Echodu et al. BMC Public Health (2025) 25:974
https://doi.org/10.1186/s12889-025-22175-8

BMC Public Health

RESEARCH

Open Access

Household predictors of malaria episode in northern Uganda: its implication for future malaria control

Richard Echodu[1,2*], William Sam Oyet[1], Tereza Iwiru[2], Felister Apili[3], Julius Julian Lutwama[4], Elizabeth Auma Opiyo[1] and Ochan Otim[5,6]

Abstract

Background Uses of indoor residual spraying (IRS), long-lasting insecticidal nets (LLINS) and treatment with artemisinin-based combination therapy (ACT) are greatly promoted in the northern part of Uganda as mitigating strategies for malaria episodes. Unfortunately, the region remains the fourth highest malaria burden in Uganda with a prevalence of 12%. This study assesses household predictors of malaria episodes in northern Uganda and their impact on malaria episodes at the household level.

Methods A cross-sectional study was conducted in four districts of Gulu, Oyam, Kitgum and Agago covering sixteen villages in northern Uganda. Data was collected through a pre-tested structured questionnaire and systematically coded for analysis using R software.

Results In total, 193 households were surveyed with 112 (58%) of them headed by women and 605 individuals were declared to have spent the night before the interview in the 193 households. On average, there were at least two-bed nets (317/159) per household and a total of 460 individuals out of 535 (86%) spent the night before the interview under a bed net. The usage of bed nets in the study area overall was 86% while malaria incidence was 50% higher in children than in adults. Hierarchical clustering on principal components (HCPC) categorizes households in northern Uganda into three types: 1) households that use bed nets and sleep in houses sprayed with insecticides; 2) households that use bed nets but no indoor residual spraying with insecticides and 3) households that have no bed nets and no indoor residual spraying. When given a choice between IRS and treated bed nets, 1 in 3 households preferred treated bed nets. At the same time, data suggests that bed nets were perceived as unnecessary once the IRS was applied. If true, the driving force for spraying insecticides indoors then becomes the lack of a bed net.

Conclusions Malaria episodes were strongly related to lack of bed nets or use thereof, and directly linked to the number of individuals in a household. Children were prone to malaria more than adults by a ratio of 2:1. The three categories of households in northern Uganda as revealed by HCPC provide an opportunity to tailor-make preventive/intervention malaria messages to fit the individual household clusters.

Keywords Predictors, Malaria, Indoor residual spraying, Long-lasting insecticidal nets Uganda

*Correspondence:
Richard Echodu
richardechodu2009@gmail.com
Full list of author information is available at the end of the article

Introduction

Malaria remains a major public health concern worldwide, more seriously in sub-Saharan Africa. With over 263 million cases reported worldwide in 2023, sub-Saharan Africa accounted for 94% of the total cases of malaria worldwide [1]. The World Health Organization (WHO), in their Global Technical Strategy for Malaria 2016–2030 publication [2] reported declining rates of malaria episodes from 82 in 2000 to 57 cases per 1000 population in 2019, before increasing to 59 in 2020. Most of these declines have been attributed to scale-up of indoor residual spraying (IRS), long-lasting insecticidal nets (LLINs) usage as well as introduction globally of artemisinin-based combination therapy (ACT) for malaria treatment and intermittent preventive treatment (IPTp) during pregnancy [2]. Despite these intervention efforts, malaria continues to be a major cause of morbidity and mortality worldwide with an estimated 3.2 billion people at risk of being infected and developing the disease [2].

Uganda remains among the five countries that contribute 50% of the global malaria cases [1, 3, 4] and ranks 3rd and 5th highest in mortality and morbidity due to malaria worldwide, respectively [5]. To achieve WHO member states ambitious target of reducing the global malaria burden by 90% by 2030, Uganda has adopted several intervention strategies with the goal of having accelerated nationwide scale-up of universal coverage of cost-effective malaria prevention and treatment interventions [5]. These interventions include mass distribution of LLIN, IRS, larval source management, scale-up malaria diagnostics using microscopy and rapid diagnostics tests (RDTs), treatment with effective antimalarial drugs, increase social mobilization, behaviour change communication, strengthening existing malaria surveillance, monitoring and evaluation systems [5]. Despite these many control strategies, malaria remains the leading cause of morbidity and mortality in Uganda, mainly due to delayed health seeking, clinical judgment without laboratory confirmation, and widespread insecticide resistance in mosquito populations [5–9]. In northern Uganda in particular, malaria season picks up between May to November with a transmission rate as high as 1,500 infective bites per person per year [10]. The region has experienced a significant decrease in malaria prevalence, dropping from 63% in 2009 to 12% in 2018–2019 [11, 12]. The current primary malaria vector control interventions in the region rely on the universal distribution of LLINs and IRS with pyrethroids and non-pyrethroids insecticides [8, 9]. However, household and individual levels of protection using LLINs and IRS are largely derived from community-level coverage [13, 14]. The WHO recommends the need to have community cooperation and acceptance of IRS and LLIN interventions [2]. Besides, other studies have shown that malaria protection from the IRS was more strongly associated with high community-level coverage than with household acceptance [15].

In this study, we look at possible predictors of malaria episodes at household levels to guide the development of control strategies to improve the acceptance of all malaria control efforts in future in northern Uganda. Understanding changes in malaria transmission and household predictors could shed light on the success or failure of current control strategies in the region. Particularly, the predictors could provide insight into local belief systems that may be affecting malaria management but which could be modified by a community-health worker partnership to empower the indigent communities under study to proactively management the disease in the domains. The benefit of this approach is enormous when community participation in surveillance, treatment and control activity initiatives is sustained. For instance, the partnership could expedite not only the rate at which possible areas under risk are located but also the planning and implementation of appropriate malaria control strategies [15].

Methods

Study sites

This study was carried out in districts of Kitgum (3°17′ 20.0″ N, 32°0.52′ 40.0″ E), Agago (2°49′ 59″ N, 33°19′ 60″ E), Gulu (2°44′ 59″ N, 32°00′ 0″ E) and Oyam (2°22′ 52″ N, 32°30′ 2″ E) (Fig. 1) during the rainy season of 2017, 2018 and the dry season of February 2019. The total land area of the four districts is 13,100 km^2 characterized by woody savannah vegetation with a population of about 1.3 million [16, 17].

Northern Uganda has two rainy seasons annually, receiving between 750–1500 mm from April to May and from August to September [17]. The dry season tends to be severe and lasts from November to March. Temperatures tend to range between 16 and 32 °C with relative humidity of 50–80%. The major water bodies in the region include River Nile, River Achwa, River Pager and Dopeth-Okok River with many other smaller tributaries that provide breeding grounds for mosquitoes in the riverbeds and swamps where human activities are responsible for the creation of man-made mosquito breeding sites.

The households here have mainly grass-thatched huts with some semi-permanent and permanent houses. About 83% of the households in northern Uganda are reported owning atleast one LLIN [12]. From 2007 to 2014, 10 districts in northern Uganda received IRS implemented first using pyrethroid insecticides and later switched to a carbamate [18]. IRS was withdrawn in 2014 in these districts which led to an increase in malaria cases

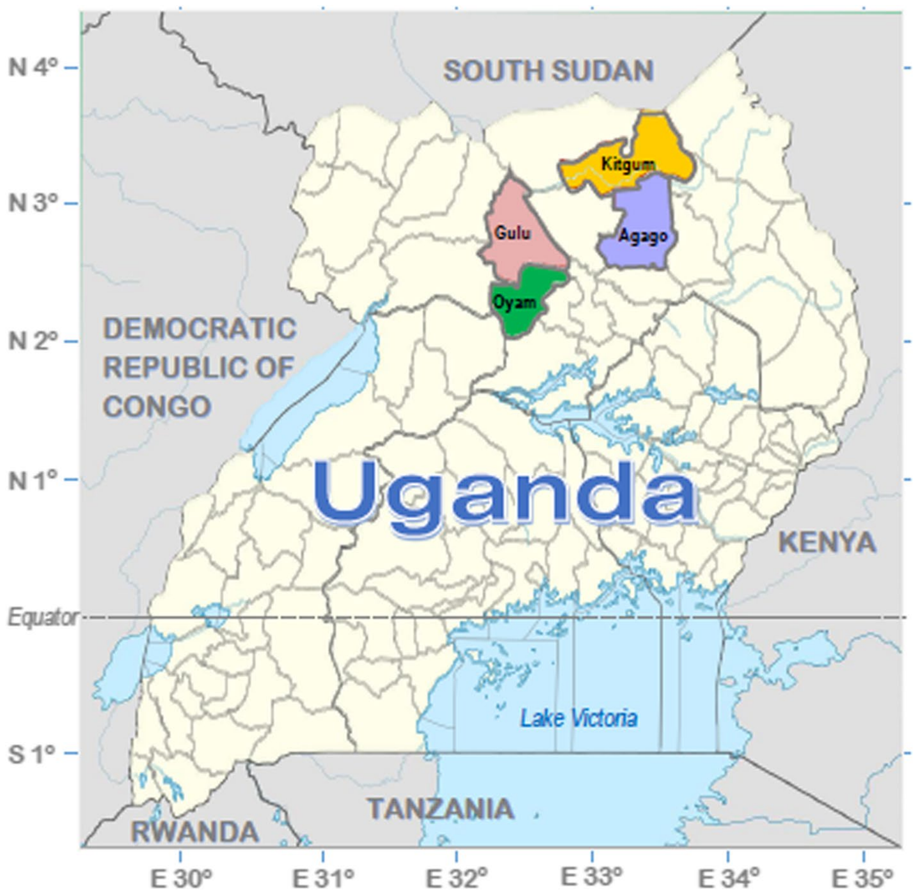


Fig. 1 Location of study districts in Uganda

[19]. The current malaria management in this region combines the use of IRS, ITN and home-based management of fever using a village health team. The annual malaria incidence in the region is 52.3 cases per 1000 per month [12].

Study design

Cross-sectional household surveys were conducted in the same households alongside the entomological surveys described in Echodu et al. (2020) during the rainy season in May of 2017, in April, June and September of 2018, and during the dry season in February of 2019. Two subcounties from each district were randomly selected out of which two villages were chosen at random for study. On average, twelve households were sampled per village for an overall study design of 48 households per district (Agago, 51; Gulu, 51; Kitgum, 43; Oyam, 48). Household observation and physical observation of the LLINs were done simultaneously on interview day.

Ethical standards were maintained throughout the survey. Local Council 1, village health teams, vector control officers, and district health officers were involved. The heads of the households were briefed on the goal of the research and written informed consents were obtained to enter their houses. This study was approved by the Gulu University Ethical Review Committee. Formal approval to conduct the study was granted by the Uganda National Council for Science and Technology and the Office of the Ugandan President (SS4610).

Data collection

A structured questionnaire paper, in multiple-choice questions format, was used for data collection. The questionnaire covered three broad areas of interest. Firstly, we recorded the general structure of a typical household which we believe to be relevant to malaria incidence. Secondly, we documented the number of people who slept in the house the previous night and their malaria history in the last three months, among both children and adults in the household. Lastly, we recorded malaria intervention measures employed at the household level. Specifically, we gathered information on (i) the total number of mosquito nets per household; (ii) whether the mosquito bed nets were treated by the household head or impregnated with insecticides by the supplier, if treated; (iii) the frequency of bed net treatments; (iv) the individuals who slept under the bed nets; (v) whether the household used insecticides other than bed nets, or in addition to bed nets; and (vi) whether indoor residual spraying was done in the house the previous or any other night. These categorical variables were coded for data analysis (Supplementary Material 2 and Table S2).

Data analysis

The analysis of the categorical data collected here was geared towards answering the question as to whether an association exists between predictors and episodes of malaria among residents of northern Uganda. The data, first entered in Microsoft Excel data sheets, cross-checked and validated for accuracy prior to use, was analyzed in two steps. In the first step, a descriptive analysis of the data was carried to see what properties were clearly discernable without much statistical aid. The outcome of this initial exploration was then used to inform as search for deeper meanings in the data, those meanings not easily accessible by other supervised methods. The latter was accomplished by modelling joint behaviour of multivariate predictors using multiple correspondence analysis (MCA), a technique that has become the accepted standard for analyzing categorical data.

MCA, an unsupervised multivariable method for nominal categorical data analysis, does not only simplify data by reducing redundancy, it can detect the underlying structure of a categorical dataset hence revealing nuances which would otherwise be missed by other techniques (see Discussion section for an example). In the context of this study, MCA is used to identify groups of individuals with similar profile in their answers to the questions in a survey.

In this study, the proportions of variance accounted for by MCA dimensions were used uncorrected for two reasons: (i) our focus was only on the 2-D presentation of results which does not change with correction [20], and (ii) contributions of high order dimensions to total variation in data (the information of importance to us) are always negligible. Overall, studies have suggested that correcting MCA dimensions adds little value to the kind of information we sought via MCA here: the strength of correlation between observables and individual households provided directly by the spatial arrangement of points in the cloud [20].

Interpreting MCA results is better said than done and, this being the first time MCA is used to study malaria in Uganda to our knowledge, we are present here as many details as possible to allow for broader access to our results and conclusions by those in the study area especially.

To aid in identifying groups of similar villages in terms of infection rate and malaria control measures, we used hierarchical clustering on principal components (HCPC), a statistical technique well suited to identifying clustering or similar incidences. To apply HCPC, the 22 multiple categorical data collected were organized into continuous predictors and pre-processed using the MCA technique to reduce the dimensions to 17. Only the first five of the 17 dimensions were kept and passed on to the HCPC tool. Of the five, the first two dimensions were found to be adequate to determine villages' similarities by HCPC.

Both MCA and HCPC were performed using the FactorMineR software package [21] with the aid of the RStudio graphic user interface running in the R platform [22, 23]. The MCA results were visually displayed using the within Factoshiny package [24].

Results

Data properties—descriptive

This study was designed to evaluate the household's malaria intervention strategies during episodes of malaria in northern Uganda. A total of 193 households (Agago, 51; Gulu, 51; Kitgum, 43; Oyam, 48) were surveyed for the study and 159 of the 193 responded to all question on the questionnaire. From these households, responses of 605 individuals were captured in our data, some in multiple categories. Of this total, 111 households with 388 individuals were headed by women and only 82 households with 217 individuals were headed by men, a cultural reversal (personal experience). The average number of individuals per household, determined by extrapolating the declared number of individuals who spent the night before the survey to one (1) household, was 3 (±2 standard deviation). Additionally, 255 of the 605 total number of individuals captured in the data (42%) had malaria in the three months prior to this survey, 171 of which were children (67% of 255).

The 159 households who responded to all questions on the questionnaire had at least two-bed nets (i.e., 317 bed nets per 159 households) under which a total of 460 individuals out of 535 (86%) slept the night before this survey (Fig. 2a). From personal experience, the observed 86% usage is empirically large and perhaps a reflection a general acceptance of bed nets usage in the study area. This statement is supported by the fact that a correlation was observed between the number of individuals that spent the night under bed nets within each household and the total number of individuals counted per household (Pearson $r = 0.654$, $p = 8.96e\text{-}21$).

In counting the frequencies of occurence above, 10 households were excluded because more individuals were reported as sleeping under bed nets than those declared to have spent the previous night in the

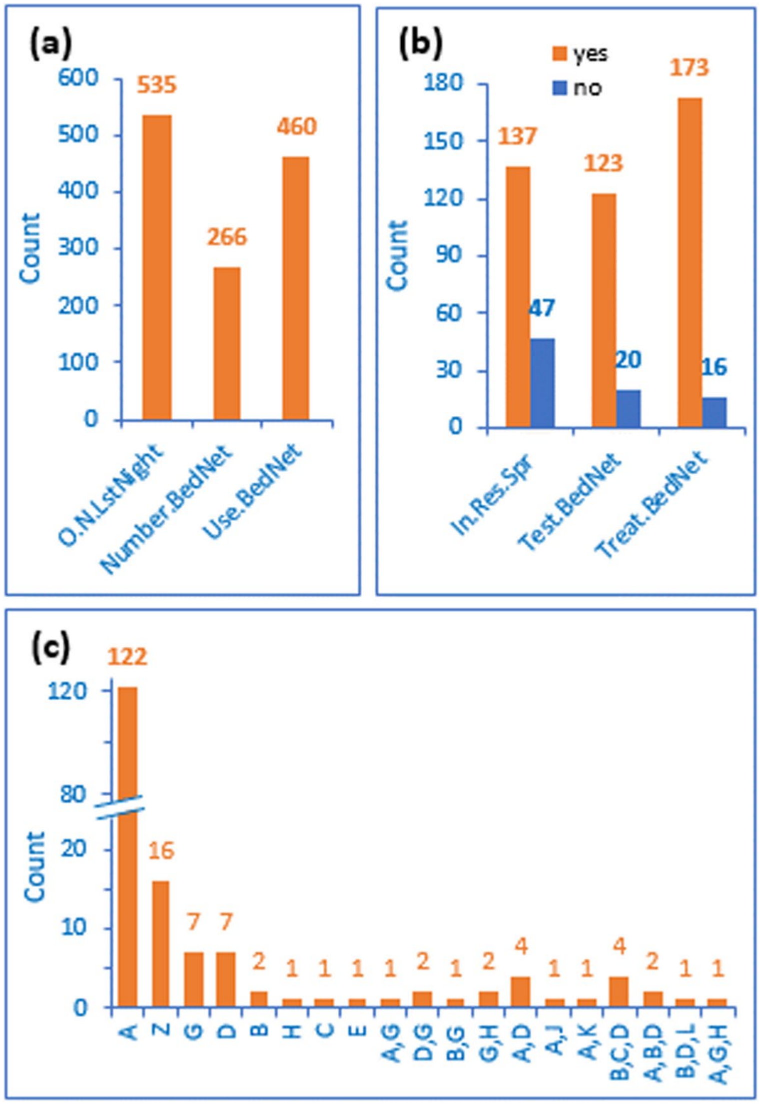


Fig. 2 Structure, nature and extent of malaria intervention in northern Uganda. **a** Comparing the number of individuals who stayed overnight in a household before interview (O.N.LstNight) and the number of bed nets in households (Number.BedNet) with how many individuals used the nets (Use.BedNet) (70 O.N.LstNight and 51 Number.BedNet values are not included; respondents did not specify Use.BedNet). **b** Comparing the extent of intervention as measured by responses to the following questions: Do you do indoor residual spraying in your house (In.Res.Spr)? Did you test bed nets before treating them (Test.BedNet)? Are bed nets impregnated or treated with insecticides (Treat.BedNet)? **c** Controlling mosquito (malaria.control) with/by A: net, B: draining stagnant water pool, C: closing doors, D: clearing grass around house (cutgrass), E: general cleanliness, G: treatment after contracting malaria, H: IRS (whether indoor spraying was applied in the house), J: Using shea nuts or external bath shelters, K: no light in the house at night, L: burning dried paste of pyrethrum at night, Z: no proactive malaria control

households. Additionally, 21 responses were excluded because they were responses other than a Yes or a No required to the question: *Who slept under treated mosquito bed nets?* The 31 excluded households owned at least one mosquito bed net (impregnated or treated with insecticides), applied IRS in their houses and reported having someone in their midst suffer from malaria in the previous three months prior to the

Table 1 A two-way contingency table assessing respondents' attitude towards indoor malaria control strategies

Questionnaire	Yes	No	TOTAL
Do you do indoor residual spraying in your house?	137	47	184
Did you test bed nets before treating them?	123	20	143
Are your bed nets impregnated or treated with insecticides?	173	16	189
SUM	433	83	516

Table 2 Comparing the effectiveness of malaria control strategies offered by respondents beyond indoor spraying

	Malaria control	Malaria episodes			Ratio
	Count (*n*)	Children	Adults	Sum (*s*)	*s/n*
Bed nets only	27	21	15	36	1.33
Bed nets + others	9	7	5	12	1.33
Treatment only	6	9	0	9	1.50
No strategy	5	6	4	10	2.00

interview. The contingency Tables 1 and 2, and the bar charts shown in Fig. 2 are provided for some context.

Data properties—exploratory

Overall, the data collected here show an active inclination towards taking measures against the spread of malaria in the study area, particularly the use of insecticides in some form. As can be seen from Fig. 2b and the two-way contingency table, Table 1, the number of households whose malaria-controlling mechanism involves insecticides was 433 (sum 137 + 123 + 173) out of a total of 516. That is, there were 516 direct responses, 433 and 83 of which were yes and no, respectively. (The number 516 (versus 193) is due to the fact that some households practiced up to three of the intervention measures shown.) In details, there were 137 respondents (27% of the total) who carry out indoor residual spraying in their houses and 47 (9% of the total) that did not, 123 (24%) that tested bed nets before treating them and 20 (4%) that did not, and 173 (33%) that used bed nets impregnated or treated with insecticides and 16 (3%) that did not. Note that the 433 yes responses represent 84% of the respondents that had some kind of malaria control.

As mentioned earlier, additional malaria-controlling mechanisms adopted for controlling mosquitoes – the carriers of malaria pathogens – were offered by respondents. They range from cutting grass around homesteads and draining stagnant water pools to not having any strategy. By the number of times these additional control mechanisms were provided (Fig. 2c), the primary one appeared to be the use of a bed net (122 out of 177). This was followed unfortunately, albeit to a minor extent, by not having any form of preventive measure against malaria whatsoever – not even receiving treatment after falling sick (16/177).

Seven households kept grass around houses low ostensibly to deny mosquitoes hiding places during the day, or relied on medical treatment only after becoming sick. A few households reported combining two to three strategies to control malaria. Four households for example combined keeping grass low around houses by using bed nets or keeping doors closed by draining stagnant water pools where mosquitoes might breed.

To assess the relative effectiveness of these different strategies, a simple ratio of the number of malaria episodes and number of times a control mechanism was offered by respondents n was computed for each category for comparison (column s/n in Table 2). The smaller the value of this ratio in comparative terms, the more successful the intervention strategy was. In that context, relying on bed nets for controlling malaria, or combining bed net usage with (i) IRS, (ii) draining stagnant water pool, (iii) clearing grass around the house, or (iv) receiving medical treatment after falling sick had the smallest value at 1.33 and therefore the best strategies among the 22 studied. Note that the ratio was higher for households (i) that relied exclusively on treatment alone or (ii) that had no strategy (1.50 and 2.00, respectively) which clearly shows that the use of bed nets is not only important in controlling malaria in the study area, but that prevention is better than getting treated after falling sick. Furthermore, the worst a household can do by this analysis is to have no strategy at all for controlling malaria – including receiving no medical treatment after falling sick.

Overall, children bore the brunt of malaria in northern Uganda in the three months prior to this survey, irrespective of actions taken to control malaria at the household level.

Selecting number of MCA dimension to retain

The MCA technique was the method of choice here because (i) our questionnaire provided a 22-level categorical dataset containing a mixture of integers and factors, and (ii) non-linear associations were found among the observables by regression (not shown), meaning regression was not appropriate for analysis here. MCA did not only reveal the internal structure of the non-linear correlations observed (as will be shown below), but allowed us to assess relationships which would not have been obvious by regression.

Of the 22 levels of the categorical dataset collected here, MCA yielded 17 important dimensions by decomposing the total MCA inertia (variance in a multivariate dataset) into a possible maximum of 22. Five of these dimensions were identified to have most of the information for inclusion into the final data matrix used in further analysis. The five dimensions accounted for 14.41%, 9.70%, 7.92%, 6.35% and 5.88% of uncorrected inertia, respectively. Uncorrected inertia was used since the information expected from MCA (i.e., the locations of points in the 'cloud of individuals') are unaffected – corrected or not [20, 25].

Identifying the most important malaria intervention strategies by MCA

Out of the 22 intervention strategies tested, we identified seven as the most significantly related to malaria in both children and adults in northern Uganda using the MCA technique. Identification was based on the quality of their representation along the five chosen dimensions which was high (see next paragraph below). These seven strategies were (i) the number of individuals staying overnight in a household (*O.N.LstNight*), (ii) the number of bed nets in the households (*Number.BedNet*), (iii) the number of individuals who actually used the bed nets (*Use.BedNet*), (iv) and (v) the number of households that do practice indoor residual spraying (*In.Res.Spr* and *IRS*), (vi) the number of households that impregnate or treat bed nets with insecticides before use (*Treat.BedNet*) and (vii) a collection of additional strategies offered by respondents assembled under *malaria.control* for analysis.

The overall qualities of how well the original 22 categories of predictors are represented by the first five MCA dimensions are displayed graphically in Supplementary Material Fig. S1. This assessment of quality is needed here to support our contentions later on here that not only were the first three dimensions the most important in understanding strategies for controlling malaria in the study region, but that the eight listed predictors of malaria were the most significant. The coordinates of the predictors along the first five MCA dimensions (Dim 1, Dim 2, Dim 3, Dim 4 and Dim 5—color coded for clarity) are displayed in Supplementary Material Fig. S1a. Here, the further the coordinate of a predictor is from 0 along a dimension (negative or positive direction), the better the predictor is represented along the dimension.

The quality of the representations as measured by the values of Cos2 (squared cosine) for each predictor, and their contributions along the dimensions are also displayed in Supplementary Material Fig. S1b and Fig. S1c, respectively. Cos2 measures the degree of association between predictor categories and each of the selected five dimensions. A predictor category is perfectly represented by two of more dimensions if (the sum of) Cos2 along those dimensions is closed to one (i.e. a simple 2-D scatter plot using coordinates of the predictor category and the identified pair of axes would adequately explain variance in the category data). Among multiple predictors, a higher relative contribution value for a predictor along any dimension means the dimension would be quite different without the predictor category (i.e., the predictor is important). In that context, results show that although some predictors appeared to be well represented (e.g., E/G along Dim 1 and Dim 3; D/G along Dim 3 and Dim 4), the qualities of their representation were low (Supplementary Material Fig. S1b) and hence the predictors did not contribute much to those dimensions (Supplementary Material Fig. S1c). On the other hand, variables such as those associated with *In.Res.Spr* and *Treat.BedNets* which are lowly represented in relative terms (Supplementary Material Fig. S1a), their presentations were actually of high quality (Supplementary Material Fig. S1b), hence higher contributions along the dimension representing them.

To definitively decide on the wellness of predictor representations along a pair of dimensions require such plots as shown in Fig. 3 in which the further a predictor is from 0, the better the representation along that dimension. One can then see that most information in this study are represented by the first two dimensions (Fig. 3a). That is, Dim 1 and 2 together represent adequately *Test.BedNet*, *Treat.BedNet*, *malaria.control*, *IRS* and *I.Res.Spr*, the five important predictors of malaria identified by MCA, and that Dim 3 and Dim 4 represent only the collection of *malaria.control* strategies offered by respondents.

When the information displayed in Supplementary Material Fig. S1 and Fig. 3 are factored into (i) determining the most important predictors of malaria, and (ii) the number of dimensions to retain for further MCA and HCPC analyses, the following is clear: that attempts to understand malaria in the study area ought to focus on the representation of bed nets, their treatment and indoor residual spraying along the first two MCA dimensions, and perhaps the third as well (i.e., Dim 1, Dim 2 and Dim 3). With this in mind, below are the MCA results with potential interpretations.

Linking identified strategies to households by MCA factor map

In Figs. 4 and 5 are displayed MCA results as factor maps showing clusters of correlated households in groups. The selection of the first three MCA dimensions to retain (Dim 1, Dim 2 and Dim 3) comes directly from Fig. 3. The first dimension (Dim 1) is tied to the state of indoor residual spraying of insecticides by households (denoted by *IRS* and *In.Res.Spr* in Fig. 4). The second dimension (Dim 2) correlates with testing and treating bed nets; the third (Dim 3) with whether some measure of malaria control is used by household or not.

In details, Dim 1 (Fig. 4a) represents steady shift from indoor residual spraying (*In.Res.Spr_yes*: positive loading, I) to none (*In.Res.Spr_no*: negative loading, II). Thirty-four (34) of the 193 households surveyed scored strongly along Dim 1, 29 of which – by relating to the original data – used bed nets (85%). Concurrently, households that answered *no* to indoor residual spraying – 24 out of the 34 which score strongly along Dim 1 (*In.Res.Spr_no* and *IRS_no*: loading negatively) and/or used bed nets impregnated or treated with insecticides (*Treat.BedNet_yes*).

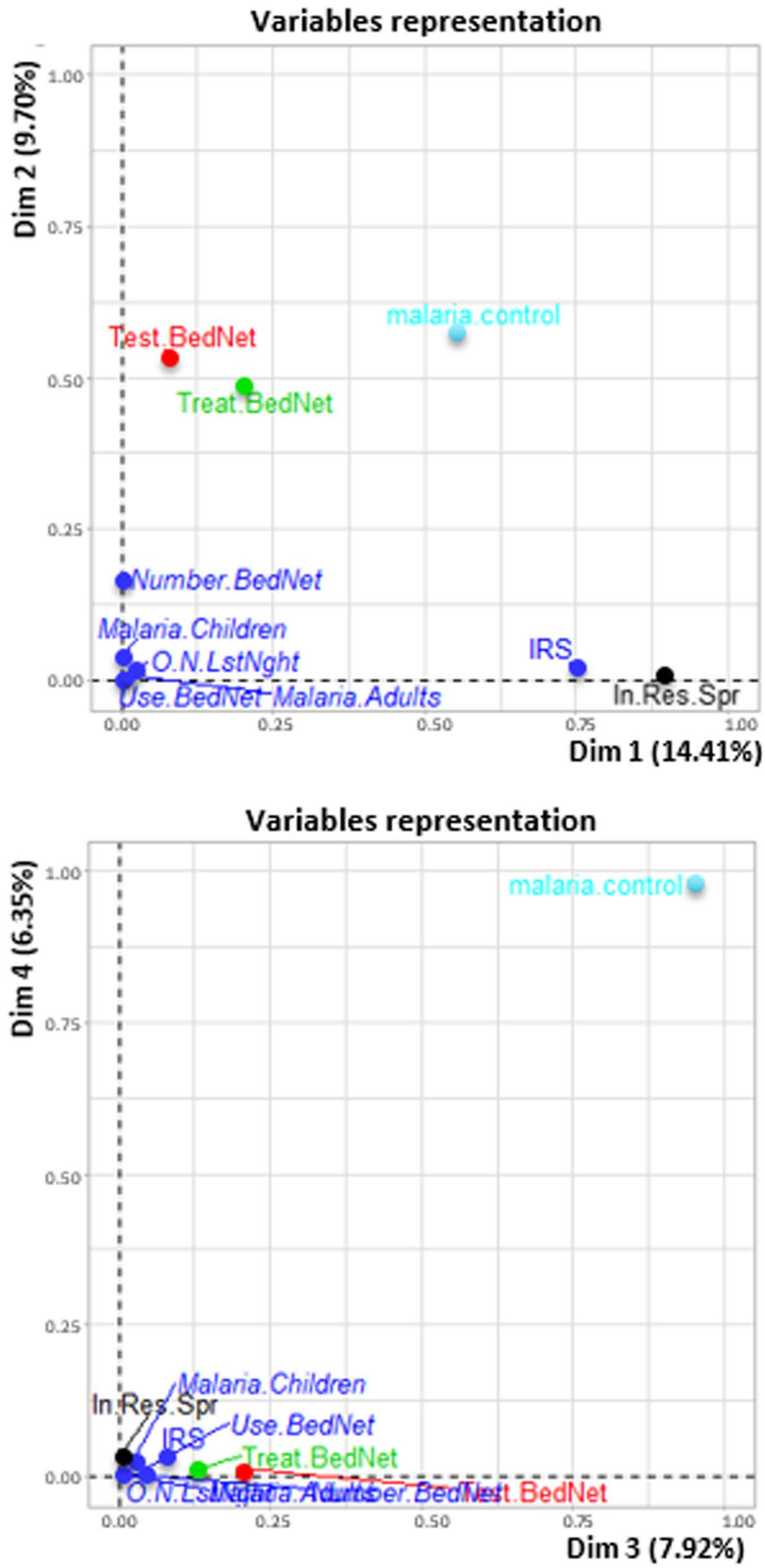
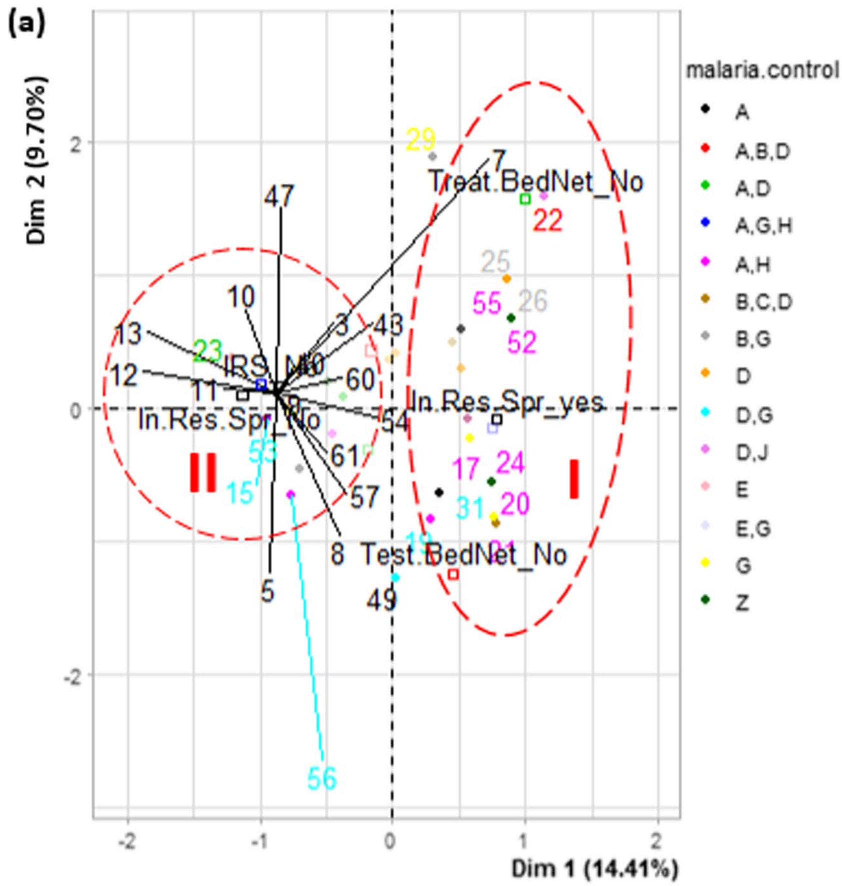


Fig. 3 Variable representation along the first four MCA dimensions showing that (**a**) Dim1 and 2 together represent Test.BedNet, Treat.BedNet, malaria.control, IRS and I.Res.Spr, the five most important predictors of malaria identified MCA, adequately while (**b**) Dim 3 and Dim 4 represent only malaria.control adequately. The first two dimensions therefore explain most of the inertia (variation) contained in the data. Number.BedNet, Use.BedNet, O.N.LstNight, Malaria. Children and Malaria. Adults are supplementary variables added for completeness (see Fig. 4)



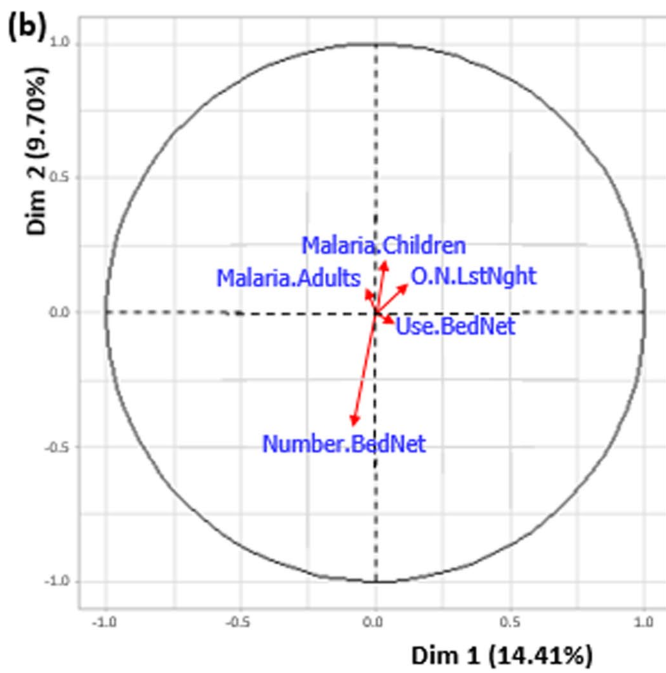


Fig. 4 **a** MCA factor map showing the clustering of 61 of the most contributive households (out of 193) and the five of the most important interventions to the two first two MCA dimensions. Key to Malaria.Control are provided in Fig. 2 caption. **b** Vectors showing the relationships between malaria episodes in children or adults and either the number of people who spent the night before in residential house (O.N.LstNight; used here as surrogate for continual residency in a household), the number of bed nets in households, or the usage of bed nets

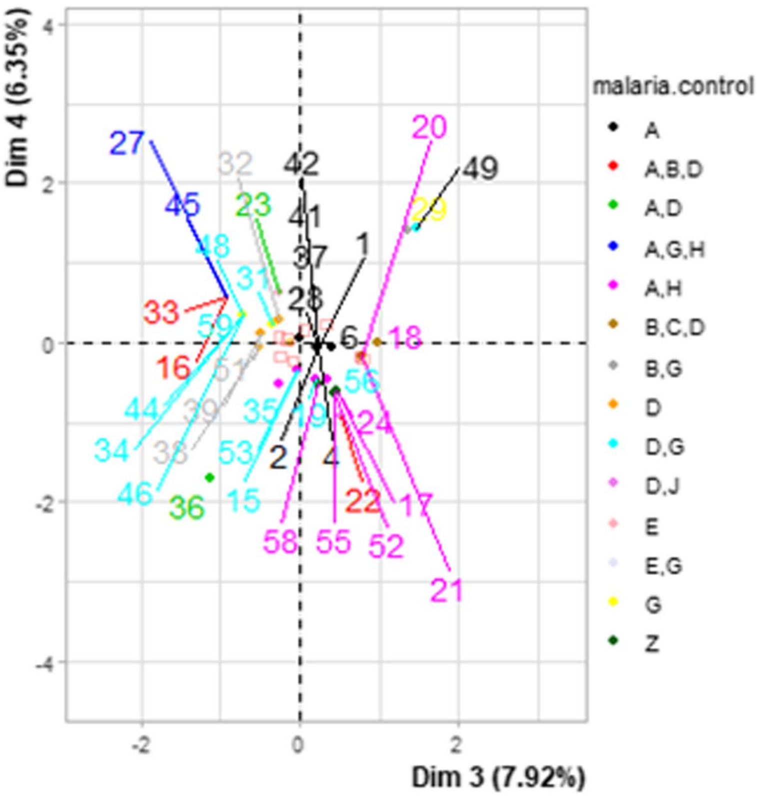


Fig. 5 Factor map showing correlations of the third and fourth dimensions which are mainly with the additional malaria control strategies defined in Fig. 2 caption (A to Z) and not with the major drivers of malaria in northern Uganda

These households are split 1:1 between non-bed nets users (who score strongly along the dimension) and bed nets users (who scoreless strongly along Dim 1).

The locations of the households that scored strongly (positively or negatively) along Dim 1 are Parabongo in Agago District, Minakulu in Oyam District, Layamo in Kitgum District, and Awach and Unyama in Gulu District. The village-level distributions are as follows: 11 in Pacer Parish in Parabongo sub-county, Agago District (10 in Jinja Village and one in Olwor Nguu), six in Adel Parish, Minakulu sub-county, Oyam (all in Obapo village), two in Abanya Parish, Oyam District (Mot-mot Atwero and Bar Owor, Acaba,), two in Pakwelo Parish, Unyama sub-county, Gulu District (Akonyibedo village) and two in Pagen Parish, Layamo sub-county, Kitgum (Lelamur village), and one household in Gweng Diya Parish in Awach sub-county, Gulu district (Pageya).

Dimension 2 (Dim 2) represented a gradual increase from those households that use treated bed nets (*Treat.BedNet_yes*) without testing them (*Test.BedNet_no*) to those households that test bed nets (*Test.BedNet_yes*) in addition to taking other malaria control measures such as draining water pool (*B*) and keeping grass short around the homestead (*D*). Dim 2 also separates households with bed nets (scoring strongly and negatively) from those without bed nets (scoring strongly and positively). For intervention, the households with bed nets rely mostly in treatment after contracting malaria while the households with no bed nets relies primarily on clearing grasses around the house to remove mosquito hiding places. All households represented by Dim 2 reported at least one household member with malaria in the three months prior to this survey.

To provide actionable items based on alignment along Dim 1 and Dim 2, the vectorial relationship among each of those most important supplementary quantitative predictors are displayed in Fig. 4b. The alignment of the vectors suggests the following: that more than any other intervention strategies studied, incidences of malarial (Malaria. Adults and Malaria. Children) were strongly related to lack of bed nets or lack of use thereof (i.e., Number.BedNets and Use.BedNets vectors point in opposite directions to vectors representing malaria incidences in children and adults), and directly associated with the number of individuals spending a night together in a household (i.e., O.N.LstNight vector points approximately in the same directions as vectors representing malaria incidences). The results also show that more children are affected in northern Uganda than adults (vectors representing children are longer than those representing adults). These two findings provide ground for concerted efforts to encourage the usage of bed nets at night in northern Uganda, especially where children are involved.

Dimensions 3 and 4 (Dim 3 and Dim 4) represent differences combinations of the additional control strategies offered by respondents under the *malaria.control* category (Fig. 5). (That is, the coordinates of predictors (*A-Z*) are furthers from 0 along these two dimensions in; Figs. 3a and 4, meaning they are well represented along these two dimensions.) The results suggest that for households which use bed nets in combination with IRS, there is a difference between a households accept treatment after getting sick (*A*, *H*, *G*; blue) and those that do not include treatment after the onset of malaria (*A*, *H*; pink). We offer no plausible explanation for this difference at this time.

HCPC results

HCPC was used here to assess similarities among the 193 households surveyed with the hope of informing a uniform public outreach on malarial control in northern Uganda, or of detecting potentially localized misinformation or misperception of activities that households are being asked to engage in regarding malaria control in the region. The data source for HCPC was the first five MCA dimensions.

The results, displayed in Fig. 6, shows that our survey households do group naturally into four clusters (Fig. 6a). Cluster 1, the most distinct of the four clusters (i.e., the longest 'arm' separating it from the others in Fig. 6b), comprises households that use bed nets but sleep in houses not sprayed with insecticides (Fig. 6c). In cluster 2 are households with no bed nets but do spray residual insecticides indoors. Clusters 3 and 4 possess similar intrinsic attributes (*IRS*, *I.Res.Spr* and *Treat.BedNet*), but have enough of a difference to be apart (*Test.BedNet*) (Fig. 6c). The conclusion from HCPC is that, at the minimum, four categories of households exist in northern Uganda in relation to malaria intervention (Fig. 6c): one that relies on bed nets only to control malaria, a second which relies mostly on residual insecticides indoor spraying, a third which relies on indoor residual spraying along with bed nets insecticides pretreatment, and a forth category of households comprising very cautious members who implement all the four important malaria control strategies identified by HCPC from our data.

For quality assurance, the links between the household clusters and the four major categorical malaria predictors, as determined by chi-square test reported by *p*-values (and degrees of freedom in parenthesis), were *Treat.BedNet*: $3.60e^{-13}$ (3); *Test.BedNet*: $3.95e^{-10}$ (3); *IRS*: $2.52e^{-09}$ (3); and *Malaria.Control* $3.85e^{-05}$ (39). This means the clustering in Fig. 6 are highly significant on the basis of the major predictors identified by MCA.

Discussion

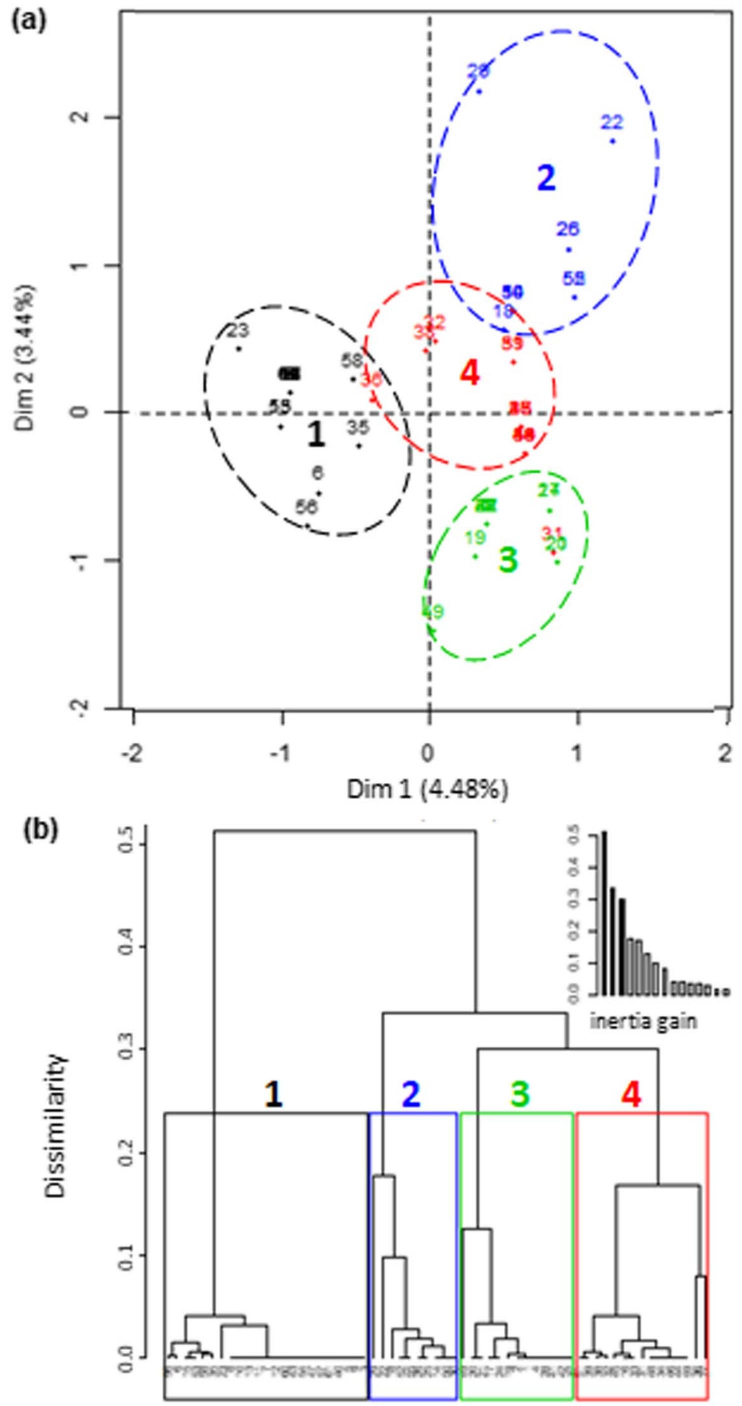
In this study, we assessed household malaria intervention strategies on episodes of malaria in northern Uganda. The goal was to gain insight into the impact of current control intervention on the dynamics of malaria transmission in the region. Such information is relevant in formulating a uniform public outreach on malaria control, and in detecting localized retrogressive information, or misperception about activities households may be asked, or are being asked to engage in for health reasons.

In general, each household was found to own two-bed nets on average under which 86% of the study population slept during the three months prior to the interview. The 86% represents a 4.2% (within errors) over bed nets usage recorded 10 years ago in the same areas of northern Uganda (81.8%) [26]. Furthermore, this finding is consistent with the findings of similar studies carried out in parts of Tanzania (80% bed net coverage) [27–30] and elsewhere in the world [3] although is higher than those reported in Kenya and the remaining 20% of Tanzania [28, 31, 32].

A statistical shift away from indoor residual spraying was observed when other alternatives were available (e.g., Fig. 4a). The shift appears to reflect a resistance to spraying residual insecticides indoors when for instance treated bed nets are available. On the flip side, households also appear to believe that bed nets are not a requirement once indoor spraying has taken place, in which case lack of a bed net would be the driving force to spraying insecticides indoors. Further study is required to explain this observation.

The small improvement in coverage here (4.2%), if real, could be attributed (i) to the national malaria control program of interventions which has visibly increased bed nets coverage in the region (in line with World Health Organization policy on ITN recommendations), and (ii) to the free bed nets which have been distributed and are being used by pregnant women and infants across the country over the years [5, 33, 34].

Our results show very clearly that the incidence of malaria in children and adult were strongly related to lack of bed net or lack of use thereof, and is directly associated with the number of individuals spending a night together in a house. Such observations have been made in previous studies in Africa [35–37] and should not be surprising given that bed nets are known to be highly protective against malaria as reported in studies around the world [36, 37].



(c)

	IRS	In.Res.Spr	Test.BedNet	Treat.BedNet
cluster 1	No	No	Yes	Yes
cluster 2	Yes	Yes	Yes	No
cluster 3	yes	Yes	No	Yes
cluster 4	Yes	Yes	Yes	Yes

Fig. 6 A factor map (**a**) and a dendrogram (**b**) showing the four household groupings identified by passing on to HCPC out of the five (5) most significant MCA dimensions. Drivers of HCPC clustering in (**a**) as delineated by v-test values (Supplementary material appendix 1). Euclidean matrix was used

In detail, the present study shows that households without bed nets control malaria by applying IRS in combination with other preventive measures such as closing doors (with the hope of keeping mosquitos at bay), draining stagnant water pools where mosquitos lay their eggs, trimming mosquito covers around the homestead (grass) and/or receiving treatment after malaria episodes. An overall inclination towards using IRS against the spread of malaria was observed in the study area. 84% of households were found to be more likely to use IRS to control malaria vectors than the percentages of households in most countries in Africa [38]. This result singularly suggests that households in the study area have achieved the successful campaign threshold of 85% IRS usage as recommended by WHO [2]. As stated earlier, the high coverage is attributable to the long history of IRS and LLINs usage in the region [39].

It's important to note that ITNs are the first major malaria vector tool used to prevent malaria in Africa, followed by IRS. And because of this serial introduction, the high but non-overlapping usage of IRS and bed nets here could be based on the local perception that given a choice between residual insecticides sprayed indoors and treated bed nets, insecticides are not needed when a household owns a bed net (100% of 24 households which MCA has identified to be similarly predisposed fall in this category). It could also be based on a perception, to a minor extent, that bed nets are not a requirement once indoor spraying has taken place. Lack of a bed net in the latter situation therefore would be the driving force for spraying insecticides indoors. We do not have definitive data to show that people who had their houses sprayed were less likely to use their nets, or vice versa. For intervention within this apparently dichotomous subpopulation of our samples, the households with bed nets rely mostly on treatment after contracting malaria while the households with no bed nets rely primarily on clearing grasses around the house to remove mosquito hiding places.

Despite these achievements of high coverage of IRS and ITNs in the study area, high malaria incidence was still reported among the local communities at levels similar to those observed elsewhere in Africa [32, 33]. Of the 605 who were declared to have spent the previous night in these households, 255 had malarial in the three months prior to this study, 171 of which were children (67%, a ratio of 2:1). Compared to adults, the high rate of malaria in children here can be explained by lack of or delayed acquired immunity to the disease. Adults normally would have acquired this immunity by a certain age through their childhood in high transmission areas like northern Uganda. WHO recommends several interventions in cases of high malaria transmission in children [4]. These recommendations include prompt diagnosis and effective treatment, use of LLINs, intermittent preventive therapy and seasonal malaria chemoprevention to coincide with peak seasons in malaria transmission areas.

As with findings in other studies, malaria has been recorded unfortunately in areas where high intervention with IRS and/or ITN has been the modus operandi against malaria [31, 32]. It is believed that factors such as high mosquito insecticide resistance [40, 41] are responsible for the observed persistence of malaria in such areas as was recently shown by Echodu et al. in the study area [9]. Sharing bed nets has also been singled out in the reduced effectiveness of IRS/ITN against malaria since the protective efficiency of bed nets is reduced by such practice. That is, an aggregate of human bodies appears to attract more mosquitoes than a single human body [31] as evident by the strong relationship between the high incidence of malaria and the number of individuals in our typical household. Bed net ownership was limited to between 1 and 5 per household (3 ± 2) which at times had more than 3 residents at night ($>605/193$). Furthermore, the high malaria burden in northern Uganda could be attributed to the cumulated hours communities spend outdoors preparing family meals, socializing, or during cultural events such as marriages, festivities and burial ceremonies in the evenings, thus exposing themselves to mosquito bites.

Lastly, we sought here to find similarities among households in the study area based on the data we collected. This was meant to find natural aggregations of similar responses to malaria across villages which could signal not only the presence of localized differential perception of how to handle or prevent malaria but could potentially unearth disparity across villages/districts, especially if such aggregations are concentrated in a region. The basis of this approach is that in the absence of extenuating factors (i.e., if perception, behaviour, approaches to containing malaria or resources were uniform), all households would belong to only one large cluster. In this context, three clusters were detected by HCPC, meaning that there were three types of households in northern Uganda at the time of this study (see HCPC results subsection for description). At the minimum, HCPC has provided incontrovertible evidence supporting the notion that malaria control in northern Uganda is not conducted uniformly. There is a need therefore to address the root causes of this non-uniformity. The least that can be done to address this non-uniformity is to tailor malaria messages to each household cluster since the pattern of clustering appears not to be random.

Limitations

We acknowledge the limitations of the current study including the time constraints of conducting this research. We had limited time which significantly affected the geographical areas and the number of participants we could cover in depth. There was no qualitative study like a focus group interview which could offer insights into the sociocultural behaviours of people from northern Uganda that contribute to malaria remaining a problem in northern Uganda despite the many intervention efforts. Our questionnaire did not capture a couple of questions regarding the levels of education and socioeconomic data of households that are often linked to health outcomes, access to malaria information, acceptance to purchase of bednets and use of IRS and timely seeking of malaria treatment.

Conclusion

In this study, we show household predictors of episodes of malaria in northern Uganda to include: 1) the number of bed nets and sleeping in houses sprayed with insecticides; 2) the use of bed nets but no indoor residual spraying with insecticides and 3) the lack of use of bed nets at night and no indoor residual spraying. High episodes of malaria were correlated strongly, more so in children than in adults, with low usage of bed nets and a high number of individuals sleeping in the same household at night. These three clusters of households identified to exist in northern Uganda by studying the combinations of strategies used by households to contain malaria provides an opportunity to tailor-make preventive/intervention malaria messages to fit the individual household clusters.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-22175-8.

Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Acknowledgements

We are grateful to the district health officers, vector control officers and communities of Agago, Gulu, Oyam and Kitgum region for participating in this research.

Authors' contributions

RE conceived, contributed design of the study, field collections, analyzed the data, and drafted an initial version of the manuscript. WSO and TI, performed field collections and analyzed the data, EAO and JJL conceived, designed the study, coordinated fieldwork and provided guidance, FA performed formal analysis, reviewed and edited the manuscript, OO carried out statistical analysis, reviewed and edited manuscript drafts. All authors read and approved the final manuscript.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported through the DELTAS Africa Initiative grant # DEL-15–011 to THRiVE-2 awarded through Career Development Award to Dr. Richard Echodu. The DELTAS Africa Initiative is an independent funding scheme of the African Academy of Sciences (AAS)'s Alliance for Accelerating Excellence in Science in Africa (AESA) and supported by the New Partnership for African's Development Planning and Coordinating Agency (NEPAD Agency) with funding from the Wellcome Trust grant # 107742/Z/15/Z and the UK government. The views expressed in this publication are those of the author(s) and not necessarily those of AAS, NEPAD Agency, Wellcome Trust or the UK government.

Data availability

The authors declare that all the main data supporting the findings of this study are available within the article (and its supplementary information files).

Declarations

Ethics approval and consent to participate

This study was approved by Gulu University Ethical Review Committee (GUREC13/11/2017). Formal approval to conduct the study was granted by the Uganda National Council for Science and Technology (UNCST) and the Office of the Ugandan President (SS4610). All methods were carried out in accordance with UNCST guidelines and regulations. Informed consent was taken from parents and guardians for participants below 16 years or in case they were illiterate. All the participants signed informed consent before participating in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Biology, Faculty of Science, Gulu University, P. O. Box 166, Gulu City, Uganda. [2]Gulu University Multifunctional Research Laboratories, P. O. Box 166, Gulu City, Uganda. [3]Department of Midwifery, Faculty of Nursing and Midwifery, Lira University, P. O. Box 1035, Lira City, Uganda. [4]Department of Arbovirology, Emerging and Re-Emerging Infectious Diseases, Uganda Virus Research Institute, P. O. Box 49, Entebbe, Uganda. [5]Department of Health Sciences and Sciences, University of California, City of Los Angeles, CA, USA. [6]Department of Chemistry, Faculty of Science, Gulu University, P.O. Box 166, Gulu City, Uganda.

Received: 19 September 2021 Accepted: 3 March 2025
Published online: 12 March 2025

References

1. World Health Organization. Wolrd malaria report 2024. https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2024.
2. WHO. Global technical strategy for malaria 2016–2030, World Heal. Organ. 2015:1–35. http://apps.who.int/iris/bitstream/10665/176712/1/9789241564991_eng.pdf?ua=1.
3. WHO. World malaria report 2017. 2017. https://doi.org/10.1071/EC12504.
4. World Health Organization. World malaria report 2018. 2018. www.who.int/malaria%0A. https://apps.who.int/iris/bitstream/handle/10665/275867/97.
5. Ugandan Ministry of Health. Annual health sector performance report. Uganda Minist Heal. 2018;4:1–238. https://doi.org/10.1111/j.1467-9299.1926.tb02260.x.
6. Ndyomugyenyi R, Clarke SE, Hutchison CL, Schultz K. Efficacy of malaria prevention during pregnancy in an area of low and unstable transmission: an individually-randomised placebo-controlled trial using intermittent preventive treatment and insecticide-treated nets in the Kabale Highlands, south western Ug. Trans R Soc Trop Med Hyg. 2011;105:607–16. https://doi.org/10.1016/j.trstmh.2011.07.012.Efficacy.

7. Achol E, Ochaya S, Malinga GM, Edema H, Echodu R. High prevalence of Pfmdr-1 N86 and D1246 genotypes detected among febrile malaria outpatients attending Lira Regional Referral Hospital, Northern Uganda. BMC Res Notes. 2019;12:1–4. https://doi.org/10.1186/s13104-019-4269-1.
8. Okia M, Hoel DF, Kirunda J, Rwakimari JB, Mpeka B, Ambayo D, Price A, Oguttu DW, Okui AP, Govere J. Insecticide resistance status of the malaria mosquitoes: Anopheles gambiae and Anopheles funestus in eastern and northern Uganda. BMC Malar J. 2018;17:1–12. https://doi.org/10.1186/s12936-018-2293-6.
9. Echodu R, Iga J, Oyet WS, Mireji P, Anena J, Onanyang D, Iwiru T, Lutwama JJ, Opiyo EA. High insecticide resistances levels in Anopheles gambiaes s.l. In northern Uganda and its relevance for future malaria control. BMC Res Notes. 2020;13:1–6. https://doi.org/10.1186/s13104-020-05193-0.
10. Okello PE, Van Bortel W, Byaruhanga AM, Correwyn A, Roelants P, Talisuna A, D'Alessandro U, Coosemans M. Variation in malaria transmission intensity in seven sites throughout Uganda. Am J Trop Med Hyg. 2006;75:219–25. https://doi.org/10.4269/ajtmh.2006.75.219.
11. Proietti C, Pettinato DD, Kanoi BN, Ntege E, Crisanti A, Riley EM, Egwang TG, Drakeley C, Bousema T. Continuing intense malaria transmission in northern Uganda. Am J Trop Med Hyg. 2011;84(5):830–7. https://doi.org/10.4269/ajtmh.2011.10-0498.
12. Uganda National Malaria Control Division (NMCD), Uganda Bureau of Statistics (UBOS), ICF. Uganda malaria indicator survey 2018–19. Kampala, Uganda, and Rockville, Maryland, USA: NMCD, UBOS, and ICF. 2020.
13. Larsen DA, Hutchinson P, Bennett A, Yukich J, Anglewicz P, Keating J, Eisele TP. Community coverage with insecticide-treated mosquito nets and observed associations with all-cause child mortality and malaria parasite infections. Am J Trop Med Hyg. 2014;91:950–8. https://doi.org/10.4269/ajtmh.14-0318.
14. Bridges DJ, Pollard D, Winters AM, Winters B, Sikaala C, Renn S, Larsen DA. Accuracy and impact of spatial AIDS based upon satellite enumeration to improve indoor residual spraying spatial coverage. Malar J. 2018;17:1–8. https://doi.org/10.1186/s12936-018-2236-2.
15. Rehman AM, Coleman M, Schwabe C, Baltazar G, Matias A, Gomes IR, Yellott L, Aragon C, Nchama GN, Mzilahowa T, Rowland M, Kleinschmidt I. How much does malaria vector control quality matter: The epidemiological impact of holed nets and inadequate indoor residual spraying. PLoS ONE. 2011;6:1–8. https://doi.org/10.1371/journal.pone.0019205.
16. Twinomujuni NK, Sempagala-Mpagi RA. Uganda districts information handbook, Kampala Fountain Publ. (2011) 372.
17. Uganda Bureau of Statistics (UBOS). Uganda national household survey, 2012/2013. Kampala: UBOS; 2012. https://www.ubos.org/wp-.
18. Epstein A, Maiteki-Sebuguzi C, Namuganga JF, Nankabirwa JI, Gonahasa S, Opigo J, et al. Resurgence of malaria in Uganda despite sustained indoor residual spraying and repeated long lasting insecticidal net distributions. PLOS Glob Public Health. 2022;2(9):e0000676. https://doi.org/10.1371/journal.pgph.0000676.
19. Raouf S, Mpimbaza A, Kigozi R, Sserwanga A, Rubahika D, Katamba H, et al. Resurgence of malaria following discontinuation of indoor residual spraying of insecticide in an area of Uganda with previously high-transmission intensity. Clin Infect Dis. 2017;65(3):453–60. https://doi.org/10.1093/cid/cix251.
20. T Otsu, H Matsuo. MTV and MGV: two criteria for nonlinear PCA. In: Baba Y., Hayter A.J., Kanefuji K., Kuriki S. (eds) Recent advances in statistical research and data analysis. Springer, Tokyo. 2002. https://doi.org/10.1007/978-4-431-68544-9_4.
21. S Lê, J Josse, F Husson. FactoMineR: an R package for multivariate analysis. J Stat Softw. 25(1):1–18. https://doi.org/10.18637/jss.v025.i01.
22. JJ Allaire. RStudio: integrated development for R. RStudio, PBC, Boston, MA. 2020. Available https://www.r-project.org/conferences/useR-2011/abstracts/180111-allairejj.pdf . Access 18 July 2020.
23. R Core Team. A language and environment for statistical computing. v3.6.3. Vienna: R Foundation for statistical computing; 2019. Available https://www.r-project.org. Access 18 May 2020.
24. FHFP Vaissie, A Monge. Perform factorial analysis from 'FactoMineR' with a Shiny application. R package version 2.3. 2020. https://cran.r-project.org/web/packages/Factoshiny/Factoshiny.pdf. Access 18 July 2020.
25. Ayele D, Zewotir T, Mwambi H. Multiple correspondence analysis as a tool for analysis of large health surveys in African settings. Afr Health Sci. 2014;14:1036–45. https://doi.org/10.4314/ahs.v14i4.35.
26. Uganda Malaria Surveillance Project. Malaria intervention coverage and associated Morbidity survey in children under five years: Indoor residual spraying in northern Uganda and LLIN coverage in central Uganda., Uganda Malar. Surveill Proj. 2012. https://doi.org/10.11693/hyhz20181000233.
27. Matiya DJ, Philbert AB, Kidima W, Matowo JJ, Dynamics and monitoring of insecticide resistance in malaria vectors across mainland Tanzania from,. to 2017: a systematic review. Malar J. 1997;18(2019):1–16. https://doi.org/10.1186/s12936-019-2738-6.
28. Mboma ZM, Overgaard HJ, Moore S, Bradley J, Moore J, Massue DJ, Kramer K, Lines J, Lorenz LM. Mosquito net coverage in years between mass distributions: A case study of Tanzania. Malar J. 2013;17(2018):1–14. https://doi.org/10.1186/s12936-018-2247-z.
29. PA West, N Protopopoff, A Wright, Z Kivaju, R Tigererwa, FW Mosha, W Kisinza, M Rowland, I Kleinschmidt. Indoor residual spraying in combination with insecticide-treated nets compared to insecticide-treated nets alone for protection against malaria: a cluster randomised trial in Tanzania. PLoS Med. 2014;11. https://doi.org/10.1371/journal.pmed.1001630.
30. Stelmach R, Colaço R, Lalji S, McFarland D, Reithinger R. Cost-effectiveness of indoor residual spraying of households with insecticide for malaria prevention and control in Tanzania. Am J Trop Med Hyg. 2018;99:627–37. https://doi.org/10.4269/ajtmh.17-0537.
31. Msellemu D, Shemdoe A, Makungu C, Mlacha Y, Kannady K, Dongus S, Killeen GF, Dillip A. The underlying reasons for very high levels of bed net use, and higher malaria infection prevalence among bed net users than non-users in the Tanzanian city of Dar es Salaam: a qualitative study. Malar J. 2017;16:1–10. https://doi.org/10.1186/s12936-017-2067-6.
32. Kamau A, Nyaga V, Bauni E, Tsofa B, Noor AM, Bejon P, Scott JAG, Hammitt LL. Trends in bednet ownership and usage, and the effect of bednets on malaria hospitalization in the Kilifi Health and Demographic Surveillance System (KHDSS): 2008–2015. BMC Infect Dis. 2017;17:1–9. https://doi.org/10.1186/s12879-017-2822-x.
33. World Malaria Report 2008, World Health Organization; 2008. https://iris.who.int/bitstream/handle/10665/43939/9789241563697_eng.pdf.
34. Ndyomugyenyi R, Tukesiga E, Katamanywa J. Intermittent preventive treatment of malaria in pregnancy (IPTp): participation of community-directed distributors of ivermectin for onchocerciasis improves IPTp access in Ugandan rural communities. Trans R Soc Trop Med Hyg. 2009;103:1221–8. https://doi.org/10.1016/j.trstmh.2009.03.006.
35. Lim SS, Fullman N, Stokes A, Ravishankar N, Masiye F, Murray CJL, Gakidou E. Net benefits: a multicountry analysis of observational data examining associations between insecticide-treated mosquito nets and health outcomes. PLoS Med. 2011;8:1–13. https://doi.org/10.1371/journal.pmed.1001091.
36. Bhatt S, Weiss DJ, Cameron E, Bisanzio D, Mappin B, Dalrymple U. The effect of malaria control on Plasmodium falciparum in Africa between 2000 and 2015. Nature. 2016;526:207–11. https://doi.org/10.1038/nature15535.The.
37. World Health Organization (WHO). World health statistics 2014. 2014. https://doi.org/10.1016/j.bbapap.2013.06.007.
38. Tangena JAA, Hendriks CMJ, Devine M, Tammaro M, Trett AE, Williams I, Depina AJ, Sisay A, Herizo R, Kafy HT, Chizema E, Were A, Rozier J, Coleman M, Moyes CL. Indoor residual spraying for malaria control in sub-Saharan Africa, to 2017: an adjusted retrospective analysis. Malar J. 2020;1997(19):1–15. https://doi.org/10.1186/s12936-020-03216-6.
39. Tukei BB, Beke A, Lamadrid-Figueroa H. Assessing the effect of indoor residual spraying (IRS) on malaria morbidity in Northern Uganda: a before and after study. Malar J. 2017;16:1–9. https://doi.org/10.1186/s12936-016-1652-4.
40. Strode C, Donegan S, Garner P, Enayati AA, Hemingway J. The impact of pyrethroid resistance on the efficacy of insecticide-treated bed nets against African anopheline mosquitoes: systematic review and meta-analysis. PLoS Med. 2014;11:1–32. https://doi.org/10.1371/journal.pmed.1001619.
41. Ranson H, N'guessan R, Lines J, Moiroux N, Nkuni Z, Corbel V. Pyrethroid resistance in African anopheline mosquitoes: what are the implicationsfor malaria control? Trends Parasitol. 2011;16:91–8. https://doi.org/10.1016/j.pt.2010.08.004.

Publisher's Note