associated with malaria infection among pregnant women in the region? Identifying geographical variations in malaria infection is very important to prioritize and design targeted prevention and intervention programmes to prevent malaria infection and associated adverse outcomes at the country level [28, 29].

Methods

Setting

This study included data from 19 countries in Sub-Saharan Africa: Angola, Burkina Faso, Burundi, Cameroon, Ghana, Guinea, Kenya, Liberia, Madagascar, Mali, Malawi, Mozambique, Nigeria, Niger, Sierra Leone, Senegal, Togo, Tanzania, and Uganda. These countries were selected because they are the only countries with available MIS datasets between the given time period.

Study design and period

A community-based cross-sectional study was conducted, incorporating spatial and hierarchical analyses. The study used data from Malaria Indicator Surveys (MIS) conducted between 2011 and 2022 across 19 Sub-Saharan African countries. The MIS is a national survey program carried out every five years, employing pre-tested, validated, and structured tools. A 12-year dataset, starting from 2011, was gathered from each region of the selected Sub-Saharan African countries to ensure a representative sample of recent data.

Data source and sampling procedure

The data source for this study was the Malaria Indicator Surveys (MIS) conducted between 2011 and 2022 across various countries in Sub-Saharan Africa. The MIS provides valuable data on malaria-related indicators such as malaria prevalence, prevention practices, and access to diagnosis and treatment. The Malaria Indicator Surveys employ a stratified two-stage cluster design, beginning with the creation of enumeration areas in the first stage and subsequently selecting a sample of households from each enumeration area in the second stage. Data were extracted from the personal record file of the MIS, which contains individual-level records with key demographic, socio-economic, and health-related variables. The dependent variable in this study is malaria status, which includes malaria infection prevalence measured through diagnostic tests. The independent variables include both individual-level factors and community-level variables. In our study, we accounted for the complex survey design by incorporating sampling weights, stratification, and clustering at both the MIS sample cluster and country levels in our multilevel regression models. The study analyzed a weighted sample consisting of 107,712 pregnant women (Table 1).

Population

The source population of the study was pregnant women aged 15–49 years in Sub-Saharan African countries. The study population was of all pregnant women residing in the selected enumeration areas included in the analysis.

Study variables

Dependent variable

The outcome variable in this study was malaria infection, determined by the results of rapid diagnostic tests (RDT) or microscopy. The dependent variable, malaria infection, was recoded into a binary variable where a value of 1 indicated a positive malaria infection (based on either a

Table 1 Sample size for Spatial variation and determinants of malaria infection among pregnant women in Sub-Saharan Africa, MIS 2011–2022

Country	Year of survey	Unweighted sample (*n*)	Unweighted sample (%)	Weighted sample (*n*)	Weighted Sample (%)
Angola	2011	3,502	3.42	3,432	3.19
Burkina Faso	2017/18	5,569	5.44	5,575	5.18
Burundi	2012	3,847	3.75	3,753	3.48
Cameroon	2022	4,536	4.43	4,399	4.08
Ghana	2019	2,632	2.57	2,867	2.66
Guinea	2021	4,169	4.07	4,080	3.79
Kenya	2020	10,522	10.27	11,587	10.76
Liberia	2022	2919	2.85	2,943	2.73
Madagascar	2016	6,667	6.51	6,931	6.43
Mali	2017	8,927	8.71	8,987	8.34
Malawi	2021	2,724	2.66	2,509	2.33
Mozambique	2018	4,460	4.35	4,367	4.05
Nigeria	2021	11,551	11.27	11,115	10.32
Niger	2021	5,038	4.92	4,925	4.57
Sierra Leone	2016	7,652	7.47	7,666	7.12
Senegal	2020/21	699	0.68	4,338	4.03
Togo	2017	2,966	2.90	3,202	2.97
Tanzania	2017	6,766	6.60	7,249	6.73
Uganda	2018/19	7,310	7.14	7,787	7.23
Total sample size		102, 456	100	107,712	100

positive RDT or microscopy result), and a value of 0 represented a negative result (when both RDT and microscopy were negative) [10, 30, 31].

Independent variables

This study included two sources of independent variables due to the hierarchical nature of MIS data. The individual-level variables encompass factors such as maternal age, marital status, educational status, number of underfive children, ITN ownership, number of mosquito nets, ITN usage, type of bed net, use of IRS in the last year, wealth index, radio and television ownership, as well as the type of main wall, floor, and roof materials. The community-level variables include media exposure, source of drinking water, type of place of residence, and country category.

Operational definitions

Media exposure

Is determined by combining three survey variables: the frequency of reading newspapers or magazines, listening to the radio, and watching television. Individuals who engage with any of these media at least once a week are classified as having mass media exposure [32].

Wealth index

As defined by the malaria indicator surveys (MIS), is a composite measure used to assess household socioeconomic status based on assets such as durable goods, housing characteristics, and access to services. It is constructed using Principal Component Analysis (PCA), which ranks households into wealth quintiles, from poorest to richest, based on the ownership of items like cars, televisions, and access to sanitation and clean water [33].

Water source

The source of drinking water is classified into improved and unimproved categories based on the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply, Sanitation, and Hygiene. Improved water sources are those that are designed to protect against contamination, including piped water into dwelling, piped to yard/plot, public fountains, and boreholes with pumps, protected wells, protected springs, and rainwater. Conversely, unimproved water sources are those more susceptible to contamination, such as unprotected wells, unprotected springs, surface water (lakes, ponds, rivers, and irrigation channels), tanker trucks, and carts with small tanks [34].

Main roof materials

Are classified into unimproved and improved based on their durability and effectiveness in providing protection against weather elements. Unimproved roof materials include materials that are less durable and may provide insufficient protection, such as palm, bamboo, or mat. In contrast, improved roof materials are those that offer greater durability and better protection, indicating higher housing quality. These materials include wood planks, tarpaulin/plastic, zinc/metal, asbestos shingles, ceramic tiles, and concrete cement [35].

Data management

Data cleaning and preparation were performed using Microsoft Excel and STATA version 17 for analysis. Missing data were managed under the Missing at Random (MAR) assumption, which assumes that the probability of missingness depends on observed variables but not on the missing values themselves. To address missing data, we used (drop if variable = =.), STATA command, ensuring that only cases with complete data for key variables were included in the analysis. Then non-pregnant women data were removed from the dataset to focus exclusively on pregnant women. Following the cleaning process, the weighted proportions of the malaria status (the primary outcome variable) and the independent variables were computed in STATA. The processed data were then imported into ArcGIS and SatScan for spatial analysis to explore geographical patterns and relationships.

In this study, we used survey design and clustering at the country and sample cluster levels throughout the entire analysis process. To make sure the estimates were representative of the target population, we used the svyset command in STATA to apply sample weights and account for clustering in the descriptive analysis. Stratification and clustering were taken into consideration in regression analysis by utilizing survey-weighted models (with the svy prefix), which produced more accurate parameter estimates and accurate standard errors. In order to find geographical patterns and spatial clusters for spatial analysis, we combined survey cluster coordinates in ArcGIS and SatScan, making sure that appropriate consideration was given to clustering at the sample cluster and national levels.

Inclusion and exclusion criteria

All pregnant women in the reproductive age (15-49years) who were in the selected enumeration areas were included in the analysis. All pregnant women in the selected enumeration areas during the survey period with incomplete survey data and missing coordinate files for spatial analysis were exclude from this study.

Multilevel analysis

The data were extracted from the most recent malaria indicator surveys (MIS) and processed using STATA version 17 statistical software. Before conducting any statistical analysis, the data were weighted using the women's weighting variable and stratum to ensure the survey's representativeness and account for the sampling design, thereby producing accurate standard errors and reliable statistical estimates. For survey-specific analyses, the weighting variable (hv005) was normalized. For pooled data, the women's individual standard weight was denormalized by adjusting for the sampling fraction. This was achieved by dividing the pregnant women's individual standard weight by the sampling fraction, calculated as: pregnant women's adjusted weight $= \frac{\text{V005} \times \text{ total number of pregnant women aged } 15-49 \text{ years}}{\text{number of pregnant women aged } 15-49 \text{ years}}$

The standard logistic regression model assumptions, such as the independence of observations and equal variance, are violated due to the hierarchical structure of the MIS data. Specifically, individuals are nested within clusters, and participants within the same cluster are likely to share characteristics, differing from participants in other clusters. This clustering violates the assumptions of independence and equal variance, necessitating a more advanced approach. To address these challenges, hierarchical mixed-effects logistic regression was employed to identify factors associated with malaria infection. Four models were used in the analysis: the null model, which included only the outcome variable to assess within-cluster variation in malaria infection rates. Model I, which included only individual-level variables; Model II, which focused solely on community-level variables; and Model III, which incorporated both individual- and community-level variables. The null model provided a baseline for understanding cluster-level variation, while Models I and II separately examined the relationships between the outcome variable and individual- and community-level factors. The final model, Model III, simultaneously assessed the association between malaria infection and factors at both individual- and community-level factors.

Spatial analysis

This study used ArcGIS version 10.7 and Sat Scan version 9.6 to conduct a spatial analysis of malaria distribution, focusing on geographical patterns and hotspots. The analysis involved multiple techniques, including spatial autocorrelation, spatial interpolation, and the identification of significant clusters or "hotspots" where malaria cases were more concentrated. To determine the overall spatial distribution pattern whether dispersed, clustered, or random, the Global Moran's I statistic was used. This statistical measure evaluates spatial autocorrelation across the entire dataset, producing a single value that ranges from − 1 to + 1. A Moran's I value close to -1 indicates a dispersed pattern, signifying that malaria cases are distributed evenly across the area without any specific grouping. On the other hand, a value close to + 1 suggests a clustered distribution, where malaria cases are concentrated in particular regions. A value of 0 represents a random distribution, indicating no discernible spatial pattern in malaria occurrence [36].

The study applied Getis-Ord Gi* statistics to identify areas with significantly high ("hot-spot") or low ("cold-spot") malaria rates. This statistical method evaluates spatial autocorrelation across the study area and determines the significance of clustering patterns using Z-scores and p-values. A high Gi* statistic indicates a hot-spot, representing a concentration of malaria cases, while a low Gi* statistic signifies a cold-spot, indicating fewer malaria cases in that region. To estimate malaria prevalence in areas with unsampled area, Kriging interpolation techniques were employed. Among the available interpolation methods, Kriging was chosen due to its precision, demonstrated by low residuals and root mean square error (RMSE), ensuring reliability in predicting values for unmeasured locations. Kriging interpolation was selected not only for its low RMSE and residuals but also because it accounts for spatial autocorrelation in the data, which is critical when modeling health outcomes like malaria that exhibit clear spatial dependence [37].

SatScan version 9.6 software was employed to conduct spatial Sat Scan analysis and identify significant primary and secondary clusters. Using the Bernoulli model, which is appropriate for binary outcome variables, pregnant women without malaria infection were classified as controls, while those with malaria infection were categorized as cases. The Bernoulli model requires data on cases, controls, and their geographic locations. Clusters exceeding the maximum spatial limit were excluded from the analysis. The default setting of a maximum spatial cluster size of less than 50% of the population was used to identify both small and significant clusters. The most likely cluster was determined as the scanning window with the highest likelihood, and p-values for each cluster were calculated using Monte Carlo hypothesis testing [38].

Random effects

Random effects or measures of variation, including the Likelihood Ratio test (LR), Intra-class Correlation Coefficient (ICC), and Median Odds Ratio (MOR), were calculated to assess the variability in malaria infection rates across clusters. By treating clusters as a random variable, the ICC was used to quantify the extent of heterogeneity in infection rates between clusters, representing the proportion of the total observed variation in malaria infection attributable to differences between clusters. The ICC was computed using the formula: ICC= $\frac{VC}{VC+3.29} \times 100\%$ [39]. The Median Odds Ratio (MOR) quantifies the variation or heterogeneity in malaria infection rates between clusters on the odds ratio scale. It represents the median value of the odds ratio when comparing a cluster with a higher likelihood of malaria infection rates to a cluster with a lower likelihood, based on randomly selected individuals from each cluster: MOR= $e^{0.95\sqrt{VC}}$ [40].

Additionally, the Proportional Change in Variance (PCV) indicates the variation in malaria infection rates explained by the determinants, calculated as follows; PCV= $\frac{Vnull-Vc}{Vnull} \times 100\%$ [41], where Vnull represents the variance of the null model, and V_C is the cluster-level variance. Fixed effects were applied to estimate the association between malaria infection and individual and community-level independent variables. The strength of these associations was assessed using adjusted odds ratios (AOR) and 95% confidence intervals, with statistical significance determined at a p-value of < 0.05. Due to the nested structure of the model, deviance (calculated as -2 times the log-likelihood ratio) was used to compare models and the model with the lowest deviance and highest log-likelihood ratio was chosen as the best fit.

Results

Socio-demographic, economic, and health service related characteristics of pregnant women in Sub-Saharan Africa, MIS 2011–2022

In this study, a total of weighted sample of 107,712 pregnant women were included. More than half of women (56.65%) had no formal education. Nearly 80% of women had ITN ownership but only less than one-third of them used it, and about 79,174 (73.51%) were living in rural areas of Sub-Saharan Africa (Table 2).

Prevalence of malaria among pregnant women in Sub-Saharan Africa

The pooled prevalence of malaria among pregnant women in Sub-Saharan Africa was 28.31% (95% CI: 27.47, 29.20). Significant regional differences of malaria were observed, with the lowest prevalence in Central Sub-Saharan Africa (1.37%) and the highest in West Sub-Saharan Africa (19.20%) (Fig. 1). The prevalence of malaria among pregnant women varied by wealth quintile, with rates of 18.17% among those in the poor quintile, 5.96% in the middle quintile, and 4.18% in the rich quintile (Fig. 2).

Spatial distribution of malaria among pregnant women in Sub-Sahara Africa

Spatial autocorrelation of malaria among pregnant women

There was a significant variation in malaria distribution among pregnant women across the Sub-Saharan African regions (Moran's index = 0.419815, p-value < 0.001). The spatial autocorrelation analysis revealed a clustering effect, indicating high malaria prevalence in some areas and low prevalence in others. The outputs displayed on both sides of the panel include established keys. The z-score of 66.777870 for the clustered pattern suggests that the probability of this pattern occurring by chance is less than 1% (Fig. 3).

Hotspot analysis of malaria among pregnant women

This study used local Getis-Ord Gi* statistics to identify hot and cold spots of malaria infection. High-risk areas, referred to as significant hot spots, are represented by red and orange colors, while low-risk areas, or cold spots, are depicted in blue. Hot spot areas with high confidence (99%) are concentrated in parts of Nigeria, Ghana, Mozambique, and Zimbabwe, while moderate and low-confidence hot spots are observed in regions of Benin, Cameroon, Ethiopia, Malawi, Uganda, and Tanzania. In contrast, cold spot areas with high confidence (99%) are found in southern Africa, including Botswana, South Africa, Lesotho, Eswatini, and parts of Angola. Moderate and low-confidence cold spots are identified in northern Kenya, Somalia, Madagascar, Zambia, and the Democratic Republic of the Congo (Fig. 4).

Interpolation of malaria prevalence among pregnant women

In the Kriging interpolation, the predicted high malaria prevalence areas are concentrated in West Africa, including Nigeria, Ghana, Liberia, Sierra Leone, Guinea, and Côte d'Ivoire, as well as Central Africa, such as Cameroon and the Central African Republic. Eastern regions like South Sudan, Uganda, parts of Sudan, and Ethiopia, along with Southern areas including Mozambique, northern Malawi, and Zambia, also exhibit high malaria prevalence. Conversely, low prevalence is observed in regions like Mauritania, Senegal, northern Mali, northern Sudan, northern Chad, Djibouti, Eritrea, Somalia, northern Kenya, and much of Southern Africa, including Botswana, Namibia, South Africa, Lesotho, and Eswatini (Fig. 5).

SatScan analysis of malaria infection among pregnant women

Spatial scan statistics identified 816 significant clusters, of which 389 were primary (most likely) clusters. The analysis highlights these primary clusters of malaria among pregnant women in Sub-Saharan Africa, represented by red areas with high log-likelihood ratio (LLR) values. The most significant cluster is located in the West African region, covering countries such as Nigeria, Mali, Burkina Faso, Benin, Togo, Cameroon, Equatorial Gunea, Niger, Liberia, Côte d'Ivoire, and Ghana. This cluster, centered at geographic coordinates (9.350716 N, 10.751600 W) with a radius of 277.02 km, exhibited the highest malaria risk among pregnant women, with a relative risk (RR) of 2.75 and an LLR of 2384.9 ($p < 0.001$). Pregnant women within this spatial window were 2.75 times more likely to

Table 2 Socio-demographic, economic, and health service related characteristics of pregnant women in Sub-Saharan Africa, MIS 2011–2022

Variables	Frequency (*n*)	Percent (%)
Individual-level factors		
Maternal age		
15–19	15,163	14.08
20–34	68,000	63.14
35–49	24,534	22.78
Educational status		
No education	61,018	56.65
Primary	27,191	25.24
Secondary and above	19,503	18.11
Number of under five children		
None	27,442	25.48
1–2	56,723	52.75
≥ 3	23,547	21.77
ITN ownership		
No	23,680	21.98
Yes	84,032	78.02
Number of mosquito net		
None	23,680	21.98
One	17,978	16.69
Two and above	66.054	61.32
ITN used		
No	76,440	70.97
Yes	31,272	29.03
Type of bed net		
Untreated	7,490	5.80
Treated	121,747	94.20
use of IRS in the last 1 year		
No	90,939	84.48
Yes	16,773	15.52
Wealth index		
Poor	51,687	47.99
Middle	21,153	19.64
Rich	34,872	32.38
Household has radio		
No	53,355	49.54
Yes	54,349	50.46
Main roof material		
Unimproved	33,093	30.72
Improved	74,616	69.28
Community-level factors		
Media exposure		
No	45,262	42.02
Yes	62,450	57.98
Source of drinking water		
Unimproved	46,816	43.46
Improved	60,896	56.54
Type of place of residence		
Urban	28,538	26.49
Rural	79,174	73.51
Country category		
East SSA	33,554	31.15
West SSA	57,122	53.03

Table 2 (continued)

Variables	Frequency (*n*)	Percent (%)
Central SSA	4,399	4.08
South SSA	12,637	11.73

ITN: Insecticide-Treated Net, IRS: Indoor Residual Spray, SSA: Sub-Saharan Africa

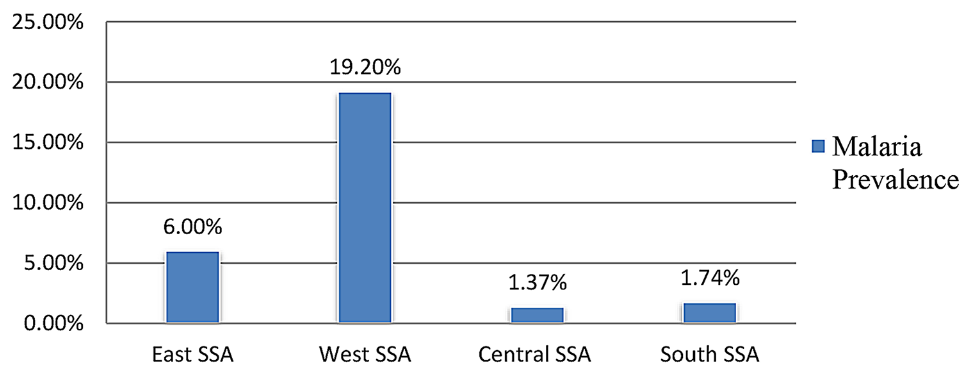

Fig. 1 Regional prevalence of malaria among pregnant women in Sub-Saharan Africa: MIS 2011-2022

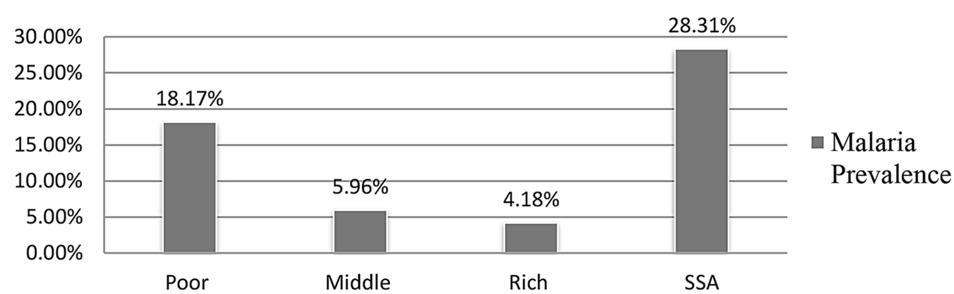

Fig. 2 Malaria prevalence in relation to wealth quantile among pregnant women in Sub-Saharan Africa: MIS 2011-2022

have a high malaria infection risk compared to those outside the spatial window (Fig. 6) (Table 3).

Random effects and model comparison

The null model, with a variance of 0.6701334, revealed significant variations in malaria infection among pregnant women across different communities. It indicated that approximately 16.92% of the overall variation in malaria infection at the cluster level is attributable to community-level factors. Additionally, when comparing an individual from a higher-risk cluster with one from a lower-risk cluster, the null model showed the highest median odds ratio (MOR) value of 2.18, meaning that individuals in higher-risk clusters have 2.18 times greater odds of contracting malaria. Model I's intraclass correlation (ICC) explained 16.60% of the variation in malaria infection rates between communities, while Model II's ICC accounted for 15.3% of the variation. The final model, Model III, explained 16.94% of the variation in malaria infection likelihood, considering both individual and community-level factors. Model III was the best-fitting model, as it had the lowest deviance (9,620.08) and the highest log-likelihood ratio (-4810.04) (Table 4).

Factors associated with malaria infection among pregnant women in Sub-Saharan Africa

In multivariable hierarchical logistic regression analysis, maternal age, educational status, bed net utilization, type of bed net, use of indoor residual spraying (IRS), wealth index, household television ownership, place of residence, and West Sub-Saharan region were significantly associated with malaria infection among pregnant women with a p-value of < 0.05.

The odds of malaria infection were higher for women aged 35–49 years (AOR: 1.19, 95% CI: 1.03, 1.37) compared to those aged 20–34 years. Women with no education had higher odds of malaria infection (OR: 1.52, 95% CI: 1.28, 1.80) compared to those with secondary or higher education. The odds of malaria infection were significantly higher among women who did not use bed nets (OR: 6.63, 95% CI: 3.20, 13.73) compared to pregnant women who used bed nets. The odds of malaria infection were also much higher for women who used untreated bed nets (OR: 4.16, 95% CI: 3.72, 8.49) compared to those using treated nets.

Women who did not use indoor residual spraying (IRS) in the last year had higher odds of malaria infection (OR:

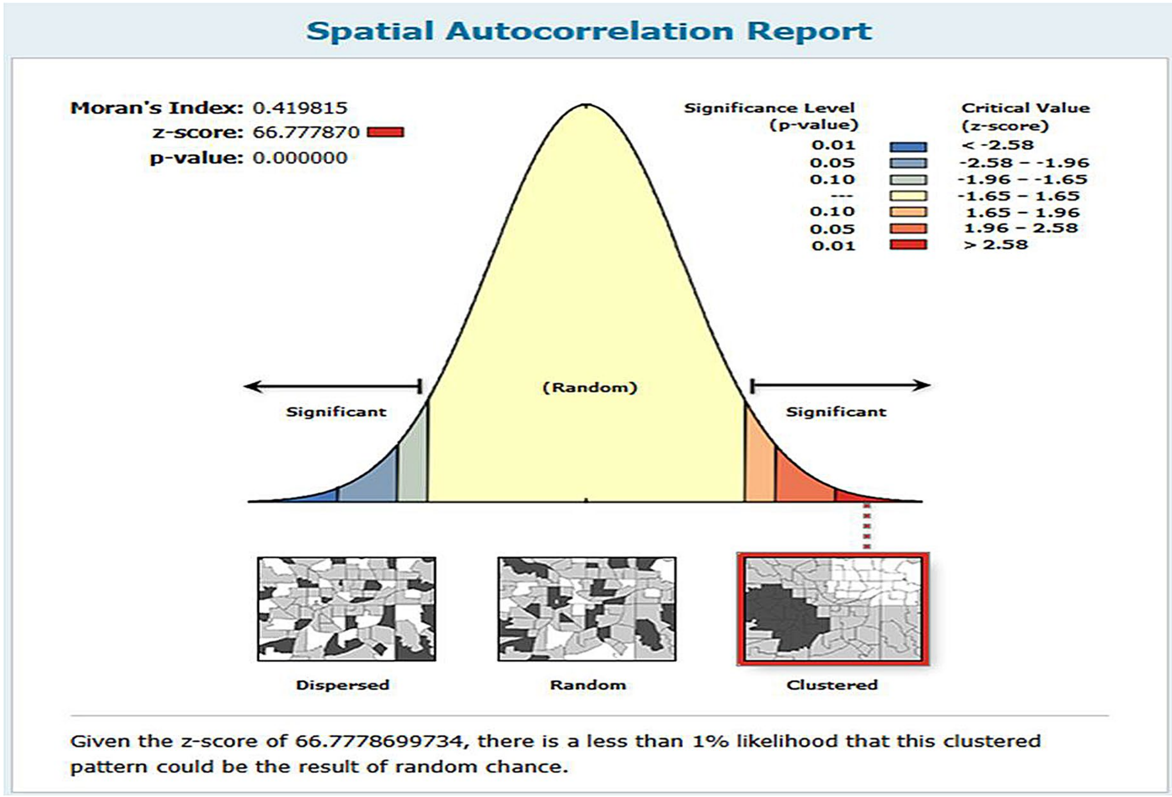

Fig. 3 Spatial autocorrelation of malaria among pregnant women in Sub-Saharan Africa based on feature locations and attribute values using the Global Moran's index statistic, MIS 2011–2022

2.07, 95% CI: 1.63, 2.64). Women in households without a television had higher odds of malaria infection (OR: 2.23, 95% CI: 1.68, 2.98). The odds of malaria infection were also higher for women living in rural areas (OR: 2.11, 95% CI: 1.64, 2.41) compared to those in urban areas. Regionally, the odds of malaria infection were higher in West Sub-Saharan Africa (OR: 6.58, 95% CI: 5.67, 7.64) compared to East Sub-Saharan Africa (Table 4).

To ensure the validity of the model, Multicollinearity was assessed using variance inflation factors (VIF), and the mean VIF value was found to be 2.77, indicating no significant multicollinearity among the explanatory variables.

Discussion

In this study, the pooled prevalence of malaria among pregnant women in Sub-Saharan Africa was 28.31% (95% CI: 27.47, 29.20). This finding was higher compared to the previous study conducted in Southeast Asia, 24.8% [42], Low-and middle-income countries, 18.95% [9], Latin America, 8.8% [43], Brazil, 8.9% [44], and India, 5.4% [45]. The discrepancies in malaria prevalence among pregnant women across regions could be attributed to various factors, including differences in transmission intensity, access to healthcare, and preventive measures. Sub-Saharan Africa has higher transmission intensity due to favorable climatic conditions, such as high temperatures and seasonal rainfall, which support the lifecycle of the malaria parasite and these conditions also favor the breeding of the mosquito vectors [46]. In contrast, Southeast Asia and India have made substantial progress in malaria control through the implementation of insecticide-treated nets (ITNs), indoor residual spraying (IRS), and antimalarial drug distribution, which may explain the relatively lower prevalence in these regions [47]. Latin America, with lower transmission rates, have also seen effective malaria control programs, including the use of artemisinin-based combination therapies (ACTs) and surveillance systems, contributing to the observed lower prevalence [48].

On the other hand, the prevalence of malaria in this study was lower than the studies conducted in Democratic Republic of the Congo, 60% [49] and Uganda, 39.7% [50]. The difference in malaria prevalence between this study and those conducted in the Democratic Republic of the Congo and Uganda could be attributed to differences in study populations, geographic locations, and the implementation of malaria control measures. In regions like the Democratic Republic of the Congo and Uganda, malaria transmission is higher due to factors such as more favorable environmental conditions for vector breeding and less widespread use of preventive

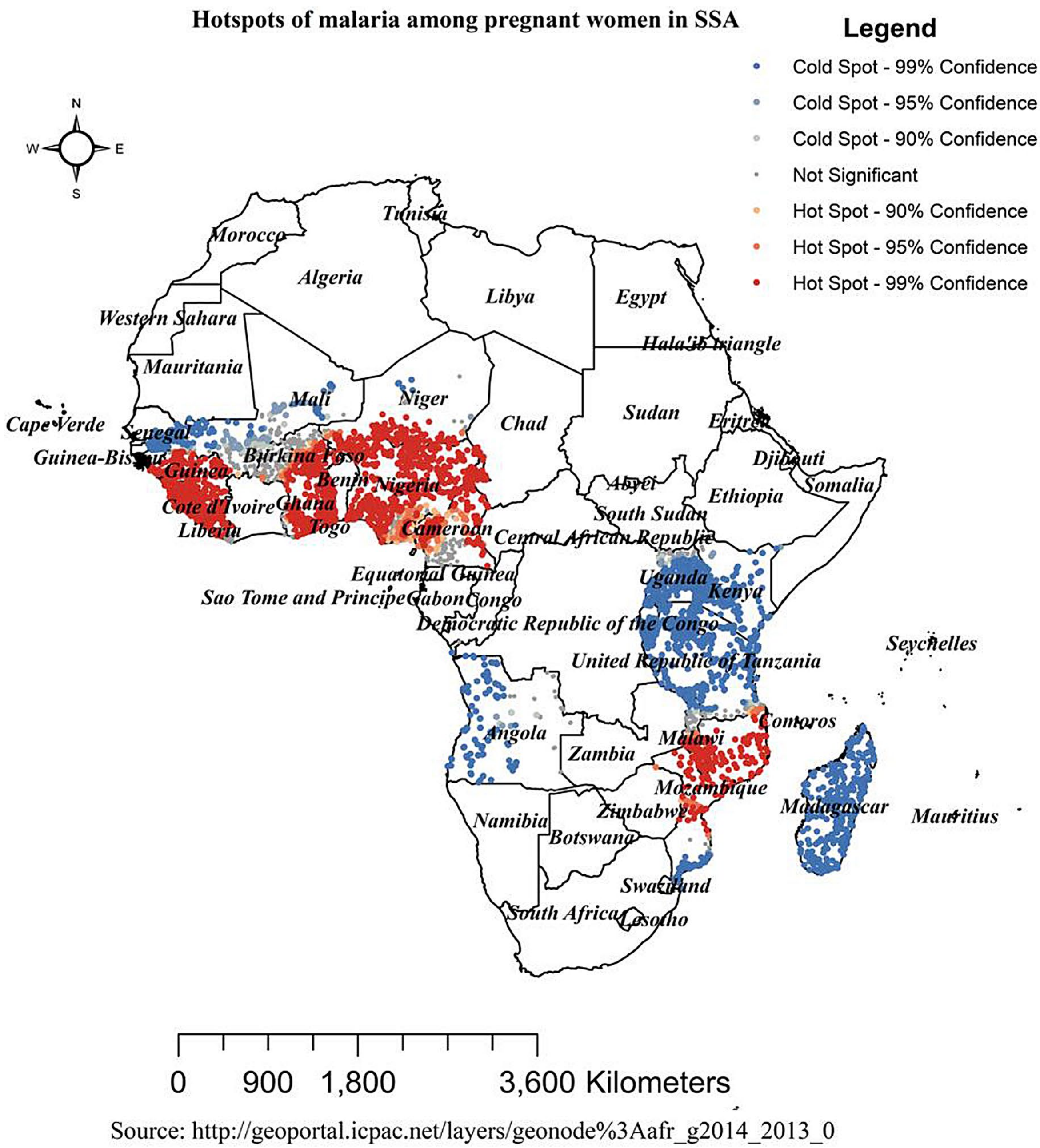

Fig. 4 Hotspot analysis of malaria among pregnant women in Sub-Saharan Africa MIS 2011–2022

measures, such as insecticide-treated bed nets or malaria prophylaxis. Additionally, varying levels of healthcare access and differences in sample size could contribute to the observed variations in prevalence rates [20, 51, 52].

In spatial analysis, the malaria infection among pregnant women was not randomly distributed in the regions of Sub-Saharan Africa. This is consistent with previous study conducted in Zambia [53], Mozambique [54], and Rwanda [55]. The spatial autocorrelation statistic confirmed that the distribution of malaria infection among pregnant women was clustered in some geographical areas of Sub-Saharan Africa (Moran's I = 0.419815, $p < 0.001$). According to the spatial hot spot analysis, geographic variations in malaria infection among pregnant women have been identified in parts of Nigeria, Ghana, Mozambique, and Zimbabwe. The most plausible explanation for this geographical variation in malaria infection among pregnant women could be attributed to significant differences in environmental, socio-economic, and healthcare access factors across these regions. Variations in climate, such as rainfall patterns and temperature, directly influence the breeding habitats of Anopheles

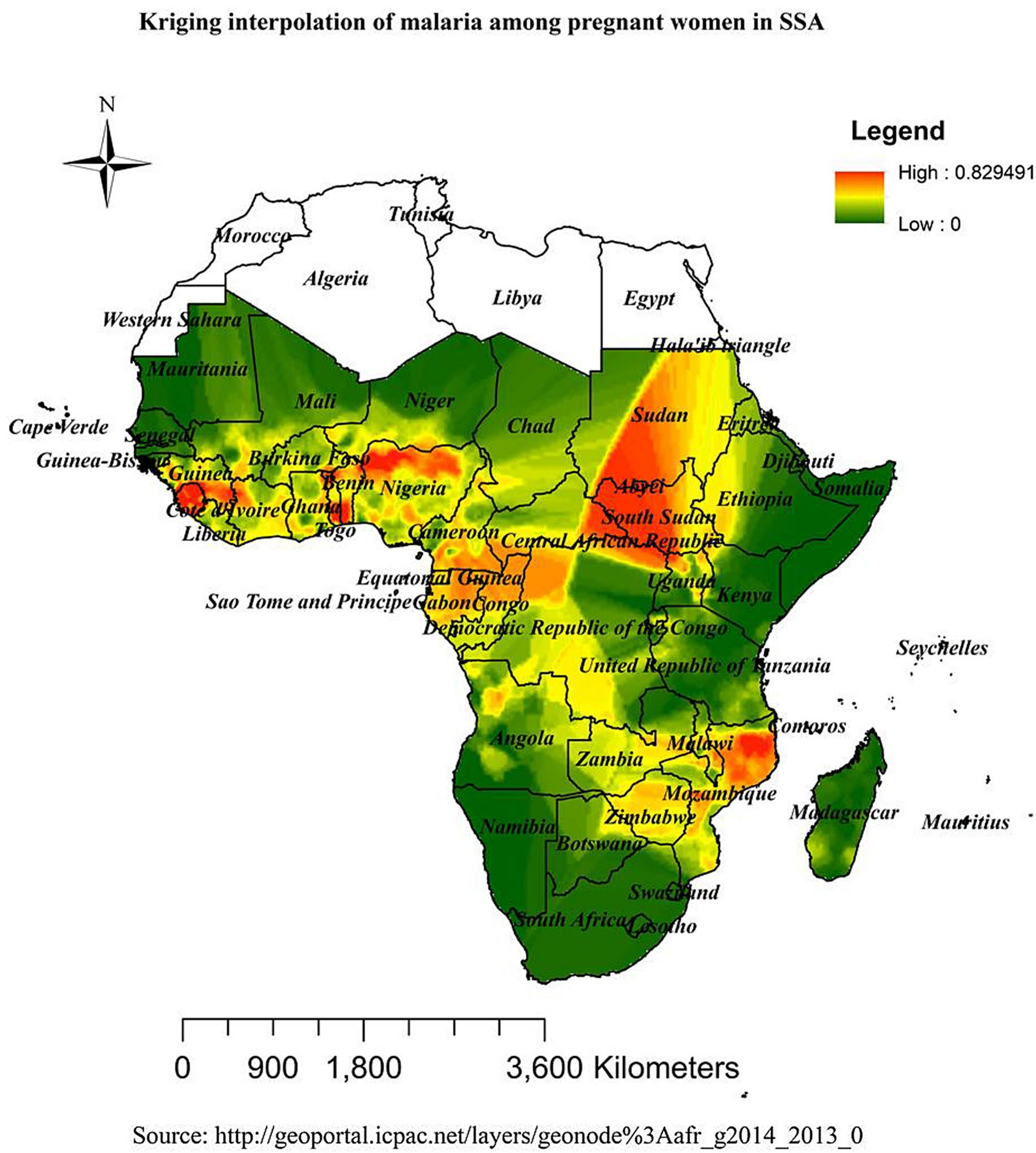

Fig. 5 Ordinary kriging interpolation analysis of malaria among pregnant women in Sub-Saharan Africa: MIS 2011–2022

mosquitoes, leading to differing transmission rates in different areas [56]. Socio-economic disparities, including access to preventive measures like insecticide-treated nets and indoor residual spraying, as well as healthcare infrastructure, contribute to uneven malaria prevention and treatment [57]. Additionally, cultural practices, education levels, and awareness about malaria prevention also vary between regions, further exacerbating the differences in infection rates [58]. In areas with limited access to healthcare, the use of preventative measures and timely treatment is often inadequate, contributing to higher infection rates among pregnant women [59].

More than eight hundred more likely significant clusters of areas with high malaria infection among pregnant women were identified using the Sat Scan analysis across the study area. This suggests that pregnant women living in those geographic clusters of areas had a higher chance of malaria infection than women located outside the spatial window.

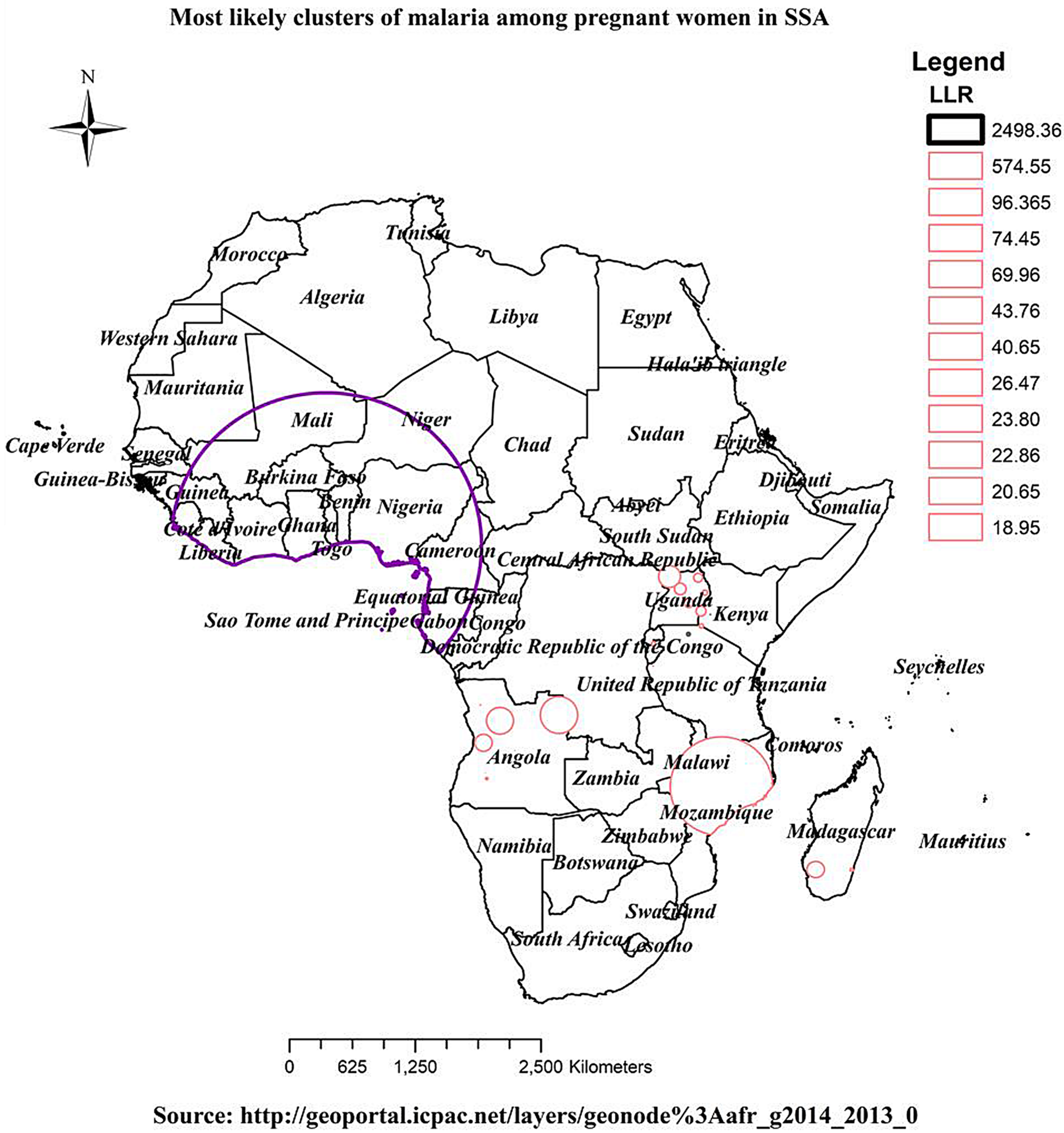

Fig. 6 Sat scan analysis of malaria among pregnant women in Sub-Saharan Africa: MIS 2011–2022

In multivariable hierarchical logistic regression analysis, maternal age, educational status, bed net utilization, type of bed net, use of indoor residual spraying (IRS), wealth index, household television ownership, place of residence, and West Sub-Saharan region were significantly associated with malaria infection among pregnant women a p-value of < 0.05.

The odds of malaria infection were higher for women aged 35–49 years compared to those aged 20–34 years. This finding is in line with the studies conducted in Ghana [60], and Ethiopia [61]. The higher odds of malaria infection among older pregnant women, specifically those aged 35–49 years, compared to younger women (20–34 years), can be attributed to several factors. Older women may have reduced immunity to malaria due to prolonged exposure, which can lead to a diminished immune response. This reduced immunity, particularly in malaria-endemic regions, increases susceptibility to infection. Additionally, pregnancy itself alters immune function, making women more vulnerable to infections such as malaria [62]. Older women are also more likely to have a higher burden of comorbidities, such as anemia or chronic diseases, which may complicate their ability to combat malaria infections [63]. Furthermore, older

Table 3 Sat scan analysis of malaria among pregnant women: MIS 2011–2022

Cluster	Enumeration areas(*n*)	Radius	Population	Cases	RR	LLR	*P*-value
1	389	277.02 km	8597	4858	2.75	2384.9	< 0.0001
2	233	490.63 km	5725	2479	1.93	574.6	< 0.0001
3	23	108.59 km	448	242	2.30	96.4	< 0.0001
4	35	49.00 km	914	382	1.78	74.5	< 0.0001
5	11	45.76 km	404	205	2.16	70.0	< 0.0001
6	1	0 km	50	43	3.65	43.8	< 0.0001
7	14	57.51 km	155	89	2.44	40.65	< 0.0001
8	2	4.46 km	51	41	3.41	36.7	< 0.0001
9	46	123.42 km	890	312	1.49	29.9	< 0.0001
10	6	59.65 km	368	152	1.76	28.3	< 0.0001
11	6	183.18 km	96	56	2.48	26.5	< 0.0001
12	17	132.50 km	186	87	1.99	23.8	< 0.0001
13	6	43.93 km	87	50	2.44	22.9	< 0.0001
14	2	14.70 km	54	35	2.75	20.7	< 0.0001
15	1	0 km	26	21	3.43	19	< 0.0001
16	6	80.06 km	289	115	1.69	18.7	< 0.0001
17	4	20.64 km	151	68	1.91	16.7	< 0.0001
18	2	10.99 km	39	25	2.72	14.4	< 0.0001
19	1	0 km	17	14	3.49	13.1	0.010
20	1	0 km	46	27	2.49	12.9	0.012
21	11	20.25 km	208	82	1.67	12.9	0.012

RR: Relative Risk, LLR: Log-Likelihood Ratio

pregnant women may have more frequent pregnancies, which may also contribute to repeated malaria exposure, increasing their risk [64].

Pregnant women with no education had higher odds of malaria infection compared to those with secondary or higher education. This is supported by the studies in Ghana [65], Ethiopia [66], Uganda [67], and Kenya [68]. This is because lower educational attainment is often associated with reduced knowledge about malaria prevention, limited access to healthcare, and poorer utilization of antenatal care services. Educated women are more likely to be aware of the importance of malaria prevention methods, such as using insecticide-treated nets (ITNs) and seeking timely medical care [69]. They are also more likely to attend antenatal clinics where malaria screening and prophylaxis are provided, reducing their risk of infection. In contrast, uneducated women may not have the same knowledge or access to these interventions, leading to a higher prevalence of malaria during pregnancy [10]. Furthermore, lower education levels often correlate with socioeconomic disadvantages, making it more challenging to access resources such as healthcare and malaria prevention measures [70].

The odds of malaria infection among pregnant women were significantly higher among women who did not use bed nets. This result aligns with previous studies in Rwanda [71], India [72], and Myanmar [73]. The possible rationale for the association between higher malaria infection rates and non-use of bed nets among pregnant women could be the protective effect against mosquito bites, which are the primary mode of malaria transmission. Bed nets, particularly those treated with insecticide; create a barrier between mosquitoes and individuals during the night, which is when most malaria transmission occurs. Pregnant women are particularly vulnerable to malaria due to changes in their immune system, making the lack of bed net use a significant risk factor for malaria infection [74–76].

The odds of malaria among pregnant infection were also much higher for women who used untreated bed nets compared to those using treated bed nets. This finding is in line with the previous studies conducted in Sub-Saharan African countries [77], United Kingdom [78], Myanmar [73], and Zambia [79]. The higher odds of malaria among pregnant women who use untreated bed nets compared to those using treated bed nets can be justified by the fact that untreated nets do not provide the same level of protection against mosquito bites as treated nets. Insecticide-treated bed nets (ITNs) are impregnated with insecticides that kill or repel mosquitoes, reducing the likelihood of mosquito transmission of the malaria parasite. In contrast, untreated nets only provide a physical barrier, leaving pregnant women vulnerable to malaria transmission [80]. The use of untreated nets, while still providing some protection, does not offer the same efficacy in malaria prevention as treated nets, which is crucial for vulnerable populations such as pregnant women [81].

Pregnant women who did not use indoor residual spraying (IRS) in the last 12 months had higher odds of

Table 4 Multivariable multilevel logistic regression analysis of individual-level and community level determinants of malaria infection among pregnant women in Sub-Saharan Africa, MIS 2011–2022

Variables	Model I, AOR (95% CI)	Model II, AOR (95% CI)	Model III, AOR (95% CI)	*p*-value
Maternal age				
15–19	0.85 (1.74, 0.97)		0.99 (0.86, 1.14)	0.849
20–34	1		1	
35–49	1.44 (1.26, 1.64)		**1.19 (1.03, 1.37)**	0.016
Educational status				
No education	1.96 (1.67 to 2.30)		**1.52(1.28, 1.80)**	0.000
Primary	0.93 (0.78 to 1.10)		1.30 (0.08, 1.57)	0.066
Secondary and above	1		1	
Number of total children				
None	0.13 (0.04, 1.46)		0.21 (0.06, 1.80)	0.072
1–2	0.76 (0.67, 1.85)		0.83 (0.74, 1.94)	0.083
≥ 3	1		1	
Number of mosquito net				
None	1.45 (1.27, 1.65)		1.07 (0.92, 1.23)	0.387
One	1.08 (0.96, 1.22)		1.02 (0.90, 1.16)	0.752
Two and above	1		1	
Bed net utilized				
No	6.88(3.30, 14.28)		**6.63(3.20, 13.73)**	0.000
Yes	1		1	
Type of bed net				
Untreated	21.56(11.80, 39.42)		**4.16 (3.72, 8.49)**	0.000
Treated	1		1	
use of IRS in the last 1 year				
No	2.96 (2.33, 3.75)		**2.07 (1.63, 2.64)**	0.000
Yes	1		1	
Wealth index				
Poor	6.00 (4.91, 7.32)		1.67 (0.32, 2.10)	0.667
Middle	2.58 (2.16, 3.07)		1.37 (0.13, 1.67)	0.061
Rich	1		1	
Household has radio				
No	0.77 (0.69, 0.86)		0.81 (0.43, 1.53)	0.524
Yes	1		1	
Household has television				
No	2.91 (2.26. 3.75)		**2.23 (1.68, 2.98)**	0.000
Yes	1		1	
Main wall material				
Unimproved	0.58 (0.50, 0.68)		0.88 (0.74, 1.04)	0.128
Improved	1		1	
Type of place of residence				
Urban		1	1	0.000
Rural		3.45 (2.92, 4.09)	**2.11 (1.64, 2.41)**	
Country category				
East SSA		1	1	
West SSA		6.12 (5.43, 6.89)	**6.58 (5.67, 7.64)**	0.000
Central SSA		0.78(0.56, 1.32)	0.45(0.44, 1.06)	0.745
South SSA		0.39 (0.32, 1.47)	0.35 (0.29, 1.43)	0.761
Model comparison and random effect analysis				
Parameter	Null model	Model I	Model II	Model III
Variance	0.6701334	0.6574007	0.5928654	0.5569623
ICC	16.92%	16.60%	15.3%	14.5%.
MOR	2.179	2.1609	2.08	2.03
PCV	Reference	1.9%.	11.54%.	16.94%

Table 4 (continued)

Variables	Model I, AOR (95% CI)	Model II, AOR (95% CI)	Model III, AOR (95% CI)	*p*-value
Model fitness				
LLR	-6056.67	-5347.06	-5133.25	-4810.04
Deviance	12,113.34	10,694.12	10,266.5	9,620.08

AOR: Adjusted Odds Ratio, ICC: Interacluster Correlation, IRS: Indoor Residual Spray, ITN: Insecticide-Treated Net, LLR: Loglikelihood Ratio, MOR: Median Odds Ratio, PCV: Proportional Change in Variance, SSA: Sub-Saharan Africa

malaria infection compared to those who did, in agreement with studies conducted in Ghana [82], Uganda [83], Columbia [84], and Iran [85]. This association may reflect the protective role that IRS plays in malaria control by reducing indoor mosquito density and exposure to malaria parasites. Pregnant women, being physiologically more vulnerable to severe malaria, may be disproportionately affected in the absence of such preventive measures. Therefore, the non-use of IRS may be associated with an increased risk of malaria infection among pregnant women due to reduced vector control [86, 87].

Pregnant women in households without a television had higher odds of malaria infection compared to pregnant Women with a television. This finding is supported by the studies conducted in Canada [88] and Latin America [89]. The potential explanation could be that television serves as a vital source of public health education, providing messages about malaria prevention strategies, such as the importance of using insecticide-treated bed nets, accessing antenatal care, and recognizing early symptoms. Pregnant women in households with televisions are more likely to be exposed to these educational campaigns, increasing their awareness and adoption of protective measures [77]. Conversely, households without television may lack access to such critical health information, leading to lower knowledge levels and fewer preventive actions [90].

The odds of malaria infection were higher for pregnant women living in rural areas compared to those in urban areas. This finding is in line with other studies in France [91], Brazil [92], and Guinea [93]. The higher odds of malaria infection among pregnant women living in rural areas compared to urban areas can be attributed to several interrelated factors. Rural areas often serve as favorable habitats for malaria vectors, such as Anopheles mosquitoes, due to the presence of stagnant water bodies, dense vegetation, and agricultural practices that create breeding sites [94]. Additionally, rural communities typically face limited access to healthcare facilities and preventive measures like insecticide-treated bed nets (ITNs) and intermittent preventive treatment during pregnancy (IPTp) [95]. Socioeconomic challenges, such as lower levels of education and income, further exacerbate the situation, reducing awareness and uptake of malaria prevention and treatment options [96]. Moreover, infrastructure deficits, including poor housing and lack of indoor residual spraying (IRS), heighten exposure to mosquito bites in rural areas [97].

Regionally, the odds of malaria infection were higher in West Sub-Saharan Africa compared to East Sub-Saharan Africa. The justification might be the differences in ecological, climatic, and socio-economic factors. West Sub-Saharan Africa experiences higher malaria transmission intensity due to its predominantly humid tropical climate, which provides ideal conditions for Anopheles mosquito breeding and survival. Furthermore, West Africa is characterized by longer malaria transmission seasons compared to East Africa, where transmission may be limited by drier climates and higher altitudes in some areas [56, 57, 59].

The study's strength was the utilization of recently conducted large sample national Malaria Indicator Surveys (MIS) to analyze the prevalence and spatial distribution of malaria among pregnant women in Sub-Saharan Africa (SSA). The other strength was the use of mixed hierarchical logistic regression, which allowed for the identification of two-level factors that standard logistic regression could not do. However, the study was limited in its ability to include other variables that might have been associated with the outcome due to the absence of certain important variables in the Malaria Indicator Surveys. Specifically, we were unable to account for maternal behavioral factors such as bed net usage consistency, which is crucial in preventing malaria, as well as environmental conditions, including temperature, rainfall, elevation, vegetation index, and proximity to mosquito breeding sites. These environmental factors are known to play a significant role in malaria transmission by influencing mosquito populations and their breeding sites. Given that climate and environmental conditions directly affect the spatial distribution of malaria risk, their absence in the analysis may have limited our ability to fully address the spatial variations in malaria transmission patterns. The absence of these critical environmental variables may have confounded the interpretation of spatial clustering patterns, potentially underestimating the role that these factors play in driving malaria risk. Furthermore, temporal variations in sociodemographic factors and the availability of insecticide-treated nets (ITNs) across different survey years may have contributed to fluctuations in malaria risk, but these were not fully accounted for in the analysis. Another key limitation of the study was the concentration of over 50% of the sampled countries in the West African region, which may reduce the generalizability of our findings to other areas of Sub-Saharan Africa, where malaria transmission dynamics may differ due to varying environmental, socio-economic, and healthcare conditions.

Conclusion and recommendations

This study concludes that the malaria infection rate among pregnant women in Sub-Saharan Africa was found to be high, with both individual and community-level factors significantly associated with malaria infection. Based on these findings, we recommended that health policies in Sub-Saharan Africa prioritize targeted interventions for pregnant women, particularly in rural areas, where access to healthcare and prevention measures is limited. Strategies should focus on improving the use of bed nets and indoor residual spraying (IRS), enhancing education, and implementing region-specific measures, such as West Sub-Saharan Africa, where spatial clustering of malaria was high.

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Author contributions

AFZ: involved in designing the study, data extraction, data analysis, interpretation, and manuscript writing.EGM: involved in data analysis, interpretation, and manuscript writing.DAG: involved in data extraction, and manuscript writing.BT: involved in data extraction and result interpretation TTT: involved in designing the study, interpretation, report and manuscript writing.

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Data availability

Third party data was obtained for this study from The DHS Program (https://dhsprogram.com/). Data may be requested from The DHS Program after creating an account and submitting a concept note. More access information can be found on The DHS Program website (https://dhsprogram.com/data/Access-Instructions.cfm). The data set is openly available upon permission from the MEASURE DHS website (https://www.dhsprogram.com/data/available-datasets.cfm). The authors confirm that interested researchers would be able to access these data in the same manner as the authors. The authors also confirm that they had no special access privileges that others would not have.

Declarations

Ethical approval and consent to participate

Since this study is a secondary analysis of malaria indicator surveys, ethical approval is not necessary. We registered, requested the dataset from the DHS online repository, and were granted permission to view and download the data files in order to perform our study. The malaria indicator surveys report states that during the survey data collection process, all participant information was anonymized. Visit: https://www.dhsprogram.com/data/dataset_admin/index.cfm.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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