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Spatial distribution of malaria among under-five children and associated factors in Tanzania: a spatial and multilevel analysis

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Abstract

Background Malaria is a major public health problem in Tanzania, accounting for 3.1% of the global cases, with under-five children being particularly vulnerable. Over half of malaria deaths in Tanzania occurred among under-five children. Identifying the spatial determinants of malaria is crucial for optimizing targeted interventions to reduce morbidity and mortality in this vulnerable population. Therefore, this study aimed to assess the spatial determinants of malaria and factors associated with malaria infection among under-five children in Tanzania.

Methods A secondary data analysis was carried out using the Tanzanian Demographic and Health Survey and Malaria Indicator Survey (TDHS-MIS) 2022 data. A total weighted sample of 4971 under-five children was included in the analysis. Spatial determinants of malaria were identified by ordinary least square and geographically weighted regression analysis. A multilevel binary logistic regression model was fitted to identify factors associated with malaria infection among under-five children.

Results Malaria among under-five children was spatially clustered in Tanzania (Moran's Index = 0.14, p-value < 0.0001). Significant primary clusters of malaria were identified in the Northwestern part of the country (western and Lake zones) (log-likelihood ratio (LLR = 80.22, p < 0.0001) and secondary clusters in the Mtwara region (LLR = 16.04, p < 0.0001). Wealth index and access to health care were significant determinants of spatial clustering of malaria among under-five children. In the multilevel analysis, maternal education [primary level (AOR = 0.71, 95% CI 0.52–0.97)], child age of 48–59 months (AOR = 3.17, 95% CI: 1.80–5.62), family size of 5 to 10 (AOR = 1.69, 95%CI 1.12, 2.54), being in poor wealth index (AOR = 2.56, 95% CI 1.18–5.57), and unimproved roof (AOR = 1.49, 95% CI 1.04–2.16) were significantly associated with malaria infection among under-five children.

Conclusion and Recommendation Malaria among under-five children in Tanzania shows significant spatial clustering, particularly in the Northwestern and Southern parts of the country. This spatial clustering of malaria was attributed to poor socioeconomic status and lack of access to health care. Improving access to health care and enhancing malaria prevention measures for the economically disadvantaged group could have a better impact on reducing the burden of malaria.

Keywords Spatial distribution, Malaria, Under-five, Children, Associated factors, Tanzania

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Background

Malaria is a life-threatening disease caused by *Plasmodium* parasites that are transmitted to people through the bites of infected female *Anopheles* mosquitoes. *Plasmodium falciparum* is the most widespread and deadly parasite species, especially prevalent in sub-Saharan Africa [1]. Malaria remains a significant global health challenge, with nearly half of the world's population at risk. In 2022, approximately 249 million people contracted malaria across 85 countries, resulting in around 608,000 deaths. The World Health Organization (WHO) African Region bears a disproportionately high share of the global malaria burden, accounting for 94% of malaria cases (233 million) and 95% (580,000) of malaria deaths [2].

Tanzania is among the ten countries with the highest malaria cases accounting for 3.1% of the global cases [3]. It also accounts for 12.8% of malaria cases in East and Southern Africa. Four countries accounted for just over half of all malaria deaths globally in 2021: Nigeria (31%), the Democratic Republic of the Congo (13%), Niger (4%), and the United Republic of Tanzania (4%) [4].

Children under five are among the most vulnerable groups to malaria, with higher morbidity and mortality rates. In the WHO African region, 80% of all malaria deaths occurred among under-five children. According to the UNICEF 2018 report, more than half (55%) of malaria deaths in Tanzania occurred among under-five children, and about 16% of deaths in this age group were attributed to malaria [5].

The WHO developed a Global Technical Strategy for Malaria 2016–2030, intending to reduce the incidence and mortality of malaria by 90% by 2030 [6]. In line with this strategy, the National Malaria Control Programme (NMCP) Strategic Plan for 2021–2025 (NMCP 2020) sets a goal to decrease the prevalence of malaria in children under 5 years old from 7.5% in 2017 to below 3.5% by 2025 in mainland Tanzania [7]. Additionally, the Zanzibar Malaria Elimination Programme (ZAMEP) Strategic Plan for 2018–2023 aims to create entirely malaria-free zones in Zanzibar [8].

To achieve these strategic goals, the country has moved towards implementing a targeted malaria control approach, which is well aligned with the WHO High Burden to High Impact (HBHI) initiative. This initiative emphasizes the strategic use of data to enhance malaria control efforts by identifying areas of greatest need and deploying interventions more effectively to maximize impact [3]. In line with this, the country has classified administrative regions and councils into risk strata of very low, low, moderate, and high [7]. Prior studies have similarly mapped the risk of malaria in Tanzania using a combination of survey and routine data, recommending targeted interventions [9–11]. The country has made many efforts, supported by various donors to reduce malaria deaths using an integrated approach emphasizing prevention through insecticide-treated bed nets (ITNs), indoor residual spraying, prevention of malaria in pregnancy, prompt diagnosis and correct treatment, strengthened malaria surveillance, developing human resources capacity, and promoting positive behaviours for malaria prevention and case management [7].

Despite many international and national efforts, malaria is still a major cause of morbidity and mortality among children in Tanzania. Identifying the spatial determinants of malaria will complement previous evidence on the risk stratification and support the country's efforts by providing valuable insights into the specific geographic factors that influence malaria transmission. Therefore, this study analyses the 2022 TDHS-MIS data to assess the spatial distribution and determinants of malaria among under-five children in Tanzania.

Methods

Study design, setting, and period

A secondary data analysis was done based on the 2022 TDHS-MIS data. The TDHS-MIS was a nationally representative cross-sectional survey conducted every five years in Tanzania. The 2022 TDHS-MIS was conducted between 24 February and 21 July 2022. Tanzania is located in East Africa and lies between latitudes 1° and 12°S, and longitudes 29° and 41°E, with a total area of 947,303 Km^2. Tanzania has a tropical type of climate and is divided into four main climatic zones notably: the hot humid coastal plain; the semi-arid zone of the central plateau; the high-moist lake regions; and the temperate highland areas. In the highlands, temperatures range between 10°C and 20 °C during cold and hot seasons, respectively. The rest of the country has temperatures usually not falling lower than 20 °C. The hottest period spreads between November and February (25 °C–31 °C) whereas the coldest period is often between May and August (15 °C–20 °C) [12]. It has 31 administrative regions: 26 in mainland Tanzania and the remaining 5 in Zanzibar). According to the 2022 Population and Housing Census, Tanzania is home to a population of 61,741,120 population, with 65% of the population living in rural areas. About 42.8% of the population is under 14 years old, and 15.4% of the population is under 4 years old [13].

Sample size and sampling procedure

The 2022 TDHS-MIS followed a stratified two-stage sample design. The first stage involved the selection of sampling points (clusters) consisting of enumeration areas (EAs) delineated for the 2012 Tanzania Population and Housing Census (2012 PHC). The EAs were selected with

a probability proportional to their size within each sampling stratum. A total of 629 clusters were selected, 211 were from urban areas and 418 were from rural areas. In the second stage, 26 households were selected systematically from each cluster, for a total anticipated sample size of 16,354 households for the 2022 TDHS-MIS. However, one EA could not be reached for security reasons, while 5 EAs had less than the targeted 26 households, and 16,312 households were selected. From the selected households, 15,705 were successfully interviewed and a subsample (50% of households) of households were selected for malaria testing. Finally, a total of 5237 under-five children were selected for malaria testing and 5042 children were tested for malaria (Fig. 1). The detailed sampling procedure has been presented in the full TDHS-MIS 2022 report [14].

Study variables

Outcome variable

Malaria prevalence: Malaria testing was conducted for children aged 6–59 months. A drop of blood taken from a finger prick (or a heel prick in the case of children age 6–11 months) was tested immediately using the SD Bioline Ag Pf rapid diagnostic test (RDT), which is a rapid qualitative test for malaria specific to *P. falciparum* [14].

Independent variables

After reviewing literatures, important potential predictors of malaria were extracted from the TDHS-MIS dataset. Given the hierarchical nature of the data, two levels of independent variables were considered. Age of the household head, sex of the household head, family size, maternal education, wealth index, availability of electricity, media access, main floor material, main wall material, main roof material, health insurance, child sex, child age, anaemia, availability of ITN, and ITN utilization were individual-level predictors. Whereas, place of residence (rural/urban), Altitude, and Zones of Tanzania were considered as community-level predictors. In addition, explanatory variables such as access to health care, perceived susceptibility to malaria, perceived severity of malaria, self-efficacy to use ITN, exposure to malaria messages in the last six months, knowledge of ways to avoid malaria, and attitude towards malaria-related behaviours were included in the spatial regression analysis.

Measurement of variables

Availability of ITN Availability of ITN was categorized as "Yes" (if there is at least one ITN in the household) or "No" otherwise.

ITN utilization ITN utilization by the child was categorized as "Yes" if the child slept under ITN on the last night before the survey.

Main floor material It was categorized as *improved* (Tablets/wood planks, Palm, bamboo, Mat, Adobe, Parquet, polished wood, Vinyl, asphalt strips, floor mat, Linoleum, Ceramic tiles, mosaic, Cement, Carpet, Stone, Bricks) and *unimproved* (Earth, sand, clay, mud, Dung) [15].

Main wall material It was categorized as *improved* (cement, Stone with lime/cement, Bricks, Cement blocks, Covered adobe, wood planks/shingles, Burnt bricks with cement) and *unimproved* (No wall, Cane/palm/trunks, Dirt, Mud and sticks, Tin/ cardboard/ paper/ bags Thatched/straw, Bamboo with mud, Stone with mud,

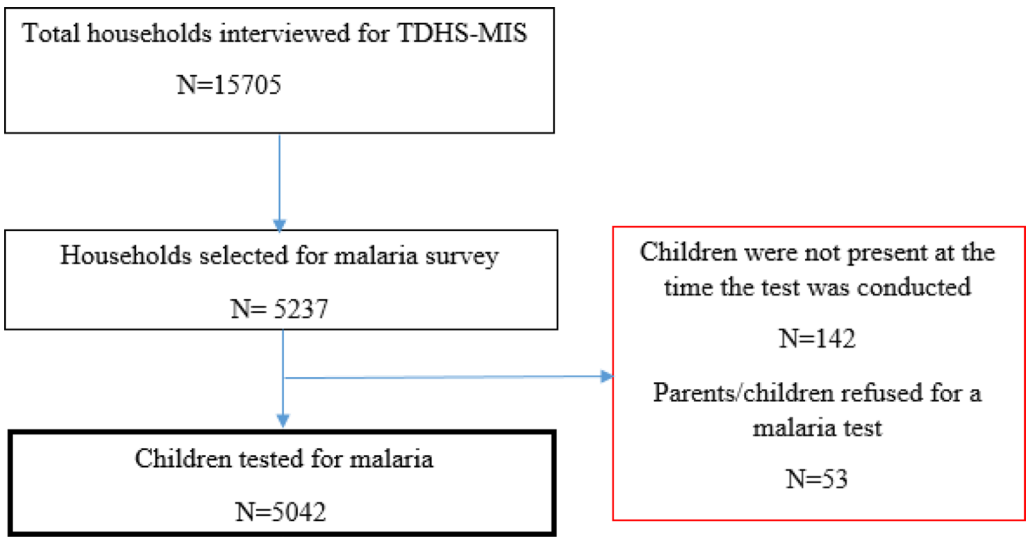

Fig. 1 Flow diagram of how samples were selected from the 2022 TDHS-MIS data for our study

Uncovered adobe, Plywood, Cardboard, Reused wood, Trunks with mud, Unburnt bricks, Unburnt bricks with plaster, Unburnt bricks with mud) [15].

Main roof material categorized as *improved* (Metal, Wood, calamine/cement fiber, Ceramic tiles, Cement, Roofing shingles, Asbestos/Slate roofing sheets) and *unimproved* (No roof, Grass/thatch/palm leaf, Sod, Straw, Rustic mat, Palm/bamboo, Wood planks, Cardboard, Tarpaulin, Plastic) [15].

Wealth index It was computed based on principal component analysis in the major DHS and categorized as poorest, poorer, middle, richer, and richest. For this analysis, the categories poorest and poorer were combined into poor, and richer and richest were combined into rich.

Anaemia children whose haemoglobin count is less than 11 g per decilitre (g/dl) were considered anaemic [14].

Data source

Data were accessed from the official database of the Demographic and Health Surveys (DHS) Program (https://dhsprogram.com/) after permission was granted following an online request outlining the objective of our study. The 2022 TDHS-MIS household member recode (PR), household recode (HR), and Individual recode (IR) datasets were used for this study. Almost all study variables were available in the PR data, but the PR dataset was merged with the HR and IR datasets for some variables such as ITN availability, perceived susceptibility, and perceived severity. Geographical coordinate data (longitude and latitude coordinates) were taken at the cluster/EA level and jittered up to 2 km in urban and 5 km in rural areas in any direction to protect the confidentiality of survey respondents. The 2022 TDHS-MIS were collected from 623 clusters/EAs.

Data management and analysis

Descriptive and summary statistics were computed using STATA version 14 software. Data were weighted using the household sample weighting variable (hv005), as recommended by the DHS program, before any statistical analysis to obtain statistics representative of Tanzania. The distribution of children tested for malaria may not represent Tanzania accurately, as some areas of the country may be over-sampled and others under-sampled. Hence, a total of 4971 weighted samples were used in the analysis to ensure the results were representative.

Spatial analysis

Spatial autocorrelation analysis

ArcGIS Version 10.7 and SaTScan Version 10.1 software were used for the spatial analysis. The spatial autocorrelation (Global Moran's I) statistic was computed to test whether there was significant clustering of malaria in Tanzania. Moran's I is a spatial statistic used to evaluate spatial autocorrelation and produces a single output value that ranges from − 1 to + 1. A Moran's I value close to −1 indicates disease dispersion, whereas a Moran's I value close to + 1 indicates disease clustering and a Moran's I value of zero indicates a random distribution of the disease[16]. A statistically significant Moran's I ($p < 0.05$) leads to the rejection of the null hypothesis, "malaria is randomly distributed", and indicates the presence of spatial autocorrelation.

Hot spot analysis (Getis-Ord Gi statistic)*

Hot-spot analysis was conducted using Getis-Ord Gi* statistics to explore how spatial autocorrelation varies across the study areas. The statistical significance of clustering was determined by computing the Gi* Z-score. A positive Z-score greater than 1.96 with a significant p-value indicates a hot spot, while a negative Z-score less than 1.96 with a significant p-value indicates a cold spot.

Spatial scan statistical analysis

Spatial scan statistics were computed to identify significant and most likely clusters using SaTScan version 10.1 statistical software. Bernoulli model was used by applying the Kuldorff method for purely spatial analysis using cases (malaria positive) and controls (malaria negative) from each cluster to identify statistically significant spatial clusters of malaria. The default maximum spatial cluster size of < 50% of the population was used as an upper limit, which allowed both small and large clusters to be detected. The primary and secondary clusters were detected and ranked according to the likelihood ratio test, based on 999 Monte Carlo replications [17].

Spatial interpolation

The ordinary kriging interpolation technique was employed to predict the burden of malaria in the unsampled areas of the country based on the data from sampled enumeration areas. There are numerous deterministic and geostatistical interpolation methods. Ordinary kriging and empirical Bayesian kriging are considered the best approaches since they incorporate spatial autocorrelation and statistically optimize the weighting of data points [18, 19]. The ordinary kriging spatial interpolation method was selected for this study since it had a smaller residual and root mean square error.

Spatial regression analysis

Spatial regression modelling was performed to identify predictors of the observed spatial patterns of malaria among under-five children. Ordinary least square (OLS)

and geographically weighted regression (GWR) analyses were conducted. OLS is a global statistical model used to examine the relationship between dependent and independent variables, assuming stationarity across the study area. OLS was used as a diagnostic tool to identify predictors for inclusion in the GWR model. Key assumptions, including spatial independence of residuals, multicollinearity, normality, and non-stationary were assessed using the global spatial autocorrelation coefficient Moran's I value, variance inflation factor (VIF), Jarque–Bera Statistics, and Koenker (BP) Statistics, respectively. GWR , a local spatial statistical technique that accounts for non-stationarity by modeling variations in the relationship between dependent and explanatory variables across clusters or enumeration areas (EAs), was then conducted. The corrected Akaike Information Criterion (AICc) and adjusted R-squared were used to compare the OLS (global) and GWR (local) models, with the best-fit model having the lowest AICc and highest adjusted R-squared. Finally, the GWR coefficients for the predictors were mapped to visualize their spatial variability.

Multilevel logistic regression analysis

Because of the hierarchical nature of the TDHS-MIS data, a multilevel analysis was required to consider the heterogeneity between clusters. Therefore, a multilevel logistic regression model was fitted to identify the individual-level and community-level factors associated with malaria among under-five children. First, the null model (a model without explanatory variables) was fitted to determine community variance, resulting in an Intra-class Correlation Coefficient (ICC) of 0.60 (95%CI: 0.52–0.68), indicating the need for a multilevel analysis. The second model was adjusted with individual-level variables; the third model was adjusted for community-level variables, while the fourth was fitted with both individual and community-level variables. Random effect parameters such as ICC, Median Odds Ratio (MOR), and Proportional Change in Variance (PCV) were computed to measure the variation of malaria among under-five children between clusters.

Variables with a p-value of ≤ 0.2 in the bi-variable analysis for both individual and community-level factors were entered into the multivariable model. Adjusted odds ratio (AOR) with 95% CI and p-value < 0.05 in the multivariable model were used to declare statistically significant associated factors of malaria among under-five children. Multicollinearity was checked using the variance inflation factor (VIF), and the VIF for all variables included in the final model was < 7, indicating no multicollinearity. Model comparison was made based on the Akaike information criteria (AIC) and deviance. Model four, the model with the lowest AIC and deviance, was selected as the best-fitted model.

Results

Socio-demographic characteristics of participants

A total weighted sample of 4971 under-five children, who tested for malaria, were included in this study, and nearly three-fourths 3686(74.14%) of them were from rural areas. Of the total children, more than half 2522(50.74%) were male, and more than one-fifth of them were aged 12–23 months. Additionally, more than half 2567(51.64%) of the mothers of the children attended the primary level of education. More than one-fifth 1138(22.89%) of the children were from a family with the poorest wealth index. More than three-fourths 3781(76.06%) of children were from households headed by men, and 1822(36.64%) were from households headed by persons aged 45 years and above (Table 1).

Table 1 Sociodemographic characteristics of the study participants, 2022 TDHS-MIS (n = 4971)

Variables	Category	Frequency	Percentage
Age of child (in months)	6–11	522	10.50
	12–23	1149	23.11
	24–35	1080	21.73
	36–47	1093	21.99
	48–59	1127	22.66
Sex of child	Male	2522	50.74
	Female	2449	49.26
Maternal education	No education	1537	30.92
	Primary	2567	51.64
	Secondary	828	16.66
	Higher	38	0.77
Residence	Urban	1285	25.86
	Rural	3686	74.14
Wealth Index	Poorest	1138	22.89
	Poorer	1012	20.36
	Middle	1014	20.40
	Richer	1004	20.20
	Richest	803	16.15
Sex of household head	Male	3781	76.06
	Female	1190	23.94
Age of the household head	< 25 years	198	3.99
	25–34 years	1523	30.63
	35–44 years	1429	28.74
	45 + years	1822	36.64
Family size	< 5	1494	30.04
	5–10	3059	61.54
	> 10	418	8.41

Housing conditions

The majority, 3942(79.30%), of the households had at least one ITN in the house, and 3187(64.10%) of the study participants slept under ITN the night before the survey. More than half, 2614(52.58%), of the participants were living in houses where the main floor materials were unimproved, 2065(41.55%) were in houses with unimproved walls, and 941(18.94) were in houses with unimproved floors. The majority, 4784(96.24%), of the households were not covered by health insurance, and more than half, 2568(51.67%), of the households did not have media access (Table 2).

Prevalence of malaria among children in Tanzania

Of a total of 4971 under-five children tested for malaria with an RDT, 388(7.8%) were positive for malaria. Among the malaria-positive children, 319(82.26%) of them were anaemic. The highest prevalence of malaria among children was seen in the Tabora region (23%), followed by Mtwara (20%), and Kagera (17.5%) regions. In contrast, no malaria cases were observed in the Zanzibar, Dodoma, Arusha, Kilimanjaro, and Singida regions.

Spatial distribution of malaria among under-five children in Tanzania

Spatial autocorrelation analysis

A total of 623 clusters were included in the spatial analysis of malaria among under-five children. The global spatial autocorrelation analysis revealed that the distribution of malaria among under-five children was spatially clustered in Tanzania with a Global Moran's Index value of 0.14 ($p < 0.0001$) (Fig. 2). A z-score of 5.55 indicated that there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Table 2 Housing condition of the participants, 2022 TDHS-MIS (n = 4971)

Variables	Category	Frequency	Percentage
Availability of ITN	Yes	3942	79.30
	No	1029	20.70
ITN utilization	Yes	3187	64.10
	No	1784	35.90
Access to media	Yes	2403	48.33
	No	2568	51.67
Availability of electricity	Yes	1437	28.90
	No	3534	71.10
Health Insurance	Yes	187	3.76
	No	4784	96.24
Floor material	Improved	2357	47.42
	Unimproved	2614	52.58
Wall material	Improved	2906	58.45
	Unimproved	2065	41.55
Roof material	Improved	4030	81.06
	Unimproved	941	18.94

Hot spot analysis of malaria among under-five children in Tanzania

Hot spot areas of malaria among under-five children were found in the Western (Tabora and eastern Kigoma regions), Lake (Kagera, Geita, Mwanza, Mara, Shinyanga, and Simyu regions), and Southern Zones of Tanzania (Mtwara and southern Lindi regions). Whereas, cold spot areas were found in Zanzibar, central (Dodoma, Northern Singida, eastern Manyara), Eastern (Dar es Salaam), Northern (eastern Arusha, Kilimanjaro, and eastern Tanga), and Southwest highlands zones (southern Mbeya) of Tanzania (Fig. 3).

Spatial scan statistical analysis

A spatial scan statistical analysis identified a total of 175 significant clusters, of which 164 were most likely (primary), and 11 were secondary clusters. The primary cluster spatial window was located in the Western and Lake zones of Tanzania, which was centered at 1.669890 S, 30.962328 E with a 468.12 km radius, and log-likelihood ratio (LLR) of 80.27, at $p < 0.0001$. Under-five children within this spatial window had a 3.74 times higher risk of getting malaria as compared with children outside the window. The secondary cluster spatial windows were located in Mtwara and Lindi centered at 10.577578 S, 39.545364 E, with a 44.15 km radius, and LLR of 16.04 at $p = 0.000053$ and western Morogoro with a 43.90 km radius, LLR of 11, and p-value = 0.0061 (Fig. 4, Supplementary file 1).

Spatial interpolation of malaria among under-five children in Tanzania

In ordinary kriging spatial interpolation analysis, Tabora, eastern Kigoma, Kagera, Mara, Simyu, Geita and Mtwara regions were predicted as high risk of malaria among under-five children. Whereas the predicted low-risk areas for malaria were identified in Dar es Salaam, Southwest Highlands, Southern Highlands, Central, Northern, and Zanzibar zones (Fig. 5).

Spatial determinates of malaria among under-five children in Tanzania

In OLS analysis, the spatial determinants of hot spot areas of malaria among under-five children were being in the poorest wealth quantile and access to health care. The OLS model yielded an R^2 value of 0.06, indicating that the model explains only 6% of the variance in the dependent variable. The Joint Wald statistic ($p < 0.01$) indicated the overall significance of the model, and no multicollinearity

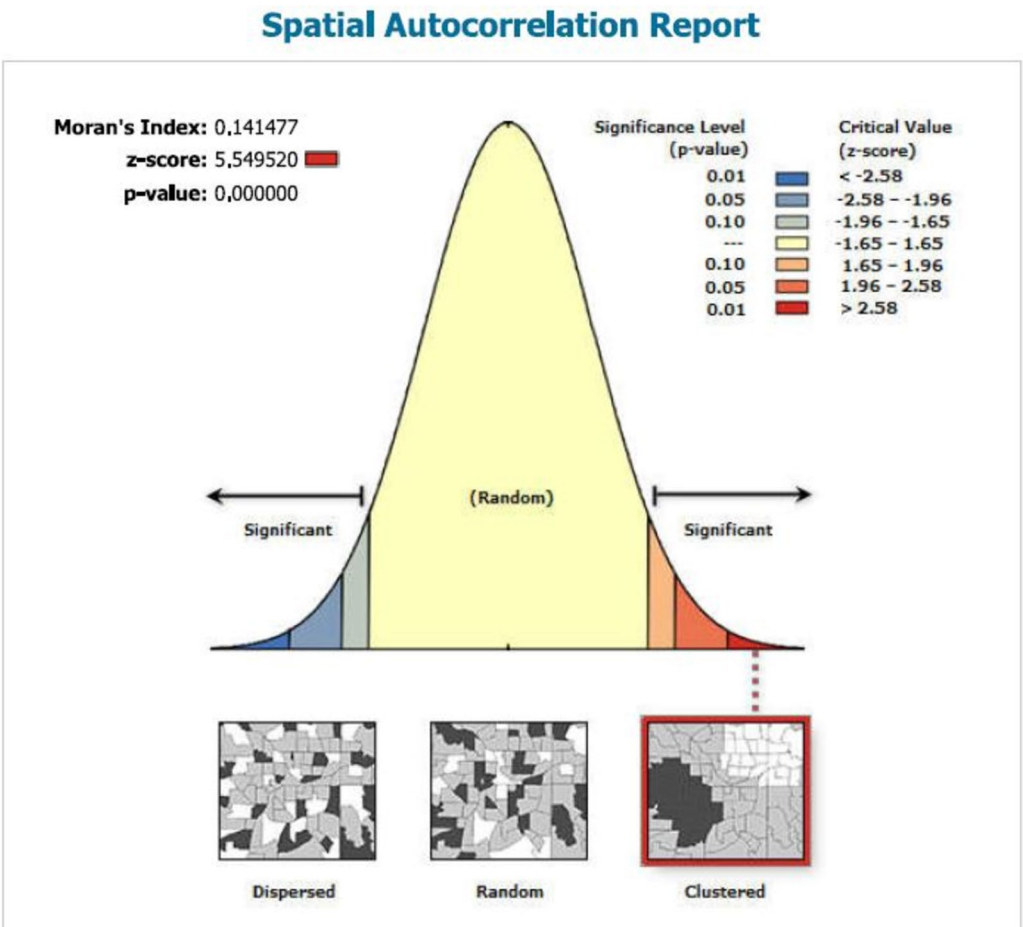

Fig. 2 Spatial autocorrelation of malaria among under-five children in Tanzania, TDHS-MIS, 2022

was detected among explanatory variables (VIF < 7.5). However, the Jarque–Bera test for normality was significant ($p < 0.01$), indicating that the residuals of the OLS model deviate from a normal distribution. This result suggests potential limitations in the model's assumptions and highlights the need to explore alternative modeling approaches, such as GWR, to better account for spatial heterogeneity and improve model fit. Since the Koenker (BP) statistic was significant, we relied on robust probabilities to determine the statistical significance of the coefficients (Supplementary file 2).

In the GWR model, the Adjusted R^2 was increased to 18%, indicating that the GWR model provides a better fit to the data compared to the OLS model. Wealth index was a significant determinant of spatial clustering of malaria among under-five children, where areas with higher proportions of children from the poorest wealth quantile had higher rates of RDT-positive results. A strong positive relationship was found in Kagera, Tabora, Geita, Shinyanga, Mtwara, and central Morogoro regions (Fig. 6). Similarly, access to health care was negatively associated with the spatial clustering of malaria, with a strong negative relationship found in the Kagera, northern Tabora, northern Kigoma, and Mtwara regions (Fig. 7).

Factors associated with malaria among under-five children in Tanzania

Random effect analysis results

In the null model, the ICC indicated that 60% of the total variance in malaria among under-five children was due to differences between clusters while the remaining 40% of the total variability of malaria was attributable to the individual (household level) differences. Additionally, the MOR was 13.77 (95% CI: 9.05, 22.69) in the null model, which indicates that the odds of acquiring malaria is increased by 14 times if under-five children move from a low-risk cluster to a high-risk cluster. In the final model, the PCV was 57%, implying that 57% of the variability in malaria among under-five children was explained by both individual and community-level variables included in the model (Table 3).

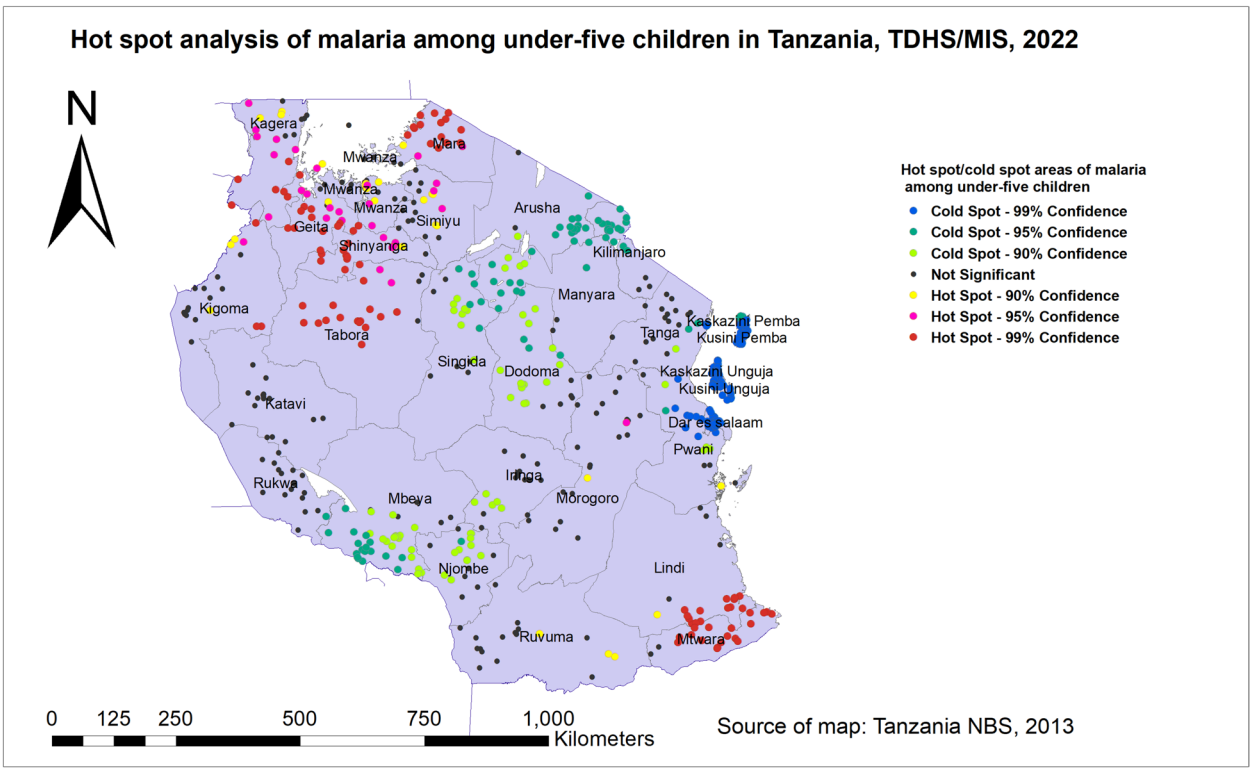

Fig. 3 Hot Spot analysis of malaria among under-five children in Tanzania, TDHS-MIS, 2022

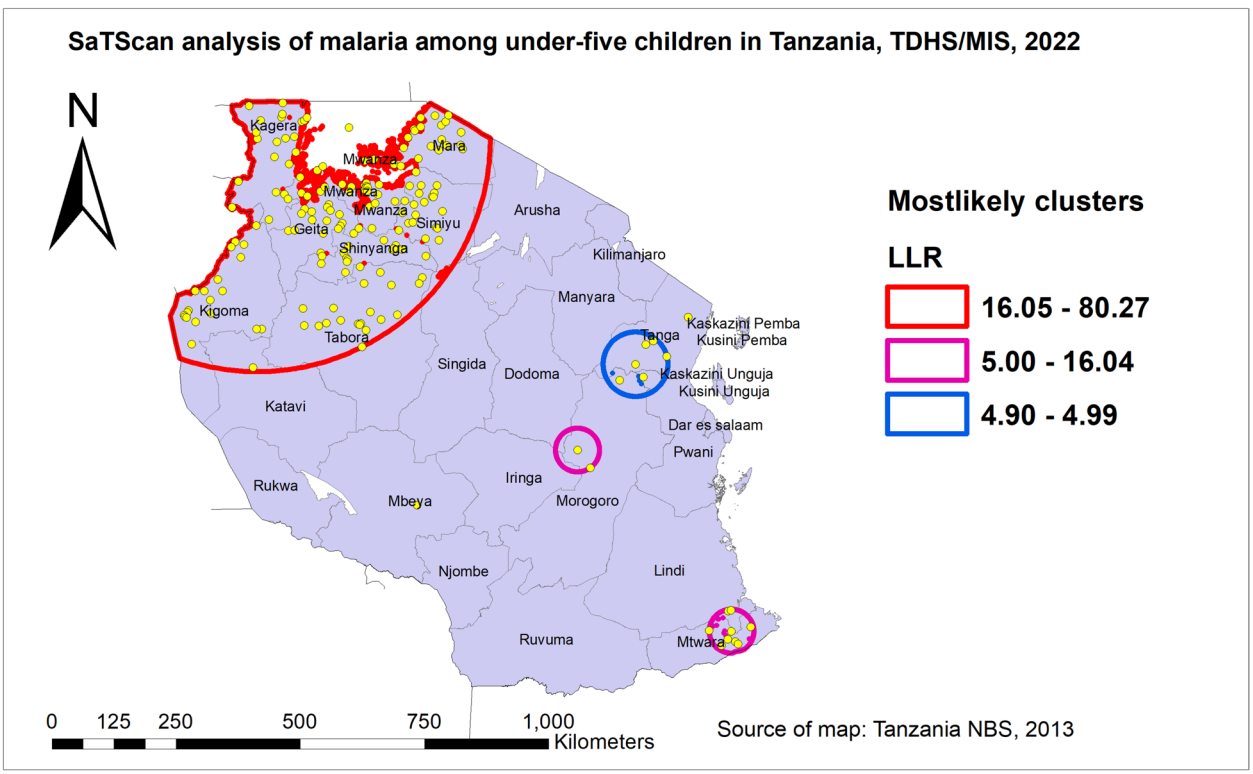

Fig. 4 SaTScan analysis of malaria among under-five children in Tanzania, TDHS-MIS, 2022

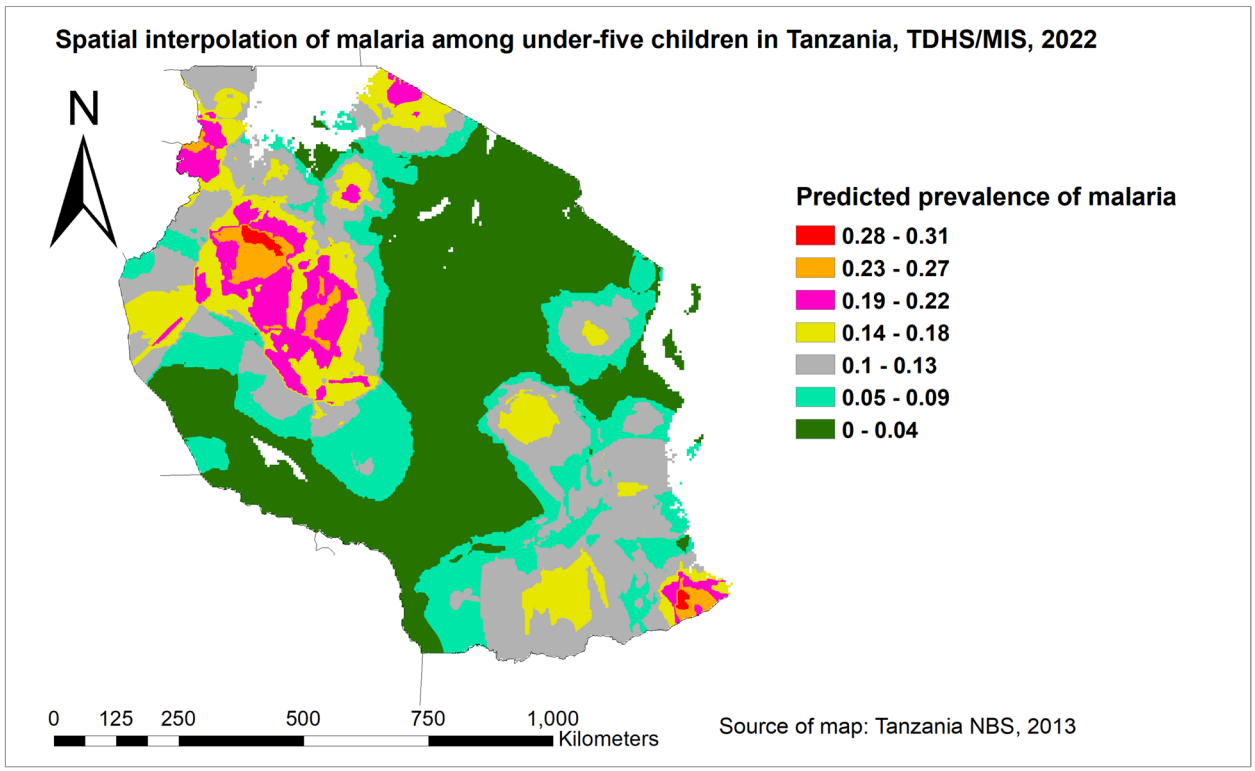

Fig. 5 Spatial interpolation analysis of malaria among under-five children in Tanzania, TDHS-MIS, 2022

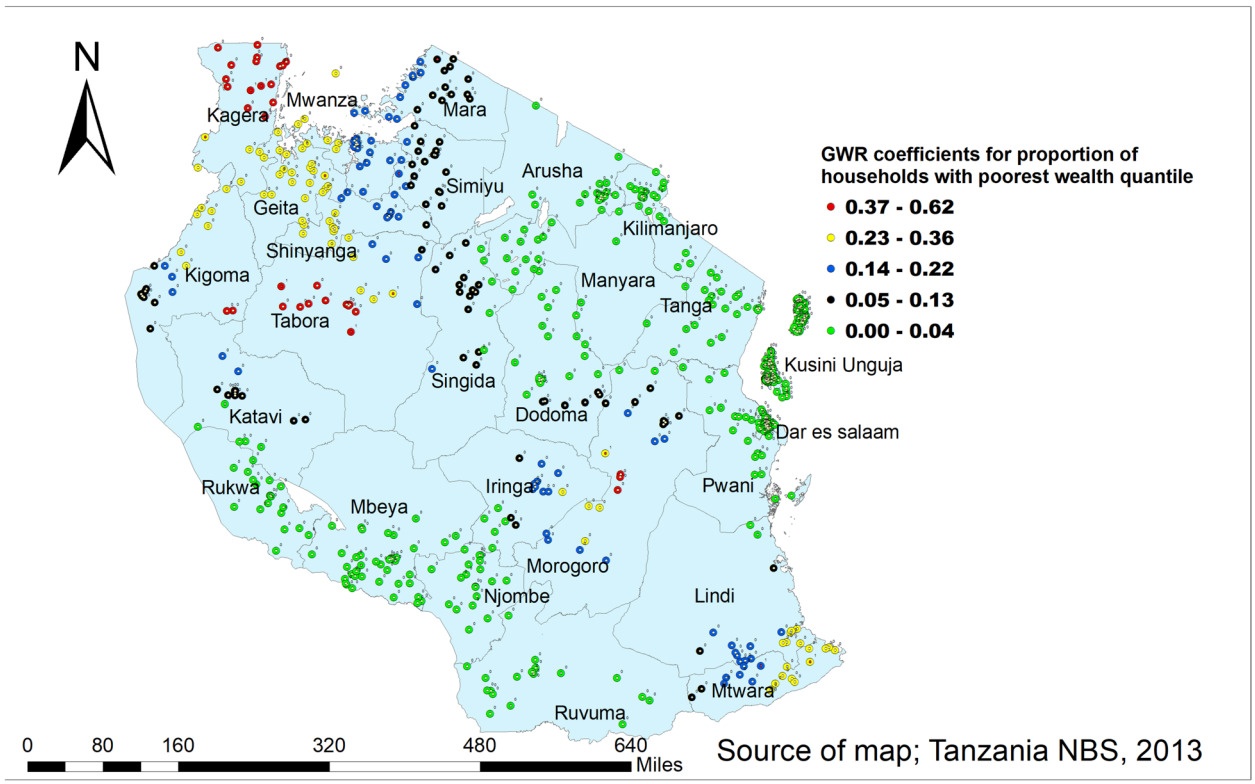

Fig. 6 Spatial variation in the relationship between wealth index and malaria among under-five children in Tanzania, TDHS-MIS, 2022

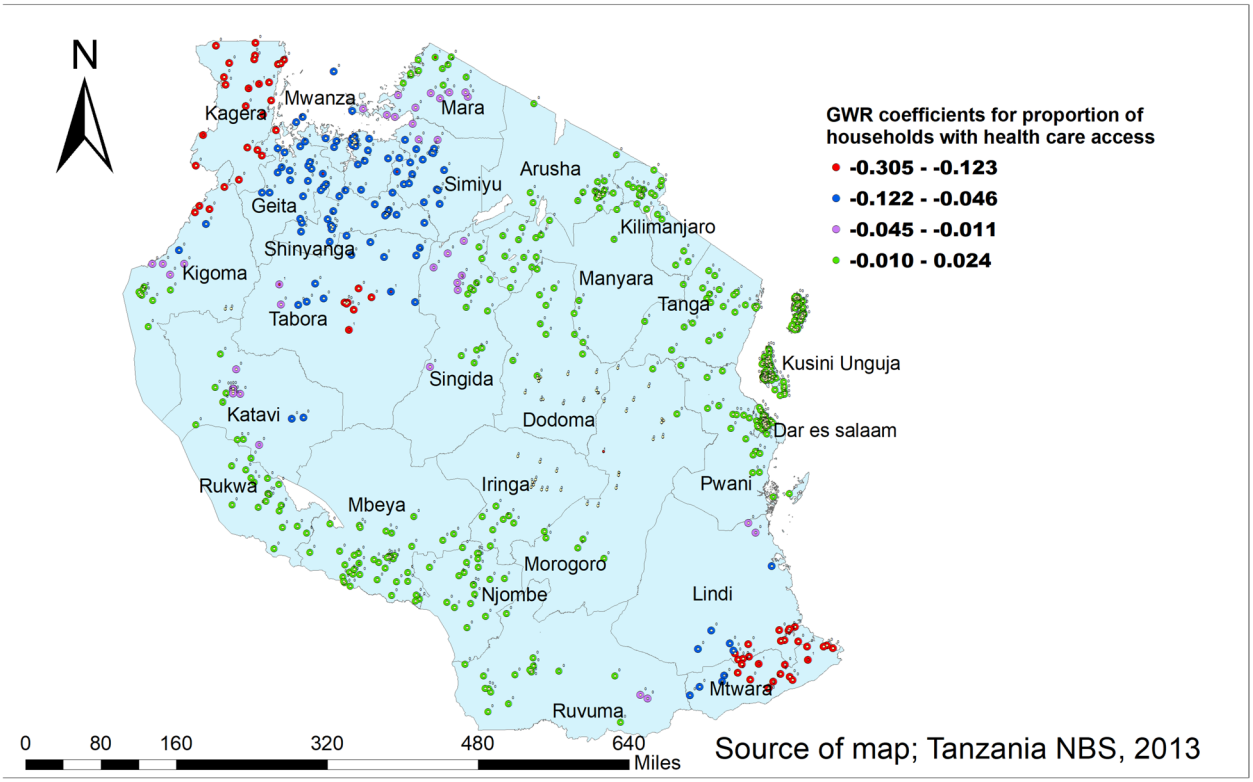

Fig. 7 Spatial variation in the relationship between healthcare access and malaria among under-five children in Tanzania, TDHS-MIS, 2022

Table 3 Multilevel parameters showing random effects on malaria among under-five children and model fitness

Parameters	Null Model	Model 1(IL)	Model 2(CL)	Model 3
ICC(95%CI)	0.60 (0.52–0.68)	0.52 (0.43–0.61)	0.38 (0.29–0.47)	0.39 (0.30–0.49)
Community level variance(SE)	4.96 (0.88)	3.56 (0.63)	2.01 (0.40)	2.12 (0.43)
PCV	Ref.	0.28	0.59	0.57
MOR	13.77	9.22	5.31	5.55
AIC	2071.54	1859.48	1887.49	1736.20
BIC	2084.59	1996.51	1965.80	1938.49
Deviance	2067.541	1817.48	1863.49	1674.20

ICC Intra-class correlation coefficient, *SE* standard error, *PCV* proportional change in variance, *MOR* median odds ratio, *AIC* Akaike information criteria, *BIC* Bayesian information criteria

Fixed effect analysis results

In the multivariable multilevel logistic regression analysis, maternal education, age of the child, family size, age of household head, wealth index, anaemia status, main roof material, residence, and Zone were significantly associated with malaria among under-five children.

The odds of malaria among children of mothers with primary education were reduced by 29% (AOR = 0.71, 95%CI 0.52, 0.97) compared to children of mothers with no education. Children aged 48–59 months had 3.17 times (AOR = 3.17, 95%CI 1.80, 5.62) higher risk of malaria compared to children aged 6–11 months. The odds of malaria among children were increased by 69% (AOR = 1.69, 95%CI 1.12, 2.54) for children from households with family sizes of 5 to 10 compared to children from households with a family size of less than five. The odds of malaria among children from households headed by individuals aged 35–44 were reduced by 56% (AOR = 0.44, 95% CI 0.20–0.98) compared to children from households headed by those aged under 25 years. Children from households with a poor wealth index had 2.56 times (AOR = 2.56, 95% CI 1.18–5.57) higher

odds of RDT positive results compared to children from households with a rich wealth index. In this study, anaemic children were nearly 5 times (AOR = 4.91, 95% CI 3.44–6.99) more likely to have malaria compared to non-anaemic children. Children from households with unimproved main roof material had 1.49 times (AOR = 1.49, 95% CI 1.04–2.16) higher odds of contracting malaria compared to their counterparts.

Children residing in rural areas had 6 times (AOR = 6.07, 95% CI 2.48–14.87) higher odds of malaria than urban children. Children living in the Western zone of Tanzania had 4.68 times (AOR = 4.68, 95% CI 1.16–18.91) higher odds of RDT positivity compared to those in the Eastern zone (Table 4).

Discussion

This study revealed that malaria among under-five children was spatially clustered in Tanzania. Significant hot spot areas were found in the Western, Lake, and Southern Zones of Tanzania. This study identified key spatial determinants of malaria among under-five children in Tanzania, revealing that wealth index and access to healthcare significantly influenced the spatial clustering of malaria. Areas characterized by higher proportions of poverty and limited healthcare access were more likely to experience concentrated malaria burdens, underscoring the intersection between socioeconomic disparities and disease risk.

The spatial clustering of malaria identified in this study was largely consistent with previous risk stratifications made in the country using health facility data [9, 20, 21], except for some regions like Katavi and Ruvuma, which were categorized as high-risk areas but are identified as low-risk in the current study. The spatial clustering of malaria in this study was primarily influenced by wealth index and access to health care, consistent with findings from studies in China [22], Senegal [23], Ghana [24], and Kenya [25]. Limited access to healthcare services may delay diagnosis and treatment, increasing the risk of sustained malaria transmission in affected areas [6, 26, 27]. Similarly, lower wealth status can reduce access to preventive measures such as insecticide-treated nets and adequate housing, further exacerbating malaria risk [28–30]. The other possible factor contributing to the spatial clustering is the proximity of these areas to large water bodies like Lake Victoria, which provides ample breeding grounds for mosquitoes [31–34]. These findings emphasize the need for targeted interventions that address both the economic and healthcare barriers contributing to malaria transmission.

In parallel, the multilevel analysis revealed that children from households with lower wealth index had a higher likelihood of malaria infection compared to those from wealthier households, with the risk being more pronounced among those from the poorest households. Evidence from the Democratic Republic of Congo [35], Togo [36], Nigeria [37], Kenya [38], and a scoping review from sub-Saharan Africa [39, 40] also highlights the significant role of socioeconomic disparities on the prevalence and risk of malaria. Households with lower socioeconomic status often face limited access to healthcare [41, 42] and malaria preventive measures [43, 44], as well as a lack of awareness about malaria prevention strategies [44, 45], increasing their vulnerability to the disease.

In this study, children whose mothers had completed primary education had a 29% reduction in the odds of malaria infection compared to children whose mothers had no education. This finding is supported by studies conducted in the Democratic Republic of Congo [46], Uganda [47], and sub-Saharan Africa [48, 49]. This could be because educated mothers have a better knowledge of the risk factors and symptoms of malaria, leading to increased uptake of preventive measures against malaria and seeking timely medical attention [50]. Therefore, efforts aimed at enhancing the education of women and girls through policy and programme initiatives will play a crucial role in alleviating the impact of malaria on children in Tanzania.

The likelihood of malaria infection increased with age, with older children being at higher risk compared to children less than 12 months. Studies conducted in Uganda [51], Nigeria [52], and Togo [36] have also reported increased malaria risk among older children, highlighting a consistent trend across diverse settings. This may be because infants may still benefit from residual immunity acquired from their mothers during pregnancy and through breastfeeding, which provides some protection against malaria [53–56]. Infants may also receive higher priority, with parents ensuring they sleep under ITN or are adequately protected. Additionally, as children grow older, they become more active and may spend more time outdoors, increasing their exposure to malaria-carrying mosquitoes [57].

This study revealed that the prevalence of malaria among children increased with increasing family size. Children from households with 5 or more members were more likely to have a positive RDT result compared to children from households with fewer than five members. These results align with evidence from India [58], and Nigeria [37, 59], which suggests that larger family sizes may strain financial and material resources, leading to inadequate malaria prevention measures and crowded living conditions that increase exposure risk [60].

Children from households headed by older individuals had lower odds of malaria infection compared to those from households headed by individuals younger than

Table 4 Multilevel multivariable analysis of factors associated with malaria among under-five children in Tanzania, 2022 TDHS-MIS

Variables	Null model	Model 1 (AOR with 95%CI)	Model 2 (AOR with 95%CI)	Model 3 (AOR with 95%CI)
Maternal educational				
No education		1		1
Primary		0.72 (0.52, 0.98)*		0.71 (0.52, 0.97)*
Secondary and above		0.60 (0.32, 1.10)		0.83 (0.45, 1.55)
Age of child				
6–11 months		1		1
12–23 months		0.92 (0.51, 1.67)		0.92 (0.51, 1.67)
24–35 months		2.67 (1.51, 4.70)**		2.69 (1.53, 4.72)**
36–47 months		3.76 (2.14, 6.62)**		3.83 (2.18, 6.71)**
48–59 months		3.08 (1.73, 5.46)**		3.17 (1.80, 5.62)**
Family size				
< 5		1		1
5–10		1.64 (1.09, 2.45)*		1.69 (1.12, 2.54)*
> 10		2.12 (1.16, 3.89)*		1.97 (1.07, 3.60)*
Access to media				
Yes		0.93 (0.66, 1.31)		0.87 (0.62, 1.22)
No		1		1
Age of household head				
< 25 years		1		1
25–34 years		0.73 (0.34, 1.58)		0.71 (0.33, 1.53)
35–44 years		0.46 (0.21, 1.02)		0.44 (0.20, 0.98)*
45 + years		0.37 (0.17, 0.83)*		0.38 (0.17, 0.85)*
Wealth index				
Poor		5.28 (2.42, 11.49)**		2.56 (1.18, 5.57)*
Middle		3.79 (1.93, 7.47)**		2.10 (1.06, 4.17)*
Rich		1		1
Anaemia status				
Anaemic		4.99 (3.50, 7.11)**		4.91 (3.44, 6.99)**
Not anaemic		1		1
Main floor material				
Improved		1		1
Un improved		1.60 (0.96, 2.69)		1.29 (0.78, 2.15)
Main wall material				
Improved		1		1
Un improved		1.02 (0.68, 1.52)		1.04 (0.71, 1.57)
Main roof material				
Improved		1		1
Un improved		1.51 (1.04, 2.18)*		1.49 (1.04,2.16)*
Availability of ITN				
Yes		0.91 (0.63, 1.32)		0.88 (0.61, 1.27)
No		1		1
Residence				
Rural			14.99 (6.72, 33.46)**	6.07 (2.48, 14.87)**
Urban			1	1
Altitude				
< 500 m			1	1
500–1000 m			1.16 (0.37, 3.60)	1.22 (0.37, 4.01)
> 1000 m			0.51 (0.16, 1.70)	0.63 (0.18, 2.20)

Table 4 (continued)

Variables	Null model	Model 1 (AOR with 95%CI)	Model 2 (AOR with 95%CI)	Model 3 (AOR with 95%CI)
Zones				
Eastern			1	1
Western			4.68 (1.23, 17.85)*	4.68 (1.16,18.91)*
Northern			0.29 (0.08, 1.11)	0.28 (0.07, 1.14)
Southern			2.15 (0.76, 6.08)	2.86 (0.96, 8.51)
Southern highlands			0.72 (0.18, 2.89)	1.15 (0.27, 4.93)
Southwest Highlands			0.53 (0.14, 1.96)	0.43 (0.11, 1.72)
Lake			2.84 (0.79, 10.22)	2.55 (0.67, 9.67)
Central or Zanzibar			0.01 (0.001, 0.06)**	0.01 (0.001, 0.08)**

* statistically significant at P-value<0.05;** statistically significant at P-value <0.001

25 years. This finding is similar to studies conducted in India [58], and sub-Saharan Africa [61]. Evidence shows that older household heads possess better knowledge, attitudes, and practices for malaria prevention and control. They understand malaria transmission and symptoms more effectively and utilize preventive measures like bed nets, reducing malaria risk among children [62–64].

In this study, malaria infection was substantially more common among anaemic children than their non-anaemic counterparts. Similar associations have been reported in studies from Malawi [65] Nigeria [57] and sub-Saharan Africa [66]. Although anaemia does not directly cause malaria, it creates a vulnerable physiological state making individuals more susceptible to infections, including malaria [67–69]. However, it is a fact that malaria causes anaemia through the haemolysis of both infected and uninfected erythrocytes and bone marrow dyserythropoiesis [70–72]. As a result of this coexistence, anaemic children were more likely to be infected with malaria than their non-anaemic counterparts. Given the reciprocal association between anaemia and malaria, it is critical to treat both conditions concurrently in endemic regions for better health outcomes [73].

In this study, housing condition was associated with the vulnerability to malaria infection among children. Children from households with unimproved roofs were at a 50% increased risk of malaria compared to children from households with improved roofs. Findings from Uganda [74], Nigeria [57, 59], Burkina Faso [75], and sub-Saharan Africa [15, 66] further reinforce this result. This may be because mosquitoes can easily enter through unimproved roofs, and poor housing conditions facilitate mosquito breeding and increased indoor malaria transmission [76, 77].

Place of residence was also another important factor determining the risk of malaria infection, with children in rural areas facing a significantly higher likelihood of infection compared to those in urban areas. This finding is well documented in previous studies [37, 49, 52, 66]. This can be attributed to factors such as higher mosquito exposure due to proximity to breeding sites, unimproved housing, poor socioeconomic status, and limited access to healthcare and preventive measures [78, 79].

The burden of malaria among under-five children varied by geographic region, with children in the Western zone of Tanzania facing a significantly higher likelihood of infection than those in the Eastern zone, while those in the Central zone and Zanzibar had a substantially lower risk. A similar finding was observed in the previous study [80] which identifies the risk of malaria as highest in the Western Zone and lowest in Zanzibar. Regional variation of malaria among under-five children was also witnessed in studies conducted in Nigeria [37, 59], Malawi [65], Ghana [79], and Uganda [74]. The regional variation in malaria prevalence among under-five children can be attributed to environmental, socioeconomic, behavioural, and health system-related factors. Addressing these variations requires tailored approaches that consider the specific context and challenges of each area.

While this study identified spatial determinants of malaria using geographically weighted regression (GWR), the model's explanatory power, as indicated by an R^2 value of 18%, was relatively low. This suggests that other unmeasured factors may contribute to the spatial variation of malaria risk among children. Future research should consider incorporating additional variables, such as climatic and environmental factors, to improve the model's goodness of fit and provide a more comprehensive understanding of malaria's spatial dynamics.

Conclusion

This study highlighted the spatial clustering of malaria among under-five children in Tanzania, with significant hot spots in the Western, Lake, and Southern Zones. It also emphasized the critical role of socioeconomic factors

and healthcare access as key spatial determinants. The positivity rate of malaria was higher among older children and anaemic children. Large family sizes, younger household heads, and rural residence were associated with a higher risk of malaria among children under five. In contrast, maternal education, better wealth index, and improved housing conditions were linked with a lower risk of malaria. These findings underscore the need for a more nuanced approach to malaria control that not only considers geographic stratification but also addresses underlying inequities in access to healthcare and socioeconomic disparities. Tailoring interventions to ensure that rural and low-income populations have access to effective malaria prevention, timely diagnosis, and treatment is pivotal. Policies should focus on reducing barriers to healthcare, enhancing educational opportunities for women and girls, and improving housing conditions for vulnerable households.

Supplementary Information

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Additional file 1.

Additional file 2.

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Author contributions
YA: Conceptualization, Data Curation, Visualization, Data Analysis, Methodology, Software, Writing the original draft, reviewing and editing the manuscript. SGN: Data Curation, Visualization, Data Analysis, Methodology, Software, reviewing and editing the manuscript. RET: Data Curation, Visualization, Data Analysis, and Methodology, Writing the original draft, reviewing and editing the manuscript. SAA: Data Curation, Visualization, Data Analysis, Methodology, Writing the original draft, reviewing and editing the manuscript. All authors have approved the final version of this manuscript.

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Availability of data and materials
The data used in this study are publicly available at https://dhsprogram.com/. The shape files of the map of Tanzania were freely accessible from the Tanzania National Bureau of Statistics at https://www.nbs.go.tz/tnada/index.php/home.

Declarations

Ethics approval and consent to participate
Ethical approval and participant consent were not applicable to this particular study since it was based on a secondary data analysis of publicly available survey data from the DHS program. However, permission for data access and use for this study was obtained from the DHS program through an online request at https://dhsprogram.com/. The authorization letter was also gained from the DHS Program.

Competing interests
The authors declare no competing interests.

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