Measuring socioeconomic inequalities in relation to malaria risk: a comparison of metrics in rural Uganda

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Abstract

Socioeconomic position (SEP) is an important risk factor for malaria, but there is no consensus on how to measure SEP in malaria studies. We evaluated the relative strength of four indicators of SEP in predicting malaria risk in Nagongera, Uganda. 318 children resident in 100 households were followed for 36 months to measure parasite prevalence routinely every three months and malaria incidence by passive case detection. Household SEP was determined using: (1) two wealth indices, (2) income, (3) occupation and (4) education. Wealth Index I (reference) included only asset ownership variables. Wealth Index II additionally included food security and house construction variables, which may directly affect malaria. In multivariate analysis, only Wealth Index II and income were associated with the human biting rate, only Wealth Indices I and II were associated with parasite prevalence and only caregiver's education was associated with malaria incidence. This is the first evaluation of metrics beyond wealth and consumption indices for measuring the association between SEP and malaria. The wealth index still predicted malaria risk after excluding variables directly associated with malaria, but the strength of association was lower. In this setting, wealth indices, income and education were stronger predictors of socioeconomic differences in malaria risk than occupation.

Introduction

Malaria is closely associated with poverty, with the odds of malaria infection doubled on average in the poorest children within a community compared with the least poor.[1] Measuring socioeconomic position (SEP), the suite of social and economic factors that determine the position held by individuals and groups within a society,[2, 3] is therefore critical both to studying the socioeconomic determinants of malaria and to most observational malaria research, since SEP confounds many relationships. However, as for many other health outcomes,[4, 5] the relative strength of metrics for evaluating the association between SEP and malaria has been little considered.

SEP can be measured directly using household consumption, expenditure or income, or indirectly using proxy metrics such as wealth indices, occupation, household vulnerability and education.[6] Consumption is generally considered to be the 'gold standard' since it is the most direct indicator of SEP, is accurate to measure and is relatively stable over time, yet it is expensive to collect, requiring detailed data on rental income, reported household consumption and fees from durable items owned.[7, 8] Household income is another direct indicator of SEP, generally adjusted for household size and composition, but also requires lengthy interviewing, is difficult to measure when derived from multiple sources and is subject to temporal fluctuation.[9, 10]

Wealth indices derived from assets have been developed as an alternative to consumption and are widely used as indirect metrics of SEP in malaria studies since they are simple to do and less subject to reporting biases. Wealth indices can have similar predictive values to consumption in estimating the relationship between SEP and health outcomes.[6, 11, 12, 13] However, findings can be affected by the weighting strategy and choice of included assets.[14] For example, the inclusion of assets in the wealth index that are associated directly with the outcome of interest can increase the association between SEP and the outcome of interest.[12] This is often relevant to malaria; for instance, house construction materials are sometimes included in wealth indices, especially if the

Demographic and Health Survey (DHS) model is used.[15, 32] Yet house construction may be independently assessed as a risk factor for malaria, since it can influence house entry by mosquito vectors.[16] SEP may also be measured indirectly using classes of occupation, as in the DHS,[17] and education, typically by measuring years of formal education completed, qualifications attained or literacy.[18, 19]

Previous studies of health inequalities have compared the household rankings produced by different SEP indicators[12, 14, 20, 21, 22, 23] and evaluated the association of different indicators with specific health outcomes.[14, 24, 25, 26] However, to our knowledge, only one study has previously evaluated indicators for measuring socioeconomic inequalities in relation to malaria risk.[27] In that study, three indices were developed using data from 25 Tanzanian villages: a consumption index and two wealth indices derived from Principal Component Analysis (PCA). Little difference was found between household rankings from the two wealth indices while a weak relationship was found between the wealth index and consumption index, with the households rankings based on PCA less discriminatory than those based on consumption. However, a higher score in both the consumption and wealth index was associated with a reduced risk of malaria infection, indicating that the wealth index was a reasonable empirical and logistical alternative to consumption in that context.[27]

In the present study we evaluate the agreement between four indicators of socioeconomic position (SEP) and explore how the risk of malaria in children varies with these indicators in Nagongera, rural Uganda. The four indicators compared are: (1) two wealth indices derived from PCA, (2) income, (3) occupation and (4) female caregiver's education. To our knowledge, this is the first evaluation of metrics other than wealth indices and consumption indices for measuring the association between SEP and malaria.

Materials and methods

Study site: The study was carried out between August 2011 and September 2014 in Nagongera sub-country, Tororo district, Uganda (00°46'10.6"N, 34°01'34.1"E). Rainfall is

bimodal, with long rains from March to June and short rains from August to December. Malaria transmission is intense with an estimated annual *Plasmodium falciparum* entomological inoculation rate of 125.[28] *Anopheles gambiae* sensu stricto (81.5%) and *An. arabiensis* (18.5%) are the primary vectors.

Data source: This study was part of a cohort study described elsewhere.[28, 29] All children aged six months to 10 years and their primary caregivers were enrolled from 100 randomly selected households in Nagongera in August-September 2011. Recruitment was dynamic, such that children reaching six months of age and meeting the eligibility criteria were enrolled and children reaching 11 years were withdrawn. Households with no remaining study participants were withdrawn and seven additional households recruited in September 2013. Participants were followed for all their health care needs at the designated study clinic in Nagongera for 36 months, until September 2014. Outcomes measured were: (1) human biting rate (HBR), measured by one night of CDC light trap catches per month in each home, (2) prevalence of parasitaemia measured routinely every three months and confirmed by microscopy and (3) incidence of all malaria episodes measured by passive case detection.

Household and women's surveys: Data on indicators of SEP were collected from three surveys: (i) a baseline household survey conducted at the time of enrolment, (ii) a second household survey conducted after 24 months of follow-up in September-October 2013 and (iii) a women's survey, administered as a separate structured questionnaire after the second household survey. Both household surveys were administered as a structured interview by trained study staff to one designated adult respondent from each household, if they met four inclusion criteria: (1) usual male or female resident, (2) present in the sampled household the night before the survey, (3) aged at least 18 years and (4) agreement to provide informed written consent. The women's survey was administered to all women of childbearing age (18-49 years), resident in each study household, who met three inclusion criteria: (1) usual female resident, (2) present in the sampled household the night before the survey, (3) agreement to provide informed written consent. Households were excluded if no

adult respondent could not be located on more than three occasions over two weeks (Table 1).

Variables for the wealth indices were collected in the first household survey (main mode of transport to the health facility) and in the second household survey (all other wealth index variables). House construction was recorded through separate house visits by the entomology field teams during 2013 and confirmed by the second household survey. Household income and occupation were measured in the second household survey. Educational status of each child's mother or the eldest female caregiver in each child's household was recorded in the women's survey.

Data analysis: Data were collected using standardized case record forms entered into Microsoft Access for follow-up of study participants and using a paperless system for the household and women's surveys. Analyses were performed with Stata Version 13 (StataCorp, Texas).

Wealth indices: Two wealth indices were produced using PCA.[11] Overall there remains a paucity of underlying theory to support the choice of variables for PCA.[10] We based our collection of data on candidate PCA variables on a literature review, the 2006 Uganda Demographic and Health Survey and the 2009 Uganda Malaria Indicator Survey.[30, 31] To avoid a narrow or skewed distribution of wealth index scores,[32] we aimed to include a balance of variables on asset ownership and access to infrastructure.[33] We included only variables with population frequency distributions of >5% and <95%, since assets that are more equally distributed are less useful in differentiating between households.[23]

For Wealth Index I, the following variables were included in the PCA: ownership of a (1) radio, (2) mobile telephone, (3) table, (4) cupboard, (5) clock and (6) sofa; (7) people per sleeping room; (8) access to an improved toilet and (9) main mode of transport to the health facility. Wealth indices often include food security and house construction variables,[34] but these factors may be independently associated with malaria in the study area.[35, 36] To evaluate whether including food security and house construction variables altered the association between the wealth index and malaria outcomes, Wealth Index II additionally

included five variables: (10) main roof material, (11) main wall material, (12) main floor material, (13) frequency of meat consumption and (14) number of meals per day. Households were ranked by wealth scores and grouped into tertiles. This was done for both wealth indices to give two categorical measures of SEP. Standardised, continuous wealth index scores were created by subtracting mean index scores and dividing by the standard deviation. Additionally, the association between Wealth Index I and the five variables additionally included in Wealth Index II was assessed using Pearson's chi-square test.

Agreement between SEP indicators: Rankings of households by Wealth Index I and II were compared using kappa coefficients and Spearman rank correlation coefficients. Cross tabulations and Pearson's chi-square test were used to explore the associations between household-level indicators of SEP and tertiles of Wealth Index I.

Sensitivity of SEP indicators to malaria risk: Each indicator of SEP was evaluated as a predictor of HBR, parasite prevalence and incidence of clinical malaria. Negative binomial regression was used to model the number of *Anopheles* caught per household per night and the number of malaria cases per child with the number of catch nights and person years included as offset terms. The prevalence of malaria infection at the time of each routine clinic visit was modelled using logistic regression. First, a crude analysis was done in which the models for HBR included no covariates and the models for parasite prevalence and malaria incidence were minimally adjusted for age and gender. Second, to evaluate the relative sensitivity of SEP indicators to inequalities in malaria risk, all indicators of SEP were included in multivariable models for HBR, parasite prevalence and malaria incidence. In all models, robust standard errors were used to adjust for clustering at the household level.

Ethics: Ethical approval was given by the Uganda National Council for Science and Technology; Makerere University School of Medicine Research and Ethics Committee; University of California, San Francisco Committee for Human Research; and London School of Hygiene and Tropical Medicine Ethics Committee.

Results

Study population 333 total children in 107 total households were enrolled into the cohort study between August 2011 and September 2014. The mean age of study children during follow-up was 5.7 years and 153 (46%) were female. All households were surveyed at enrolment in the first household survey. Seven households were withdrawn and replaced immediately before the second household survey in September 2013, such that the second household survey collected data for 100 households and 318 (95%) children. 105 women were surveyed, such that data on female caregivers' education was collected for 301 (90%) children enrolled (Figure 1).

Wealth indices: In Wealth Index I (no housing or food security variables), the first principal component explained 29.3% of overall variability in the asset variables. Greatest weight was given to ownership of a cupboard (Table 1). In Wealth Index II (all variables), the first principal component explained 30.5% of the overall variability in the asset variables. Greatest weight was given to main floor material. Both indices were right-skewed, with wealth index scores ranging from -2.4 to 6.6 (Figure 2). Wealth Index I was strongly associated with the five variables additionally included in Wealth Index II: main roof material ($p=0.001$), main wall material ($p<0.001$), main floor material ($p<0.001$), frequency of meat consumption ($p<0.001$) and number of meals per day ($p<0.001$).

Agreement between SEP indicators: Ranking of households by scores from the two wealth indices was similar but not identical (Spearman's $\rho = 0.93$, $p<0.001$) as was the grouping of households into tertiles (Spearman's $\rho = 0.87$, $p<0.001$; $\kappa = 0.73$, $p<0.001$), with 82% of households placed into the same tertile by both wealth indices (Figure 3, Table 2). Households placed in higher tertiles of Wealth Index I (reference index) had greater income and better educated adult women than households in the lowest tertile (Table 2). However, there was no association between Wealth Index I and occupation.

Sensitivity of SEP indicators to malaria risk:

Human biting rate: 124,746 adult female *Anopheles* were caught over 3,489 collection nights, yielding an overall HBR of 35.8 *Anopheles* per house per night. All households contributed at least one collection night. Controlling for all other SEP indicators, human biting rate (HBR) was associated only with Wealth Index II (highest *vs* lowest tertile: adjusted Incidence Rate Ratio (aIRR) 0.67, 95% confidence intervals (CI) 0.49-0.92, p=0.01) and income from remittances (received *vs* did not receive remittances in past 12 months: aIRR 0.67, 95% CI 0.47-0.96, p=0.03) (Table 3).

Parasite prevalence: 3,367 total routine blood smears were taken of which 1,037 (30.8%) were positive. All participants contributed at least one blood smear. Controlling for age, gender and all other SEP indicators, parasite prevalence was associated with the wealth indices only (highest *vs* lowest tertile of Wealth Index I: aOR 0.57, 95% CI 0.40-0.82, p=0.003; Wealth Index II: aOR 0.57, 95% CI 0.40-0.82, p=0.002) (Table 4).

Incidence of clinical malaria: 2,399 episodes of uncomplicated malaria were diagnosed after 802 person years of follow-up, yielding an overall incidence of 3.0 episodes per person year at risk. One participant was withdrawn immediately after enrolment and did not contribute person time. Controlling for age, gender and all other SEP indicators, only female caregiver's education was associated with malaria incidence (attended school *vs* never attended school: aIRR 0.70, 95% CI 0.49-0.98, p=0.04). Malaria incidence was not associated with either wealth index nor income or occupation (Table 5).

Discussion

We compared two wealth indices and three additional indicators of SEP for measuring socioeconomic inequalities in malaria risk in children in a rural, high transmission area of Uganda. HBR was 29-31% lower in households in the highest tertile of Wealth Indices I and II, compared to the lowest tertile, and 37% lower in households that received any remittances in the past 12 months. However, after controlling for all other SEP indicators, only access to remittances and Wealth Index II (which included house

construction and food security variables) were significantly associated with lower HBR. Controlling for age, gender and all other SEP indicators, the odds of malaria infection were 43% lower in children in the highest tertile of both Wealth Index I and II, compared to the lowest tertile, and malaria incidence was 30% lower in children whose primary female caregiver had attended school, compared to those whose caregiver had not. No association was found between occupation and malaria.

Since their early development and adoption by the DHS and World Bank,[11, 37] wealth indices have become widely used to measure SEP in epidemiological studies in low and middle income settings.[1] While there is continuing debate over how well wealth indices agree with consumption,[13] they are a pragmatic means to rapidly assess SEP and can theoretically represent long-term SEP, similar to consumption expenditure, because assets are relatively resilient to short-term economic shocks.[6] We observed that the wealth index was relatively sensitive to socioeconomic inequalities in HBR and parasite prevalence and indeed it is possible that this metric was less subject to measurement error than other metrics and more indicative of long-term living conditions.[38] The one previous comparison of indicators for measuring socioeconomic inequalities in malaria risk found that the wealth index was a reasonable alternative to consumption in rural Tanzania.[27]

Although there is a paucity of underlying theory to guide the choice of included variables in wealth indices,[10] the inclusion of assets with a direct association with the outcome of interest may increase the observed socioeconomic inequalities in health.[12] Furthermore, variables often included in the wealth index, such as house type, are sometimes evaluated independently as malaria risk factors.[16] We therefore sought to evaluate how the choice of variables included in the wealth index affected the association with malaria outcomes. Household rankings from the two wealth indices were highly correlated, but controlling for other SEP indicators, only the wealth index that included house construction and food security variables was associated with HBR. House structure may also explain part of the association between SEP and malaria in Nagongera since it is both a malaria risk factor[36] and associated with relative wealth, so it is plausible that its inclusion

219 strengthens the association between the wealth index and malaria risk and that there is a trade-off between house type and SEP in the model. Previous wealth indices based on assets alone[39] and on assets and food security[36] in the same district were not significantly
222 associated with parasite prevalence.

We observed that female caregiver's education was better able to predict differences in malaria incidence than other metrics of SEP. Good education is commonly associated
225 with improved health outcomes elsewhere[25, 40] and generally considered to be a useful metric of SEP since it is a proxy for knowledge-based assets and can be strongly related to other measures of SEP such as income and occupation.[6, 19] However education was not
228 associated with HBR nor parasite prevalence and the epidemiological meaning of this remains unclear. The use of education as a metric of SEP can be complicated by changes in the cost, ease and social expectations of educational attendance over time.[6] While we
231 restricted our analysis to female education only, removing gender differences, variation across women's age groups or ethnic groups may have persisted, making it difficult to identify variation in malaria risk reflecting education alone.

234 We found no association between agricultural income and malaria, but we observed that HBR was lower in households that had received remittances in the past 12 months. We also observed that both agricultural income and access to remittances were strongly
237 associated with the reference wealth index. It is plausible that income may be a reasonable proxy for underlying SEP but that our specific measures of income were inadequate to fully detect differences in malaria risk related to SEP. Income is difficult to measure in low income
240 settings such as Nagongera, due to multiple household income sources, home production and seasonal or annual variation in income.[6] Thus we simply estimated the total estimated income from the sale of crops and livestock and recorded whether or not households had
243 access to remittances. Our approach did not account for other income sources and this, together with measurement error due to recall bias, unwillingness to divulge income and interviewing only the household head, may help explain the inconsistent association with
246 malaria outcomes.[9] Of course, our findings may alternatively reflect a scenario of no

underlying relationship between income and malaria, if a lack of cash income is not a barrier to having those characteristics that offer some protection against malaria.

We did not observe any association between malaria infection risk and occupation, when classed as unskilled and agricultural *versus* skilled. Occupational life can be complex and therefore difficult to measure in low-income settings since people often have casual, seasonal, or multiple jobs.[41] In Nagongera, where households predominantly rely on smallholder farming and small home enterprises, further differentiation between commercial and subsistence farmers may have been needed to determine underlying SEP.[26] For example, the DHS typically classifies households using occupation-based social class measures that include subdivisions of types of agricultural activity.[17]

Overall, our study supports the continued use of wealth indices as a pragmatic approach to estimating SEP in malaria studies. While we did not compare the wealth index with consumption, the wealth index was consistently more sensitive to inequalities in malaria risk than income and occupation. However, there remains a need to better understand how to select and weight the included variables. While the inclusion of variables directly associated with the outcome may inflate health inequalities,[12] such variables may be an important part of what makes wealth protective. Moreover, the inclusion or exclusion of different variables can improve understanding of the causal pathway between SEP and a health outcome.[12] However, it may be pragmatic to remove from the wealth index any variables being investigated as exposures of interest. Individual studies should consider what is appropriate for the study setting and design.

Our study has a number of limitations. First, to avoid excessive questioning we did not evaluate consumption, yet this is the gold standard measure of SEP.[6] Second, metrics such as income and occupation may be subject to measurement error due to recall bias, inaccurate reporting during lengthy interviews and social desirability bias when asking questions related to socioeconomic conditions. Third, our findings may not be generalizable outside the study population in Nagongera. For example, in generating both wealth indices the smallest weight was assigned to mode of transport to the health facility, possibly

reflecting reimbursement of clinic travel expenses to study participants. Additionally, we compared two wealth indices only, limiting the conclusions that may be drawn. Fourth, we used PCA as a weighting strategy, but this was originally designed for use with continuous data. We also did not analyse other weighting strategies, such as factor analysis or Multiple Correspondence Analysis (MCA), but a recent study concluded that variable coding may be more important than the weighting strategy in improving wealth index agreement with consumption.[23] Finally, variables used to construct the wealth index were collected at more than one time point. However, we consider household assets to be relatively stable over time.[6]

In conclusion, wealth indices, income and education were stronger predictors of socioeconomic differences in malaria risk than occupation in this setting. The wealth index was still a predictor of malaria risk after excluding variables directly associated with malaria, but the strength of association was lower.

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Disclosures

We declare we have no conflicts of interest.

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Figure Legends

Figure 1. Study profile

Figure 2. Distribution of wealth index scores from Principal Component Analysis (PCA) in 100 households in Nagongera, Uganda.

Variables entered into the PCA for Wealth Index I (A): ownership of a (1) radio, (2) mobile telephone, (3) table, (4) cupboard, (5) clock and (6) sofa; (7) people per sleeping room; (8) access to an improved toilet facility and (9) main mode of transport to the health facility. Additional variables entered for Wealth Index II (B): (10) main roof material, (11) main wall material, (12) main floor material, (13) frequency of meat consumption and (14) number of meals per day.

Figure 3. Association between scores from two wealth indices derived from Principal Component Analysis in 100 households in Nagongera, Uganda.

Lines perpendicular to the axes represent cut-offs for tertiles of each wealth index.

Table 1. Variables included in two wealth indices for 100 households in Nagongera, Uganda and their impact on household wealth index score

Item	Proportion of households with item	Weight	
		Wealth index I[a]	Wealth index II[b]
Radio	0.53	0.29	0.18
Mobile telephone	0.61	0.30	0.27
Table	0.62	0.37	0.31
Cupboard	0.07	0.45	0.27
Clock	0.12	0.43	0.29
Sofa	0.05	0.41	0.31
≤2 people per sleeping room	0.23	0.19	0.14
Improved toilet	0.18	0.29	0.20
Transport to health facility other than walking	0.33	0.10	0.05
Tiled or metal roof	0.65	Not included	0.21
Cement or plaster wall	0.24	Not included	0.35
Wood, brick or cement floor	0.17	Not included	0.38
Meat eaten ≥3 days in the past week	0.40	Not included	0.26
≥3 meals per day in past week	0.28	Not included	0.33

[a]Wealth Index I: variables entered into Principal Component Analysis (PCA): ownership of a (1) radio, (2) mobile telephone, (3) table, (4) cupboard, (5) clock and (6) sofa; (7) people per sleeping room; (8) access to an improved toilet facility and (9) main mode of transport to the health facility. Individual household wealth index scores are calculated by summing the coefficients of assets or characteristics possessed by each household.

[b]Wealth Index II: variables entered into PCA were those included in Wealth Index I in addition to: (10) main roof material, (11) main wall material, (12) main floor material, (13) frequency of meat consumption and (14) number of meals per day.

Table 2. Agreement between indicators of socioeconomic position in 100 households in Nagongera, Uganda

Indicator			All tertiles (%)	Wealth Index I (reference)[a] (%)			
				Poorest	Middle	Highest	p
Indicators at the level of the household			-	N=35	N=32	N=33	-
1. Wealth index	Wealth Index II[b] (%)	Poorest tertile	34	91.4	6.3	0.0	<0.001
		Middle tertile	34	8.6	75.0	21.2	
		Highest tertile	32	0.0	18.8	78.8	
	Wealth Index II[b]	Mean score (95% CI)[c]	-	-0.9 (-0.9, -0.8)	-0.1 (-0.3, 0.0)	1.0 (0.7, 1.4)	<0.001
2. Income	Total income from agriculture in the past 12 months, UGX[d] (%)	<100,000	37	51.4	40.6	18.8	0.001
		100,000 - <300,000	35	37.1	40.6	28.1	
		≥300,000	27	11.4	18.8	53.1	
	Remittances received in the past 12 months (%)	No	85	94.3	87.5	72.7	0.04
		Yes	15	5.7	12.5	27.3	
3. Occupation	Main occupation of the household head (%)	Agriculture or unskilled	72	80.0	78.1	57.6	0.08
		Skilled	28	20.0	21.9	42.4	
	Main source of household income (%)	Agriculture or unskilled	80	85.7	84.4	69.7	0.27
		Skilled	16	11.4	15.6	21.2	
		Remittances or other	4	2.9	0.0	9.1	
Indicator at the level of the child			-	N=110	N=107	N=101	-
4. Education	Female caregiver ever attended school (%)	No	24.9	29.9	21.9	22.5	0.33
		Yes	75.1	70.1	78.1	77.6	
	Female caregiver's highest level of school completed (%)	None	24.9	29.9	21.9	22.5	0.003
		Incomplete 1^{ry}	55.2	62.6	52.1	50.0	
		1^{ry} or higher	19.9	7.5	26.0	27.6	

[a]Wealth Index I: variables entered into Principal Component Analysis (PCA): ownership of a (1) radio, (2) mobile telephone, (3) table, (4) cupboard, (5) clock and (6) sofa; (7) people per sleeping room; (8) access to a toilet facility and (9) main mode of transport to the health facility.

[b]Wealth Index II: variables entered into PCA were those included in Wealth Index I in addition to: (10) main roof material, (11) main wall material, (12) main floor material, (13) meat consumption and (14) number of meals per day.

[c]Standardised wealth index scores were created by subtracting mean index scores and dividing by the standard deviation. The p-value for this variable was calculated using analysis of variance.

[d]UGX: Ugandan shilling

Table 3. Association between household-level indicators of socioeconomic position and the human biting rate in 100 households in Nagongera, Uganda

Characteristic			HBR[a]	Crude IRR (95% CI)[b]	p	Adjusted IRR (95% CI)[c]	p
1. Wealth index	Wealth Index I	Poorest tertile	41.5 (1136)	1	-	1	-
		Middle tertile	34.4 (1132)	0.86 (0.65-1.13)	0.27	0.88 (0.68-1.14)	0.34
		Highest tertile	28.8 (1110)	0.71 (0.54-0.93)	0.01	0.75 (0.56-1.02)	0.06
		Continuous score[d]	-	0.87 (0.77-0.99)	0.03	0.92 (0.81-1.05)	0.22
	Wealth Index II	Poorest tertile	40.8 (1124)	1	-	1	-
		Middle tertile	35.8 (1173)	0.90 (0.68-1.18)	0.44	0.93 (0.72-1.20)	0.58
		Highest tertile	27.9 (1081)	0.69 (0.52-0.91)	0.008	0.67 (0.49-0.92)	0.01
		Continuous score[d]	-	0.79 (0.71-0.89)	<0.001	0.80 (0.69-0.91)	0.001
2. Income	Total income from agriculture in past 12 months (UGX)[e]	<100,000	37.0 (1291)	1	-	1	-
		100,000 - <300,000	29.3 (1142)	0.80 (0.61-1.04)	0.10	0.77 (0.59-1.01)	0.06
		≥300,000	40.0 (910)	1.05 (0.79-1.40)	0.72	1.16 (0.86-1.58)	0.34
	Remittances received in the past 12 months	No	37.0 (2872)	1	1	1	-
		Yes	23.0 (506)	0.63 (0.46-0.86)	0.004	0.67 (0.47-0.96)	0.03
3. Occupation	Primary occupation of the household head	Agriculture, unskilled or cannot work	35.3 (2431)	1	1	1	-
		Skilled	34.1 (947)	0.95 (0.74-1.24)	0.72	0.98 (0.71-1.34)	0.89
	Main source of household income	Agriculture or unskilled	36.8 (2690)	1	-	1	-
		Skilled	30.0 (544)	0.82 (0.60-1.13)	0.23	0.83 (0.57-1.23)	0.36
		Remittances or other	19.2 (144)	0.53 (0.30-0.95)	0.03	0.80 (0.42-1.50)	0.48

[a]HBR: Human biting rate: total female *Anopheles* / total collection nights. Total collection nights are shown in brackets.
[b]IRR: Incidence rate ratio; CI: Confidence interval.
[c]IRR adjusted for categorical Wealth Index I and all other SEP indicators, excluding all other Wealth Index variables. IRRs for the categorical Wealth Index II and continuous Wealth Indices I and II variables were adjusted for all other indicators of SEP, excluding all other Wealth Index variables.
[d]Standardised wealth index scores were created by subtracting mean index scores and dividing by the standard deviation.
[e]UGX: Ugandan shilling

Table 4. Association between indicators of socioeconomic position and malaria infection in children aged six months to 10 years in Nagongera, Uganda

Characteristic			% positive[a]	Crude OR (95% CI)[b]	P	Adjusted OR (95% CI)[c]	p
Age at the time of the blood smear		6m to <3yrs	19.2 (657)	1	-	1	-
		3 to <5 yrs	27.6 (699)	1.60 (1.18-2.18)	0.002	1.60 (1.16-2.20)	0.004
		5 to <11 yrs	35.7 (2011)	2.34 (1.77-3.09)	<0.001	2.40 (1.83-3.17)	<0.001
Gender		Female	29.9 (1518)	1	-	1	-
		Male	31.5 (1849)	1.07 (0.86-1.35)	0.54	1.04 (0.82-1.30)	0.75
1. Wealth index	Wealth Index I	Poorest	38.4 (1087)	1	-	1	-
		Middle	29.6 (1170)	0.65 (0.48-0.87)	0.003	0.69 (0.51-0.94)	0.02
		Highest	25.3 (1010)	0.52 (0.35-0.78)	0.001	0.57 (0.40-0.82)	0.003
		Continuous score[d]	-	0.82 (0.64-1.04)	0.10	0.80 (0.65-0.99)	0.04
	Wealth Index II	Poorest	37.7 (1109)	1	-	1	-
		Middle	28.9 (1210)	0.63 (0.46-0.87)	0.004	0.64 (0.47-0.88)	0.005
		Highest	26.4 (948)	0.58 (0.40-0.84)	0.004	0.57 (0.40-0.82)	0.002
		Continuous score[d]	-	0.73 (0.60-0.88)	0.001	0.71 (0.59-0.86)	<0.001
2. Income	Total income from agriculture in the past 12 months (UGX)[e]	<100,000	34.0 (1180)	1	-	1	-
		100,000 - <300,000	29.7 (1136)	0.79 (0.56-1.11)	0.17	0.77 (0.55-1.09)	0.15
		≥300,000	28.0 (908)	0.75 (0.53-1.07)	0.12	0.87 (0.62-1.22)	0.43
	Remittances received in the past 12 months	No	32.2 (2847)	1	-	1	-
		Yes	23.8 (420)	0.62 (0.37-1.04)	0.07	0.65 (0.40-1.05)	0.08
3. Occupation	Primary occupation of the household head	Agriculture or unskilled	32.9 (2416)	1	-	1	-
		Skilled	26.3 (851)	0.76 (0.51-1.15)	0.19	0.77 (0.55-1.08)	0.13
	Main source of household income	Agriculture or unskilled	32.1 (2635)	1	-	1	-
		Skilled	27.0 (497)	0.82 (0.48-1.41)	0.48	1.03 (0.58-1.81)	0.93
		Remittances or other	28.9 (135)	0.83 (0.33-2.07)	0.68	1.04 (0.49-2.20)	0.93
4. Education	Female caregiver ever attended school	No	33.4 (788)	1	-	1	-
		Yes	30.4 (2296)	0.90 (0.65-1.25)	0.54	0.87 (0.59-1.29)	0.49
	Female caregiver's highest level of school completed	None	33.4 (788)	1	-	1	-
		Incomplete 1^{ry}	31.7 (1703)	0.96 (0.68-1.36)	0.83	1.26 (0.92-1.74)	0.16
		1^{ry} or higher	26.6 (593)	0.74 (0.48-1.15)	0.18	Omitted due to collinearity	-

[a]Percentage of blood slides positive with malaria parasites. Total blood slides are shown in brackets.
[b]OR: Odds ratio minimally adjusted for age at the time of the blood smear and gender; CI: Confidence interval.
[c]OR adjusted for mean age during follow-up, gender, categorical Wealth Index I and all other SEP indicators, excluding all other Wealth Index variables. ORs for the categorical Wealth Index II and continuous Wealth Indices I and II variables were adjusted for mean age during follow-up, gender and all other indicators of SEP, excluding all other Wealth Index variables.
[d]Standardised wealth index scores were created by subtracting mean index scores and dividing by the standard deviation.
[e]UGX: Ugandan shilling

Table 5. Association between indicators of socioeconomic position and malaria incidence in children aged six months to 10 years in Nagongera, Uganda

Characteristic			Malaria incidence[a]	Crude IRR (95% CI)[b]	p	Adjusted IRR (95% CI)[c]	p
Mean age during follow-up		6m to <3yrs	4.1 (134)	1	-	1	-
		3 to <5 yrs	4.2 (177)	1.01 (0.85-1.19)	0.93	0.99 (0.82-1.20)	0.96
		5 to <11 yrs	2.3 (491)	0.54 (0.46-0.65)	<0.001	0.54 (0.46-0.65)	<0.001
Gender		Female	2.7 (361)	1	-	1	-
		Male	3.2 (441)	1.13 (0.97-1.32)	0.12	1.14 (0.97-1.35)	0.11
1. Wealth index	Wealth Index I	Poorest	3.0 (258)	1	-	1	-
		Middle	3.1 (280)	1.12 (0.90-1.40)	0.31	1.16 (0.93-1.43)	0.18
		Highest	2.9 (241)	1.05 (0.83-1.34)	0.68	1.08 (0.86-1.37)	0.51
		Continuous score[d]	-	0.95 (0.86-1.06)	0.35	0.96 (0.88-1.06)	0.46
	Wealth Index II	Poorest	3.2 (264)	1	-	1	-
		Middle	2.9 (289)	1.03 (0.83-1.29)	0.77	1.10 (0.90-1.35)	0.33
		Highest	2.9 (226)	1.00 (0.78-1.27)	0.98	1.04 (0.80-1.36)	0.75
		Continuous score[d]	-	0.95 (0.84-1.07)	0.38	0.97 (0.86-1.10)	0.67
2. Income	Total income from agriculture in the past 12 months (UGX)[e]	<100,000	3.1 (283)	1	-	1	-
		100,000 - <300,000	2.5 (270)	0.84 (0.66-1.06)	0.14	0.79 (0.62-1.00)	0.05
		≥300,000	3.5 (215)	1.13 (0.90-1.42)	0.29	1.11 (0.88-1.40)	0.37
	Remittances received in the past 12 months	No	3.1 (679)	1	-	1	-
		Yes	2.6 (100)	0.88 (0.65-1.20)	0.42	1.10 (0.76-1.57)	0.62
3. Occupation	Primary occupation of the household head	Agriculture or unskilled	3.0 (576)	1	-	1	-
		Skilled	3.0 (203)	0.93 (0.74-1.19)	0.58	0.90 (0.66-1.23)	0.51
	Main source of household income	Agriculture or unskilled	3.1 (628)	1	-	1	-
		Skilled	2.8 (118)	0.93 (0.70-1.23)	0.59	1.01 (0.69-1.48)	0.97
		Remittances or other	2.5 (33)	0.77 (0.43-1.36)	0.37	0.67 (0.38-1.19)	0.17
4. Education	Female caregiver ever attended school	No	3.5 (188)	1	-	1	-
		Yes	2.9 (546)	0.80 (0.67-0.95)	0.01	0.70 (0.49-0.98)	0.04
	Female caregiver's highest level of school completed	None	3.5 (188)	1	-	1	-
		Incomplete 1^{ry}	3.0 (406)	0.83 (0.69-1.01)	0.06	1.26 (0.91-1.74)	0.16
		1^{ry} or higher	2.4 (140)	0.69 (0.53-0.91)	0.008	Omitted due to collinearity	-

[a]Malaria incidence: episodes per person years at risk. Total person years at risk shown in brackets.
[b]IRR: Incidence Rate Ratio minimally adjusted for mean age during follow-up and gender; CI: Confidence interval.
[c]IRR adjusted for mean age during follow-up, gender, categorical Wealth Index I and all other SEP indicators, excluding all other Wealth Index variables. IRRs for the categorical Wealth Index II and continuous Wealth Indices I and II variables were adjusted for mean age during follow-up, gender and all other indicators of SEP, excluding all other Wealth Index variables.
[d]Standardised wealth index scores were created by subtracting mean index scores and dividing by the standard deviation.
[e]UGX: Ugandan shilling