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Socioeconomic health equity with malaria burden: quantifying slope (Relative) index of inequity in malaria infection outcomes in the Southeastern-coastal Tanzania

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Abstract

Background Malaria remains a significant public health challenge in Tanzania, with socioeconomic factors playing crucial roles in disease outcomes. While previous studies have explored the relationship between socioeconomic status and malaria infection, quantitative assessment of equity condition in malaria outcomes remains understudied. This study innovatively applies Slope Index of Inequality (SII) and Relative Index of Inequality (RII) to quantify the equity conditions between socioeconomics and malaria burden in three Districts located in the Southeastern coast of Tanzania.

Methods Data from the baseline survey of the China-Tanzania Demonstration Project on Malaria Control conducted in 2019 were analyzed. Key variables included: (1) socioeconomic status quantified through Principal Component Analysis incorporating household infrastructure, asset ownership, and social potential; (2) malaria infection outcomes, including blood test results, treatment costs, and days absent from work/education (days off). Logistic and linear regression analyses were performed to assess socioeconomic impacts, while SII and RII were calculated to measure health equity conditions across socioeconomic strata in three districts of Rufiji, Kilwa, and Kibiti.

Results Higher socioeconomic status was associated with a lower risk of malaria infection (OR = 0.9975, 95% CI: 0.9972–0.9978), lower treatment costs (coefficient = -3.13, $P < 0.05$), and fewer days off work (coefficient = -0.0017, $P < 0.05$). Rufiji district demonstrated the most significant socioeconomic equality in malaria infection risk (SII=-12.62%, 95%CI: -17.19% to -8.06%; RII = 1.28, 95%CI: 1.12 to 1.55), treatment cost (SII = 837.769, 95%CI: -1182.44 to -491.75; RII = 1.30, 95%CI: 1.09 to 1.63) and days off (SII=-0.46, 95%CI: -0.62 to -0.30; RII = 1.21, 95%CI: 1.05 to 1.46).

Conclusion The findings highlight significant socioeconomic disparities in malaria-related outcomes across the studied districts, emphasizing the need for targeted public health interventions to address inequities. By prioritizing equity-focused policies, such as enhanced access to prevention and treatment, Tanzania can make strides toward

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more inclusive malaria control and health system strengthening, particularly for the most vulnerable populations. Furthermore, the use of SII and RII offered a nuanced understanding of health disparities across the socioeconomic spectrum.

Keywords Malaria, Health equity, Socioeconomic factors, Tanzania, Slope index of inequality, Relative index of inequality

Introduction

Malaria remains a significant public health challenge in sub-Saharan Africa with an estimated 246 million cases and 569,000 deaths in 2023 [1]. While the health burden of malaria has been alleviated through international and regional governance over the past two decades, malaria prevention and control in the region have reached a bottleneck since 2015 amid substantial governance and socioeconomic challenges [2, 3]. Understanding the complex interplay of factors influencing malaria transmission and developing targeted interventions are crucial for achieving global malaria elimination goals.

In 2023, Tanzania ranked fourth globally in malaria mortality, with approximately 8.555 million malaria cases and 25,800 deaths [1]. From 2017 to 2023, the malaria mortality rate declined by 13%, from 61.1 to 52.4 cases per 100,000 population [1]. However, the declines have not been observed everywhere and resulting in an interesting malaria epidemiological diversity. Malaria transmission is persistently intense in the Lake Zone (upper northwest) and coastal belt (east and south), with prevalence ranging from 20% to more than 40%. The Central Plateau of the country experiences seasonal malaria transmission, with prevalence between 5% and 20%. The Northern highlands have a pattern of low or seasonal transmission (less than three months per year) and a prevalence of less than 5% [4, 5]. The underlying drivers for these regional variations remain unclear.

Due to the diversity that has been reported to exist at the level of the household and the individual, it is necessary to expand beyond the sub-national level stratification by investigating the underlying dynamics of malaria risk factors at a high resolution to enhance evidence-based decision making and resource allocation for more effective malaria control strategies based on the established. Emerging challenges in Tanzania's malaria landscape also raise significant attention on the infection outcomes, including the labor lost, treatment cost, as well as health disparities among different regions and populations [6–9]. These challenges necessitate a deeper understanding of the socioeconomic factors influencing malaria infection and the development of tailored interventions to address persistent and emerging threats.

The relationship between malaria infection and socioeconomic factors has been the subject of extensive research. A systematic review by Degarege, et al. [10] found that individuals living in poor-quality houses, with lower education levels, and engaged in farming occupations had significantly higher odds of *Plasmodium* infection. Taylor, et al. [11] also applied analyses to show disparities in insecticide-treated net ownership across socioeconomic strata. Additionally, Sumari et al. [12]found significant differences in malaria knowledge, attitude, and practices among primary school children in Tanzania, highlighting the need for health education equity. Tusting, et al. [13]also demonstrated through a systematic review that socioeconomic development can be an effective intervention against malaria, emphasizing the importance of addressing broader determinants of health. In the Tanzania context, Dickinson, et al. [14] found the association between poverty and malaria infection, evidencing that a lower socioeconomic condition would lead to negative consequences in malaria prevention, control, and treatment. Additionally, original research by Somi, et al. [15]found that family income acted as a significant barrier to malaria treatment, and families with lower socioeconomic status suffer a higher share of spending for malaria treatment. This body of work has significantly contributed to our understanding of malaria epidemiology and control, while also revealing important gaps in knowledge.

Even though the relationship between socioeconomic status and malaria is well recognized, and socioeconomic equity has been widely described, the relationship between socioeconomic equity and malaria infection has not been specifically researched. This insufficiency of evidence and consideration limits approaches for further malaria control on a global scale. More context-focused research is necessary to address the latest malaria control challenges of transmission from a social equity perspective, particularly in high-transmission settings like Tanzania.

To address these gaps and gain a more comprehensive understanding of socioeconomic disparities in malaria outcomes, the use of measures of health equity, such as the Slope Index of Inequality (SII) and Relative Index of Inequality (RII), offers several advantages. Unlike simple comparisons between extreme groups, SII and RII take into account the entire socioeconomic distribution, providing a more complete picture of the equity condition across the population of different classes [16]. While SII provides an absolute measure of inequality (the difference between the hypothetically most and least advantaged individuals), RII offers a relative measure (the ratio

between these extremes) [17]. These indices are relative measures that account for differences in the size of socioeconomic groups, allowing for valid comparisons across different populations or periods, and have been adopted in cancer, oral health equity issues in Europe and North America [18–20]. SII and RII are also sensitive to changes in the distribution of health outcomes across socioeconomic strata, making them valuable tools for monitoring progress in reducing health inequities over time [21]. This comprehensive approach is particularly important in the Tanzanian context, where diverse socioeconomic landscapes and varying malaria transmission intensities across regions necessitate tools that can capture subtle gradients in malaria risk.

Additionally, employing SII and RII in malaria research in Tanzania can provide valuable insights and contribute to more effective, equity-focused malaria control strategies. These indices can reveal inequities that might be missed by cruder measures, informing more targeted interventions [22]. As Tanzania strives to achieve its malaria elimination goals, tracking progress in reducing socioeconomic disparities in malaria outcomes becomes crucial. These indices can also help elucidate the complex relationships between malaria and various socioeconomic factors, supporting an intersectoral approach to malaria control that addresses broader determinants of health [23].

Furthermore, SII and RII facilitate valid comparisons of malaria-related inequities across different regions of Tanzania, helping to identify areas where disparities are most pronounced and informing the allocation of resources [24]. This comprehensive approach to measuring and analyzing health inequalities is crucial for developing evidence-based, equity-focused strategies to accelerate progress towards malaria elimination in Tanzania.

In light of these considerations, this study aims to address two key research questions:

1. How do socioeconomic factors (wealth, education, housing) influence malaria infection risk, treatment costs, and productivity loss in southeastern Tanzania?
2. What are the differences in health equity of malaria infection outcomes among different regions (Rufiji, Kilwa, and Kibiti) in Southeastern Tanzania?

By employing SII and RII analyses, this research seeks to provide a novelly nuanced understanding of the socioeconomic disparities in malaria outcomes across different regions of Tanzania. The findings will contribute to the development of targeted, equity-focused interventions and inform policy decisions aimed at reducing the burden of malaria in the region.

Methodology

Data and research background

This was a secondary data analysis study from the cross-sectional household survey of China-Tanzania Demonstration Project on Malaria Control conducted from July to September 2019 in three districts of Kilwa, Rufiji, and Kibiti in southeastern coastal Tanzania [25, 26]. Description of study area and objectives has been described in other peer-reviewed publications [27, 28], where a 1,7-mRCTR malaria surveillance and control project was implemented. Briefly, malaria control activities in Rufiji, Kibiti, and Kilwa districts are implemented through an integrated approach coordinated by the National Malaria Control Programme and local health authorities. Core interventions focus on vector control, including universal coverage with insecticides treated bednets through mass and continuous distribution channels. Case management is strengthened through routine use of rapid diagnostic tests or microscopy and prompt treatment of confirmed cases with artemisinin-based combination therapies. Intermittent preventive treatment in pregnancy is provided through antenatal care services. Surveillance is conducted through routine reporting in the District Health Information System (DHIS2), complemented by community-based surveillance and outbreak investigation when case increases occur. Community engagement supports these efforts by promoting ITNs use, early care seeking, and participation in vector control activities. This study utilized the dataset from the project, which covered 185,000 people in the intervention areas and 40,000 in the control areas by deploying a stratified sampling approach. Within the project region of Kilwa, Rufiji, and Kibiti, the project team at first randomly selected wards, villages, and households, and then identified participants within these households [29]. The household surveys conducted in the project were developed following the structure of the Malaria Indicator Survey Tool [30] customized to the context of the study area. These survey firstly collected blood samples from individual participants with their consent for malaria infection diagnosis; then collected comprehensive data on various aspects, including asset ownership, which could help derive the socio-economic conditions of households, knowledge and adherence to malaria preventative measures, healthcare expenditures, utilization of medical services, and travel history. Considering the capacity of local health infrastructure, 10% follow-up slots were offered to the participants for their continued access to malaria infection treatment and healthcare. Demographic details of the participants are in Table 1.

Table 1 Demographic details of the participants in China-Tanzania demonstration project on malaria control

Demographic Categories	Specific	Whole Numbers (%)	Whole Malaria Positive Cases (%)	Rufiji Numbers (%)	Rufiji Malaria Positive Cases (%)	Kibiti Numbers (%)	Kibiti Malaria Positive Cases (%)	Kilwa Numbers (%)	Kilwa Malaria Positive Cases (%)
Gender	Male	8267 (72.48%)	2282 (27.6%)	1694 (74.66%)	155 (9.15%)	1932 (71.56%)	638 (33.02%)	4641 (72.1%)	1489 (32.08%)
	Female	3139 (27.52%)	819 (26.09%)	575 (25.34%)	41 (7.13%)	768 (28.44%)	237 (30.86%)	1796 (27.9%)	541 (30.12%)
Age (Year)	Younger than 17	5737 (50.3%)	2092 (36.47%)	1150 (50.68%)	126 (10.96%)	1546 (57.26%)	632 (40.88%)	3041 (47.24%)	1334 (43.87%)
	17 to 64	4966 (43.54%)	914 (18.41%)	927 (40.86%)	60 (6.47%)	1042 (38.59%)	228 (21.88%)	2997 (46.56%)	626 (20.89%)
	Older than 64	703 (6.16%)	95 (13.51%)	192 (8.46%)	10 (5.21%)	112 (4.15%)	15 (13.39%)	399 (6.2%)	70 (17.54%)
Education	No education received	5847 (51.26%)	1638 (28.01%)	1131 (49.85%)	94 (8.31%)	1380 (51.11%)	434 (31.45%)	3336 (51.83%)	1110 (33.27%)
	Primary school	5068 (44.43%)	1388 (27.39%)	1036 (45.66%)	100 (9.65%)	1212 (44.89%)	418 (34.49%)	2820 (43.81%)	870 (30.85%)
	Secondary school and higher	491 (4.3%)	75 (15.27%)	102 (4.5%)	2 (1.96%)	108 (4.0%)	23 (21.3%)	281 (4.37%)	50 (17.79%)
Income Source	No income or receives donations	388 (3.4%)	80 (20.62%)	80 (3.53%)	4 (5.0%)	125 (4.63%)	31 (24.8%)	183 (2.84%)	45 (24.59%)
	By other method or casual labor	107 (0.94%)	20 (18.69%)	28 (1.23%)	1 (3.57%)	26 (0.96%)	8 (30.77%)	53 (0.82%)	11 (20.75%)
	By agriculture (fishing, farming, livestock keeping)	8797 (77.13%)	2548 (28.96%)	1636 (72.1%)	157 (9.6%)	2016 (74.67%)	665 (32.99%)	5145 (79.93%)	1726 (33.55%)
	By industries or commercial (skilled labor, driver, salary, business, pension)	2114 (18.53%)	453 (21.43%)	525 (23.14%)	34 (6.48%)	533 (19.74%)	171 (32.08%)	1056 (16.41%)	248 (23.48%)
Total		11,406 (100.00%)	3101 (27.19%)	2269 (100.00%)	196 (8.64%)	2700 (100.00%)	875 (32.41%)	6437 (100.00%)	2030 (31.54%)

Independent variables: quantifying local socioeconomical fact

As the data collected for socioeconomic factors are qualified, we used Primary Component Analysis (PCA) to quantify the participants' socioeconomic conditions and transform them into continuous variables. The PCA output is presented in Appendix 1. In this study, the system measured the participant's socioeconomic condition from three perspectives: (1) Household Infrastructure; (2) Ownership and Property, and (3) Social Potential. The inclusion of the perspectives was with the consideration of the household's current status, property ownership of items indicating wealth situation, as well as the household's socioeconomic sustainability in maintenance and promotion. The method of variable inclusion and exclusion was adjusted from studies by Filmer and Pritchett [31] and Schellenberg et al. [32], where tangible belongings (item ownerships) and intangible features (occupation, education, etc.) were selected, as these variables presented significant associations with socioeconomic status.

The PCA generated weights objectively from the dataset, ensuring the resulting socioeconomic score reflects the asset-based wealth structure of the 2019 study population itself, rather than relying on external or subjective benchmarks. The PCA weighting methods for socioeconomic status have been applied by studies by Vyas and Kumaranayake [33], Houweling et al. [34], and McKenzie [35] in rural areas in Brazil and Ethiopia, where it was proven to be valuable in practical guidance with a reference range of proportion of variance value from 12% to 27% and eigenvalue from 2.2 to 4. The PCA output in this study showed a proportion of variance of 12.56% and an eigenvalue of 6.404, with acceptance for adoption and representativeness capturing the participant's socioeconomic facts [36].

By applying PCA, each participant was given a "Score" to estimate their socioeconomic condition according to the weighting criteria (Appendix 1). Table 2 presented the distribution of the PCA scores, including the mean (100.78), standard deviation (132.35), and total sample size (11,406, 100%) of score, with regional data for Rufiji (116.14, 148.72; 2,269, 19.89%), Kibiti (129.92, 121.64; 2,700, 23.67%), and Kilwa (83.15, 127.64; 6,437, 56.44%). A higher score refers to a higher socioeconomic condition with better household construction, decoration,

Table 2 Distribution of scores by PCA analysis in whole study region, Rufiji district, Kibiti district, and Kilwa district

	Score		*n* (%)
	mean	sd	
Whole	100.78	132.35	11,406(100%)
Rufiji	116.14	148.72	2269 (19.89%)
Kibiti	129.92	121.64	2700 (23.67%)
Kilwa	83.15	127.64	6437 (56.44%)

sd Standard deviation, *n* Number in total

richer ownership of assets, and more socioeconomic potential for higher social classes. Unidentified socioeconomic characteristics and missing values were assigned as "other" in their following categories.

Dependent variables: selection and data cleaning

Dependent variables related to malaria infection outcomes were selected as (1) mRDTs blood test for malaria infection (binary: positive/negative), (2) Total cost for malaria infection treatment (continuous, Tanzania Shilling), and (3) Total days absent from work or education caused by malaria infection (continuous, day). Dependent variable distribution is as Table 3, showing dependent variables for 11,406 samples, where Rufiji has the lowest malaria positive rate (8.64%), while Kilwa shows higher treatment cost (mean 2437.52) and days off (1.21) across regions.

There was no missing value in blood test diagnosis. For missing values shown in total cost, as the total cost was summed by: (a) clinical registration fee, (b) clinical consultation fee, (c) medicine purchase fee, (d) clinical infection test fee, and (e) clinical admission fee. Missing value occurred in the subcategory and was replaced by the mean value of the subcategory; for those with negative malaria blood test outcome, missing value for total cost was replaced by zero. Missing values presented in days absent were replaced by mean value; for those with negative malaria blood test outcome, missing value was replaced by zero.

Data analysis I: socioeconomic status to malaria infection outcomes

The data analysis was performed via R (version 4.3.3) with "PHEindicatormethods" package [37]. Based on the socioeconomic score (continuous) quantified by the PCA method, logistic regression was first applied to learn the socioeconomic status's impact on the malaria infection diagnosis outcomes. Linear regression was then performed to estimate the impact of the socioeconomic scores on the total cost and work/education days absent caused by the infection. Both logistic regression and linear regression were performed four times, respectively, for (1) The whole studied area, (2) Rufiji area, (3) Kilwa area, and (4) Rufiji area.

Data analysis II: equity in malaria infection outcomes

The SII and RII were adopted to equity conditions of malaria infection outcomes (infection rate, treatment spent, and absent days) across different areas. Both approaches are essential for assessing the magnitude of health disparities within a population. By using SII and RII, it is possible to compare disparities across various populations for outcomes related to disease infection and treatment. Adjusted from linear regression, SII can capture absolute change of health outcomes across different population groups, while RII can capture the relative rate of health outcomes over different population groups. According to the Eqs. [38–40]:

$$SII = \frac{\sum_{j=1}^{J} p_j R_j (\mu_j - \mu)}{\sum_{j=1}^{J} p_j - \left(\sum_{j-1}^{J} p_j R_j\right)^2}$$

$$RII = \frac{SII}{\mu}$$

Where μ_j refers to the average health condition (outcome) of the socioeconomic population group j, p_j refers to the population size of the group j, $R_j = \sum_{\gamma}^{j-1} - 0.5p_j$ referring to the Relative Rank of the population group j, and $\mu = \sum_{j=1}^{J} p_j \mu_j$, referring to the average health condition (outcome) of the whole socioeconomic population [38–40].

Transformed into the case of analysis:

$$SII = \frac{\sum_{Low}^{High} Population_{Low} RelativeRank_{Low} (Outcome_{Low} - Outcome_{Average})}{\sum_{Low}^{High} Population_{Low} RelativeRank_{Low}^2 - \left(\sum_{Low}^{High} Population_{Low} Rank_{Low}\right)^2}$$

Table 3 Distribution of dependent variables: malaria positive, treatment cost, and days absent from labor or education caused by infection

	Malaria positive rate	Treatment cost		Days off		*n* (%)
		mean	sd	mean	sd	
Whole	27.19%	2066.68	4550.1	1.04	1.7	11,406(100%)
Rufiji	8.64%	713.51	2234.3	0.34	1.09	2269 (19.89%)
Kibiti	32.41%	2319.72	3484.19	1.24	1.79	2700 (23.67%)
Kilwa	31.54%	2437.52	5387.74	1.21	1.78	6437 (56.44%)

sd Standard deviation, *n* Number in total

$$RII = \frac{SII}{Outcome_{Average}}$$

It requires a series of pre-defined variables as follows:

1. Groups of the population ranked by socioeconomic conditions ($\sum_{Low}^{High} Population_{Low} RelativeRank_{Low}$). Required by the formula and SII, RII application in the existing literature evidence [17, 39, 41, 42], we grouped the population by a quintile cut of the socioeconomic score distribution: [-133,23.8], (23.8,180], (180,337], (337,493], (493,650].
2. Respective population size of the each groups ($\sum_{Low}^{High} Population_{Low}$).
3. Respective infection outcomes of the groups ($Outcome_{Low} - Outcome_{Average}$). In this case, the outcomes were a. blood test positive rate, b. total cost, and c. days-off.

Both SII and RII analyses were respectively performed four times for one whole studied area and three mentioned districts. To interpret SII result, although the population and dependent variable are categorized into five groups, SII and RII, according to the aforementioned formula, do not produce five separate results based on the variable grouping; instead, the five-group stratification yields only a single SII outcome and a single RII outcome. The single outcome refers to the health outcomes difference between the most privileged population group and the most impoverished population group. A SII outcome value near zero means a better health equity condition, where the richest population (socioeconomic score between 493 and 650) presents no difference in malaria infection risks, treatment cost, and days-off compared to the poorest population (socioeconomic score between – 133 and 23.8); vice versa. A RII result near to one means a better health equity condition; vice versa.

Result

Equity in malaria infection

Based on the logistic regression, SII, and RII analyses (Fig. 1), the Rufiji area exhibited the most equitable distribution, with the lowest odds ratio, an SII closest to 0, and an RII closest to 1. An odds ratio of 0.9965 (95% CI: 0.9952–0.9977) indicates that each score increase in socioeconomics reduces the risk of malaria infection by 0.35%. In Rufiji, socioeconomic improvement had the most significant impact on risk reduction compared to other districts.

In Rufiji, the SII was – 12.62% (95% CI: -17.19% to -8.06%), indicating that the wealthiest group had a 12.62% lower malaria infection risk compared to the poorest group. The RII was 1.28 (95% CI: 1.12 to 1.55), showing that the poorest group had a 1.28-fold higher malaria infection risk relative to the wealthiest group. In Kibiti and Kilwa, malaria infection risk outcomes were worse than in Rufiji, with odds ratios of 0.9979 (95% CI: 0.9971–0.9985) and 0.9975 (95% CI: 0.9969–0.9978), respectively. These values, closer to 1 than Rufiji's, indicate minimal reductions in infection risk associated with socioeconomic improvements. Kilwa exhibited the largest socioeconomic disparities in malaria infection risk among the studied districts, with an SII of -22.66% (95% CI: -26.79% to -18.50%), indicating a 22.66% lower risk for the wealthiest compared to the poorest, and an RII of 1.80 (95% CI: 1.62–2.05), showing the poorest had a 1.80-fold higher risk than the wealthiest. Kibiti displayed similar disparities, aligning with regional trends.

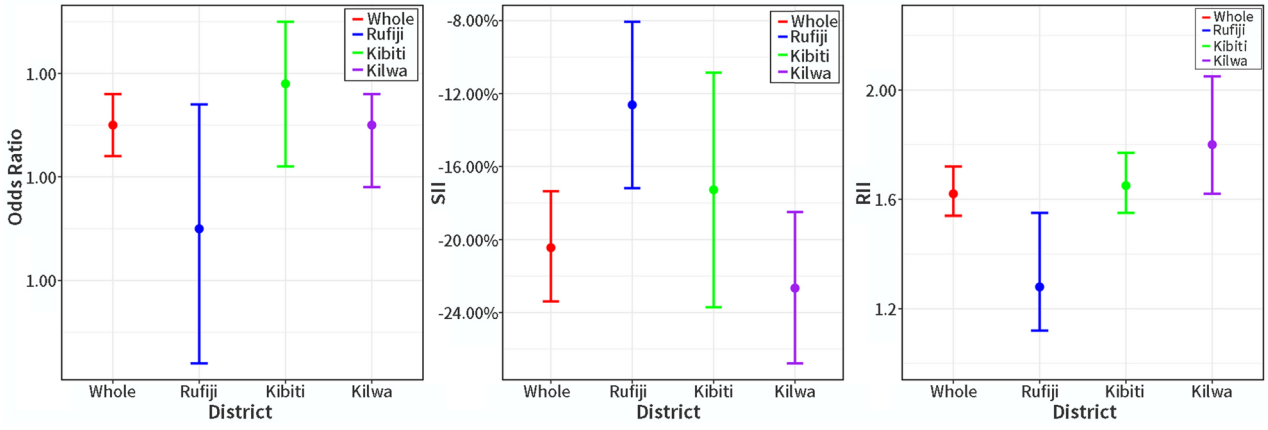

Fig. 1 Analysis outcomes of malaria infection risk in logistic regression, SII, and RII statistics among the whole studied area, Rufiji, Kibiti, and Kilwa with 95% confidence interval ($n = 11406$)

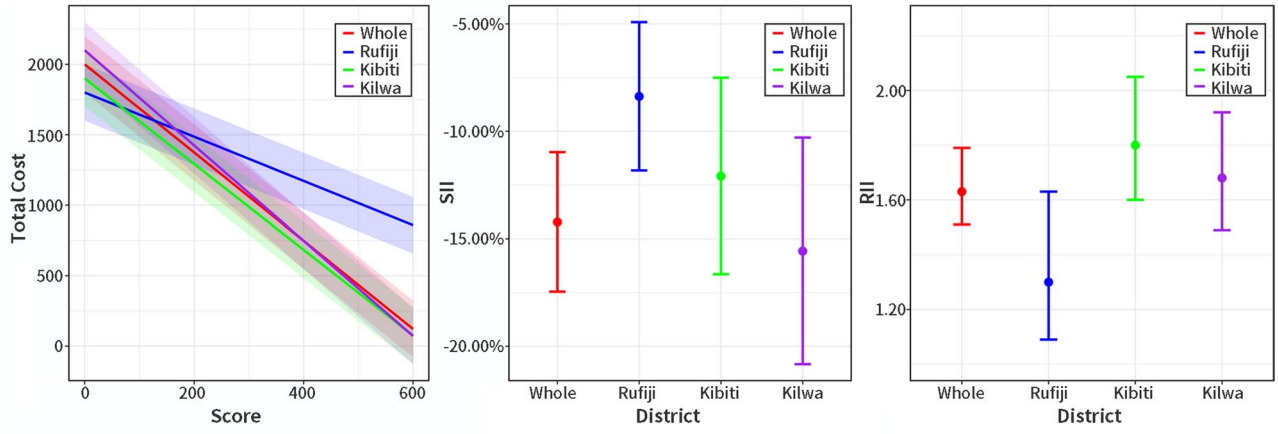

Fig. 2 Analysis outcomes of malaria treatment cost in linear regression, SII, and RII statistics among the whole studied area, Rufiji, Kibiti, and Kilwa with 95% confidence interval ($n = 11406$)

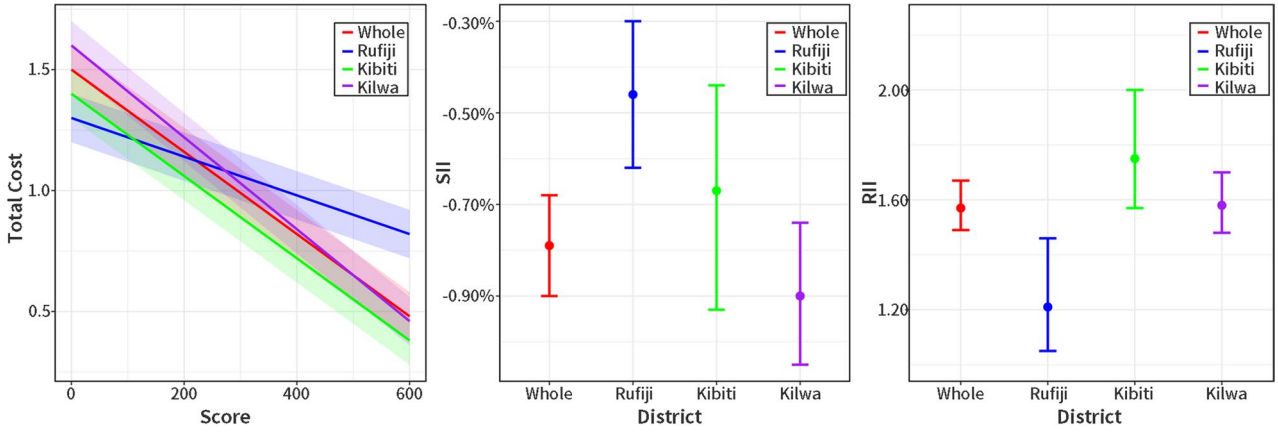

Fig. 3 Analysis outcomes of days absent from education or work due to malaria infection in linear regression, SII, and RII statistics among the whole studied area, Rufiji, Kibiti, and Kilwa with 95% confidence interval ($n = 11406$)

Equity in total treatment cost

Figure 2 showed that total treatment cost outcomes reflect a similar equity pattern to malaria infection risk. Rufiji district exhibited the most equitable distribution of malaria treatment costs, with the smallest change in expenditure per socioeconomic score increase (-3.13, $P < 0.05$). The SII was – 837.769 TZS (95% CI: -1182.44 to -491.75), indicating that the wealthiest population spent approximately 838 Tanzanian Shillings less on malaria treatment than the poorest. The RII was 1.30 (95% CI: 1.09–1.63), showing that treatment costs for the poorest were 1.30 times higher than for the richest. Kibiti and Kilwa exhibited greater treatment cost inequities compared to Rufiji. In Kibiti, the poorest population incurred treatment costs 1.80 times higher than the wealthiest (RII: 1.80, 95% CI: 1.60–2.05). In Kilwa, the poorest spent approximately 1557 Tanzanian Shillings more than the wealthiest (SII: -1556.91, 95% CI: -2083.58 to -1029.32).

Equity in days absent from work or education

Figure 3 presented linear regression, SII, and RII analyses for days absent from work or education due to malaria infection, revealing equity patterns across the studied areas. Rufiji demonstrated the most equitable outcomes, with the lowest regression coefficient (-0.0008, $P < 0.05$), an SII of -0.46 (95% CI: -0.62 to -0.30), and an RII of 1.21 (95% CI: 1.05–1.46). These indicate minimal impact of socioeconomic status on absenteeism, with the wealthiest in Rufiji spending 0.46 fewer days absent than the poorest, and the poorest experiencing 1.21 times higher absenteeism than the richest. In contrast, Kibiti and Kilwa showed greater inequities. In Kibiti, the poorest population's absenteeism was 1.75 times higher than the richest (RII: 1.75, 95% CI: 1.57–2.00), reflecting the largest relative disparity. In Kilwa, the wealthiest spent 0.90 fewer days absent compared to the poorest (SII: -0.90, 95% CI: -1.05 to -0.74).

Discussion

Major findings

This study examines socioeconomic disparities in malaria infection risk, treatment costs, and days absent from work or education across Rufiji, Kibiti, and Kilwa districts in Tanzania, utilizing logistic and linear regression alongside SII and RII analyses. The findings offer valuable insights into health and economic equity patterns, providing a foundation for public health policy and targeted interventions to address malaria-related disparities.

Infection risk equity

The analysis of malaria infection risk highlights variations in equity across the studied districts, with differences in how socioeconomic status influences infection likelihood. These variations likely stem from differences in access to preventive measures, such as insecticide-treated nets, health education, or healthcare infrastructure. Districts with greater inequities may face structural challenges, including limited healthcare access or socioeconomic barriers that disproportionately affect the poorest populations. These findings align with prior research indicating that socioeconomic factors, such as poverty and access to preventive tools, significantly influence malaria incidence [1, 13]. The regional differences highlighted the micro need for tailored interventions that consider local socioeconomic contexts, and echoing calls for macro implementation approaches in malaria control interventions, considering as well and covering different places as a whole [1, 42, 43].

Treatment cost equity

The examination of malaria treatment costs reveals parallel equity patterns to infection risk, with variations in financial burdens across socioeconomic groups. Districts with more equitable cost distributions likely benefit from better healthcare infrastructure, subsidized treatment programs, or improved access to facilities, which alleviate financial strain on lower-income populations. In contrast, areas with higher cost disparities may reflect barriers such as distant healthcare facilities, out-of-pocket expenses, or limited subsidy programs. These observations are consistent with studies highlighting the economic burden of malaria on low-income households, particularly in areas with limited healthcare access [44]. The community-based malaria control programs, including health education and health workforce integration that reach across socioeconomic strata, have been witnessed with feasibility to transform in other regional settings [25, 26, 45]. With Rufiji's reference, further malaria control implementations, accessibility construction, local health education, as well as community engagement could be applied to improve equity issues regarding malaria infection in other malaria endemic regions.

Work and education absenteeism equity

The analysis of absenteeism due to malaria further illustrates socioeconomic disparities in the broader impacts of the disease. Districts with more equitable outcomes likely benefit from effective disease management or support systems that minimize disruptions to work and education across socioeconomic groups. In contrast, areas with greater inequities may experience prolonged illness among the poorest, possibly due to delayed treatment or inadequate healthcare access, leading to increased absenteeism. These findings resonate with research showing that malaria significantly affects productivity and educational outcomes, particularly among low-income populations [46]. Interventions such as workplace or school-based health programs could help reduce these disparities by ensuring timely treatment and support for affected individuals [47].

Comparison with prior studies

These findings are consistent with existing evidence indicating that socioeconomic inequalities shape malaria infection risk, cost, and productivity outcomes. Prior studies have also reported that districts with stronger healthcare systems and better preventive resource distribution experience lower disparities in malaria outcomes [10, 13, 44]. Notably, our results further contextualize these inequalities by highlighting the critical role of structural access barriers in remote, underserved regions—an aspect that has been less emphasized in previous research. Specifically, in the southeastern coastal areas of Tanzania targeted by our study, inadequate health infrastructure and limited connectivity have hindered the reach of donor-supported free malaria interventions to marginalized low-income populations [48]. This aligns with qualitative evidence from the same China-Tanzania malaria cooperation framework, which documented that poor communities in these remote regions often face unaffordable treatment costs and resort to ineffective traditional remedies due to limited access to formal free services—ultimately leading to higher economic burdens and prolonged work absences [48]. However, compared with previous research that focused on single outcome dimensions, this study contributes a multidimensional assessment combining infection, cost, and absenteeism indicators under SII and RII frameworks, providing a more comprehensive evaluation of malaria-related equity.

Hypothesis: low burden and high equity

As previous academic efforts evidenced that Rufiji area experienced more malaria control programs with lower malaria health burden than other two regions [49–51], and Rufiji place presented the equitable condition for malaria infection outcomes in this study, we are hinted

that whether there would be a statistical significance of relationship between "malaria burden" and "infection equity conditions." Theoretically, for a region with a lower malaria health burden, there would be better infection outcome equity conditions. This hypothesis may also be generalized to other health issues. Sufficient studies were found focusing on equity conditions, while limited academic work was found focusing on learning the causation between health equity and disease burdens from a public health view [41, 43, 52]. Further academic devotion and research output of this aspect are highly essential. Evidence for the hinted hypothesis may provide critically important guidelines for malaria control and social justice for policymaking and public health implementations. Importantly, to address these inequities, policies should prioritize expanding access to affordable or free treatment and improving healthcare infrastructure in underserved areas [53].

Rufiji case: Understanding high equity

Based on the comprehensive analysis of malaria infection outcomes across the studied areas, Rufiji district consistently emerges as the district with the most equitable condition for malaria infection risk, malaria treatment cost, and days absent from education or work due to malaria infection.

Firstly, Rufiji demonstrated the strongest reduction in malaria infection risk with each unit increase in socioeconomic score, showing a 0.35% decrease per score. It also had the smallest variation in infection risk across socioeconomic levels, as indicated by the lowest SII value of − 12.62% and an RII of 1.28. Secondly, Rufiji exhibited the weakest association between socioeconomic improvement and treatment cost, with a reduction of only 1.57 Tanzanian shillings per socioeconomic score, an SII of − 837.77, and an RII of 0.26—together reflecting the narrowest gap between socioeconomic extremes. Thirdly, socioeconomic status had the least influence on days lost from work or education in Rufiji, where the regression coefficient was − 0.0008, the SII reached − 0.46, and the RII remained at 0.19. This pattern of equitable health outcomes has been observed in other public health interventions [54].

The equitable outcomes in Rufiji suggested by its lower SII/RII values were possibly linked to documented interventions. Firstly, malaria control project by Khatib, et al. [49] implemented the distribution of insecticide-treated nets and indoor residual spraying across socioeconomic groups. The distribution of the equipment with sufficient coverage of different socioeconomic groups led to a decreased inequity of family spend for malaria prevention and a lowered risk for malaria infection [55]. Secondly, the 1,7-mRCTR malaria programs conducted in Rufiji by Mlacha, et al. [28] focused on the local health service accessibility by mobilizing local clinics and health workers to provide prompt diagnosis and treatment in less than one day. The implementation of providing accessible health services in developing regions has been identified as a crucial factor in reducing health inequities [56]. Thirdly, community education engagement also played a significant role in Rufiji's equity for malaria infection outcomes. Education program conducted in Rufiji by Mosha, et al. [57] for local female and children's health led to a higher blood and pregnant awareness, ending up with further focus on malaria prevention and treatment for women and children with lower socioeconomic conditions.

Policy implications

The observed variations in equity across the districts suggest that successful strategies in the most equitable areas could serve as models for others. Policymakers should investigate factors such as healthcare access, community health initiatives, or socioeconomic support systems that contribute to equitable outcomes. Targeted interventions, including equitable distribution of preventive resources, subsidized treatments, and health education, are essential to reducing disparities in less equitable districts. Addressing structural determinants, such as poverty and healthcare accessibility, will be critical to achieving health equity in malaria control [58].

Based on these findings, we propose several recommendations to improve equity in malaria control: implementing targeted interventions for vulnerable socioeconomic groups, particularly in high-inequity areas like Kilwa and Kibiti; improving housing conditions for the poorest households; enhancing malaria education programs across all socioeconomic levels; improving access to affordable malaria diagnosis and treatment services; strengthening community-based malaria control programs; promoting intersectoral collaboration to address broader socioeconomic determinants of malaria risk; implementing regular monitoring of malaria equity indicators using tools; and conducting in-depth studies of areas achieving high equity, like Rufiji, to identify transferable strategies. By addressing these recommendations, Tanzania can work towards more equitable malaria outcomes, contributing to the broader goal of malaria elimination while ensuring that the benefits of control efforts reach all segments of the population. From an academic and research advocacy perspective, the use of SII and RII as quantitative measures of health inequality should be further promoted in other endemic contexts, such as schistosomiasis and neglected tropical diseases (NTDs). These indices provide valuable insights into how disease burdens are distributed across socioeconomic strata, particularly among impoverished and marginalized populations. Expanding their application could enhance the

visibility of health inequities within NTD programs and guide the allocation of resources toward achieving more equitable disease elimination.

Limitations

This study is constrained by its focus on three districts, which may not fully represent broader regional or national trends. The cross-sectional design of our study captures a snapshot in time and cannot establish long-term relationships between socioeconomic factors and malaria outcomes. Longitudinal studies could provide deeper insights into the causal relationships between socioeconomic status and malaria outcomes, informing more effective policy strategies [59].

Additionally, the SII and RII used in this study highly relied on the continuous independent variables, which posed a strict requirement in data formatting. The transformation from original categorical data to continuous score data by PCA lead to an unavailable information loss. As the consequence, the PCA presented a proportion of variance of 12.56%. Although this proportion stands with practical value for statistics and estimation, it is not adequately high to completely represent the socioeconomic factor's influence on malaria infection outcomes and equity conditions [33–35, 60]. Further malaria control projects with more specific socioeconomic-focused survey design, as well as more comprehensive statistical model design, may help the PCA with better practical values. Furthermore, some variables, such as time absent from work or education, relied on self-reporting, which may be subject to recall bias, which may have affected the precision of our estimates [60]. Further cohort study based on continuous surveillance and follow-up focusing on the participants' socioeconomic status and malaria infection equity may provide a comprehensive vision for exact measurement.

Another limitation relates to the lack of species-specific data on malaria infections. The diagnostic tools employed in the project could detect Plasmodium falciparum specifically and pan-malaria (non-species-specific infection), but detailed species identification (e.g., distinguishing *P. falciparum* from *P. vivax*) was not recorded in the study database. This prevented us from analyzing the malaria species separately, despite their well-documented epidemiological differences (e.g., transmission dynamics, clinical manifestations, and response to interventions). Combining *P. falciparum* and *P. vivax* in our analyses may have obscured species-specific patterns in socioeconomic inequities, limiting our ability to capture nuanced relationships between socioeconomic status and malaria outcomes for each species.

Unmeasured confounders may influence malaria outcomes beyond the socioeconomic factors assessed in our study. For example, behavioral patterns, seasonal variations in malaria transmission, and differences in healthcare quality were not included in our analysis. These factors, potentially linked to socioeconomic conditions, could affect malaria susceptibility but were not accounted for in our study [45, 56, 60]. To address these unmeasured confounders, future studies could incorporate detailed behavioral surveys, longitudinal data on seasonal transmission patterns, and standardized assessments of healthcare quality to better quantify their impact on malaria outcomes. Also, the coverage of study areas may not be representative of all of Tanzania or other East African countries. The generalizability of our findings to other regions with different socioeconomic profiles and malaria transmission patterns should be considered with strong caution [61]. These limitations align with challenges noted in similar studies [62]. Future research should explore these factors and evaluate the effectiveness of specific interventions in reducing inequities.

Conclusion

This study quantifies socioeconomic disparities in malaria-related outcomes across districts in Southeastern Tanzania, highlighting the critical need for targeted public health interventions to address health inequities. Our findings reveal a clear inverse correlation between malaria burden and health equity: districts with lower malaria prevalence exhibit higher socioeconomic health equity. Notably, the Rufiji district demonstrates a successful model, achieving both low malaria burden and high health equity, offering actionable insights for designing interventions in high-burden regions. These results emphasize the necessity of integrating strategies to reduce malaria prevalence with efforts to mitigate socioeconomic disparities, ensuring equitable and effective malaria control policies.

Abbreviations

CI	Confidence Interval
DHIS2	District Health Information System 2
ITNs	Insecticide-Treated Nets
mRCTR	malaria Reactive Community-Based Testing and Response
mRDTs	Malaria Rapid Diagnostic Tests
NTDs	Neglected Tropical Diseases
OR	Odds Ratio
PCA	Principal Component Analysis
RII	Relative Index of Inequality
SII	Slope Index of Inequality
SES	Socioeconomic Status
TZS	Tanzanian Shillings

Supplementary Information

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Supplementary Material 1.

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Authors' contributions
Dr XNZ, and Dr SA conceived and designed the project. Dr DQW and Dr YPM designed and implemented the project. LSL drafted the manuscript. Dr YPM and Dr DQW provided further revisions. LSL performed the statistical analysis of the study, and all the other authors implemented the study and reviewed the manuscript. All authors read and approved the final manuscript.

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Data availability
For data request, please contact corresponding author Dr Duoquan Wang: wangdq@nipd.chinacdc.cn and Dr. Yeromin P. Mlacha ymlacha@ihi.or.tz. Original data including local sensitive private information will be deleted. Data requested will only be permitted for science research.

Declarations

Ethics approval and consent to participate
This study used secondary data from previous academic efforts. This study did not collect any data from human participants. The China-Tanzania Demonstration Project on Malaria Control was conducted with approval number NIMR/HQ/R.8a/Vol.IX/2005 by The Medical Research Coordination Committee of the National Institute for Medical Research, 201,505 by Chinese Centre for Disease Control, IHI/IRB/No: 18-2015 by the Ifakara Health Institute Institutional Review Board, and NIMR/HQ/R.8c/Vol. II/865 for ethical permission extension.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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