Household Predictors of Incidence of Malaria in Northern Uganda: Its Implication for Future Malaria Control

Richard Echodu (richardechodu2009@gmail.com)
Gulu University Bioscience Research Laboratories https://orcid.org/0000-0002-1979-1012
William Sam Oyet
Gulu University
Tereza Iwiru
Gulu University
Felister Apili
Lira University
Julius Julian Lutwama
Uganda Virus Research Institute
Elizabeth Auma Opiyo
Gulu University
Ochan Otim
University of California Los Angeles

Research

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Abstract

Background: Use of indoor residual spraying (IRS), long-lasting insecticidal nets (LLINS) and treatment with artemisinin-based combination therapy (ACT) have been greatly promoted in northern Uganda but the region still records highest number of malaria cases with prevalence up to 63%. This study assesses household predicators of malaria in the region and its impact on incidence of malaria at household levels.

Methods: A cross-sectional study was conducted in four districts of Gulu, Oyam, Kitgum and Agago covering sixteen known hyper-endemics villages with high malaria burden in northern Uganda. In total, 193 households were surveyed. Data was collected through pre-tested structured questionnaires and systematically coded and analyzed using *R* software.

Results:

Women headed 58% of the 193 households surveyed. Six hundred and five (605) individuals were declared to have spent a night in the 193 households surveyed. Nighttime is when mosquitoes mostly gain access to victims in the study area. On average, there were two bed nets per household and out of the 605 individuals declared, 502 502 (86%) spent the night prior to interview under a bed net. Despite this effort, these households still reported malaria incidences in the last three months. Overall, children were prone to malaria more than adults by a ratio of 3:2, and in general, malaria incidences were strongly related to lack of bed nets or use thereof, and also linked directly to the number of individuals in a house. Households without bed nets controlled malaria by means of IRS in combination with closing doors (with the hope of keeping mosquitos at bay), draining stagnant water pool where mosquitos lay their eggs, trimming mosquito covers (grass) around homestead and/or receiving treatment after malaria incidences. When given a choice between insecticides (IRS) and treated bed nets, 1 in 3 households preferred treated bed nets. At the same time, bed nets were perceived unnecessary once IRS was applied. If true, the driving force to spraying insecticides indoor then becomes lack of a bed net.

Conclusions:

Household predicators of incidence of malaria in northern Uganda includes bed nets, use of treated bed nets, and indoor residual spraying with households not practicing any of these bearing the heaviest burden of malaria. Hierarchical clustering on principal components (HCPC) clusters households into four types in northern Uganda, 1) household that use bed nets and sleep in houses sprayed with insecticides; 2) households that use bed nets but no indoor residual spraying with insecticides; 3) households that have no bed nets and no indoor residual spraying; and 4) test bed nets before use. An opportunity therefore arises for tailoring malaria messages to fit each cluster of households given that clustering here appears not to be random. Malaria incidence was higher in children as compared to the adults that necessities having guidelines for management of interventions in local community setting.

Background

Malaria remains a major public health concern worldwide, more seriously in the sub-Sahran Africa. With the over 228 million cases reported worldwide in 2018, sub-Saharan Africa accounted for 93% of the total cases of malaria worldwide [1]. The World Health Organization (WHO), in their Global Technical Strategy for Malaria 2016–2030 publication [2] repored positive results with malaria incidence rates declining globally from 76 to 57 cases per 1000 population at risk in the period of 2010 to 2018 [1, 3]. Most of this decline has been attributed to scale-up of indoor residual spraying (IRS), long-lasting insecticidal nets (LLINs) usage as well as introduction of artemisinin-based combination therapy (ACT) for malaria treatment and intermittent preventive treatment (IPTp) during pregnancy [2]. Despite these intervention efforts, malaria still continues to be a major cause of morbidity and mortality globally with an estimated 3.2 billion people at risk of being infected and developing the disease [2]. Among the most affected groups by malaria, pregnant women and children in Africa are the hardest hit with over eleven million being infected with malaria and close to 1 million children produced with low birth weight associated to malaria [1]. This is mainly attributed to the over 40% of pregnant women not sleeping under an insecticide treated nets (ITN) in 2018 while two thirds were not receiving the recommended three or more doses of preventive therapy during the course of their pregnancy [1].

Uganda remains among the five countries that contribute 50% of the global malaria cases [1, 4] and standing at ninth and tenth highest mortality and morbidity respectively due to malaria worldwide [5]. World Health Organization recommends intermediate interventions with seasonal malaria chemoprevention in areas with high seasonal transmission [6]. Uganda adopted this strategy earlier before it was recommended by WHO using integrated community village health team strategy to bridge human health resources gap in rural and peri-urban areas in case management of diseases including malaria [7]. Despite these interventions, malaria remains the number one leading cause of morbidity and mortality in the country [5]with transmission being endemic and perennial throughout the country. High malaria transmission picks up following the end of rainy seasons with the peaks being seen in December to Feb and May to July [8].

To achieve global strategy reduction plan of at least 40% in malaria cases incidence by 2030, Uganda has adapted a couple of other interventions strategies with the goal of having accelerated nationwide scale up of universal coverage of cost-effective malaria prevention and treatment interventions [5]. These interventions includes 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, behavior change communication, strengthening existing malaria surveillance, monitoring and evaluation systems [5].

Despite these many control strategies deployed in Uganda, malaria cases and deaths remain high in the country mainly due to delayed health seeking, clinical judgment without laboratory confirmation, widespread insecticide resistance in mosquito populations [5, 9–12]. Understanding changes in malaria transmission and household predictor factors could shade light on the success of these control strategies. These predictors can help give knowledge on community beliefs and pro-actives involvement in malaria disease management can be empowered and how to sustain participation of the communities in surveillance, treatment and control activity initiatives and locate the possible areas under risk to plan for appropriate malaria control strategies [13].

In northern Uganda, malaria season picks up with transmission between May to November to as high as 1,500 infective bites per person per year, the highest in the whole world [14]. The current primary malaria vector control interventions in the region rely on universal distribution of LLINs and IRS with pyrethroids and non-pyrethroids insecticides [11, 12]. However, household and individual level of protection using LLINs and IRS is largely derived from community level coverage [15, 16]. The WHO recommends the need to have community cooperation and acceptance of IRS and LLINs interventions [2]. Besides, other studies have shown that malaria protection from IRS was strongly associated with high community level coverage than with household acceptance [17]. Northern Uganda has a long history of LLINs and IRS usage for management of malaria vectors [18] but also continues to register the highest number of malaria cases recorded in the country (63% prevalence in 2009) [14, 18, 19] In this study, we look at possible predictors of malaria incidences at household levels in order to guide development of control strategies to improve on the acceptance of all malaria control efforts in future in northern Uganda.

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) 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 [20].

These four districts were affected by a 20 year long civil war between the Holy Spirit Movement and the Lord’s Resistance Army (LRA) on the side, and the government forces, (Uganda People’s Defense Force) on the other side which disrupted social service delivery between the mid 1980’s till 2006. The civil war resulted in the creation of many internally displaced person (IDP) camps out of people who depend on small-scale agriculture as their primary source of income [21]. Since leaving IDP camps, 98% of the farmers are engaged in crop production, while a small percentage rear livestock, including Ankole and Zebu cattle in the mid-north [21]. The region has two rainy seasons annually, receiving between 750–1500 mm from April to May and from August to September [20]. Dry season tend to be severe and lasts from November to March. Temperatures tend to range between 16 and 32 °C (61 and 90°F) with relative humidity of 50–80% [20]. 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 creation of man-made mosquitoes breeding sites.

The households have mainly grass-thatched huts with some semi-permanent and permanent houses. The region has 82% household ownership of at least one insecticide treated bed net in 2010 [22] with the total coverage of 67% of LLIN in the region and 79% of usage in children under 5 year [8]. Malaria prevalence still remains high with the prevalence of 63% recorded in 2009 [19]. Malaria management in the region combines the use of IRS, ITN and home-based management of fever using village health team.

Study Design

A cross-sectional household surveys were conducted 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 sub-counties from each district were randomly selected out of which two villages were chosen at random for study. We randomly sampled on average twelve households per village for an overall study design of 48 households per district (Agago, 51; Gulu, 51; Kitgum, 43; Oyam, 48). Household observations were done along with physical seeing of the LLINs, a mark of IRS. We used a structured standard questionnaire to collect the following information type of housing structure, number of people who slept in the house the previous night, was the indoor residual spraying done in the house, and was the house sprayed the previous night. We also collected information on the kind of insecticide used, whether anyone has suffered from malaria in the last three months, the number, how many were children, how many were adults, were the sick malaria cases tested before treatment. Besides, we collected information on total number of mosquito nets, whether the mosquito nets were treated, were they impregnated with insecticides, who treated it, who slept in it, how often were the bed nets treated, if they have applied IRS, when it was done and any other control malaria measures used by the family.

Ethical standards were maintained throughout the survey. Local council 1, village health teams, vector control officers,and district health officers were involved. The head of the household were briefed on the goal of the research and written informed consent was obtained to enter their houses. This study was approved by 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

The survey provided multiple choice questions. Care was taken to validate each data entry into Microsoft Excel program. The questionnaire covered three broad areas of interests. First, we documented the general structure of a typical household which we believe to be relevant to malaria incidence. Here, we wanted to know whether individuals were living in temporary structure (to which the answer was yes in all cases), and the number of people who slept in the house the previous night. Concurrently, we collected responses about malaria incidences and whether there was any difference between children and adults falling sick. Here, we wanted to know whether anyone in the household had suffered from malaria in the last three months, and the number of the sick who were children or adults. Lastly, we recorded malaria intervention measures employed at the household level. The information we sought included (i) total number of mosquito nets per household; (ii) whether bed nets were tested before treatment for those who had them; (iii) if treated, whether the mosquito bed nets were treated by household head or impregnated with insecticides by supplier (iv) how often were bed nets treated; (v) who slept under the bed nets; (vi) whether household use insecticides other than/or in addition to bed nets; and (vii) whether indoor residual spraying was done in the house the previous or any other night.

Data analysis

Answering the real-life question whether an association exists between predicators of malaria in a region and incidences of malaria among residents of the region is best addressed by modeling joint behavior of multivariate predictors using multivariate statistical tools. In this study, we chose to use multiple correspondence analysis (MCA), technique for this purpose and to reduce the dimension of our data for ease of interpretation. MCA is a statistical technique well suited for detecting and representing underlying structures of a categorical data set. The proportions of variance accounted for by the resulting MCA dimensions were used as it is (uncorrected) because (i) our focus was on the 2-D presentation of MCA results which does not change after correction [23], and (ii) it is well established that contributions of high order dimensions to the total variation in data (the information of importance to us) are always negligible. Studies have suggested that such correction perhaps adds little value to the kind of information we sought via MCA here: the spatial arrangement of points in the cloud [23].

Interpreting MCA results is better said than done from our experience. In that light, we prefer to present as much details as possible here to allow a broader access to our results and conclusions, especially by those affected in the study area. Furthermore, this is the first time MCA is used to study malaria in Uganda to our knowledge.

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). Applying HCPC required organizing the multiple categorical data types we collected into continuous predictors. MCA was used to accomplish this pre-processing as well, the principal components of which were then passed on to HCPC tool. The MCA dimensions kept for this purpose was the first five of seventeen generated by MCA (although first three dimensions would have sufficed).

All factorial analyses were performed using *RStudio* in *R* platform [24, 25] with *FactorMineR* software package [26]. Graphical displays of the MCA results were performed within *Factoshiny* package [27].

Results

Baseline characteristics of respondents

This study was designed to evaluate the impact of family structure and malaria intervention strategies on incidences of malaria in the study area. A total of 193 households were surveyed. The average number of individuals in these households, extrapolated from the declared number who spent the night in a household before the survey was 3 (± 2). Of the 193 households, 111 were headed by women (388 individuals) and 82 by men (217 individuals). Of the 605 total number of individuals, 255 had malaria in the three months prior to this survey; 171 of the sick were children (67%).

Among the malaria intervention strategies included in the survey questionnaire were the availability of bed nets (*Number.BedNet*), the number of individuals who used the nets at night (*Use.BedNet*) and extent of usage as measured by a snapshot count of individuals that spent a previous night in the household (*O.N.LstNight*). Layered over these strategies were the following qualitative predictors: indoor residual insecticide spraying by respondents themselves (*IRS*) or by others (*In.Res.Spr*), testing bed nets whether treated or not before use (*Test.BedNet*), and impregnating or treating bed nets with insecticides (*Treat.BedNet*). Several intervention strategies were offered by respondents in addition to, or as the only means of, controlling malaria in response to the question: How do you control malaria vectors in the family? These included using only bed nets, cutting grass around homestead, draining stagnant water pools, relying on mosquito-repelling incense (from burning dried paste of pyrethrum powder in coils at night), keeping household doors closed, maintaining general cleanliness, applying Shea butter on the skin, and not using solar lighting at night. Overall, obtaining complete data set was possible only for 159 of the 193 cases.

The descriptions of this curated data are displayed in Fig. 1. Each of the 159 cases with complete data set had at least two bed nets (317/159) under which 460 individuals out of 535 (86%) slept the night before this survey (Fig. 1a). The 86% usage is a large empirical number, perhaps reflecting the general attitude towards using bed nets in the study area. Indeed, there was a moderate correlation between the number of individuals in a household overall and the number of individuals in a household that spent the night under bed nets Pearson $r = 0.654$, $p = 8.96e^{-21}$). Ten (10) households were not included in computing this correlation because they reported more individuals sleeping under bed nets than those declared to have spent the previous night in the house. Also excluded were 21 responses other than a *Yes* or a *No* to the question: Who slept under treated mosquito bed nets? That said, the 31 excluded households, had at least one mosquito bed net (impregnated or treated with insecticides), had applied *IRS* in their house, and reported having someone in their midst suffer from malaria in the previous three months.

Overall, a general appreciation for taking measures against the spread of malaria in the study area appears to have taken roots in northern Uganda, particularly the use of insecticides. As can be seen from Fig. 1b, the proportion of households whose malaria coping mechanism involves insecticides was 433 out of a total of 516 (84%). The number 516 (vis-a- vis 193) is due to the fact that some households practiced up to three of the intervention measures shown.

As mentioned earlier, additional coping mechanism adopted by households to control mosquitoes –the carrier of malaria pathogens – were offered by respondents. They range from cutting grass around homestead and draining stagnant water pools to not having any strategy for coping with malaria. The frequencies of these additional coping mechanisms are displayed in Fig. 1c. It can be seen that the singular most dominant coping mechanism remains to be some kind of bed net usage (122 out of 177).

This encouraging result, unfortunately, is followed (albeit to a minor extent), by not having any form of preventive measure or coping mechanism against malaria whatsoever – not even receiving treatment after falling sick (16/177). Seven households kept grass low around houses (ostensibly to deny mosquitoes hiding places during the day) or rely only on medical treatment after becoming sick. A few households reported combining two-to-three strategies to cope with malaria. Four households for example combined keeping grass low around houses with using bed nets, or keeping doors closed with draining stagnant water pool where mosquitoes might breed.

To assess the relative effectiveness of these different strategies against malaria, we computed the ratio: [number of malaria incidences, *s*] / [number of cases, *n*] (*s*/*n* column in Table 1) for each category for comparison. The smaller this ratio is, the more successful the intervention strategy was comparatively. In that context, the ratio was 0.96 for households that relied only on bed nets for controlling malaria (i.e., not even IRS) while for those households that combine nets with IRS, draining stagnant water pool, clearing grass around the house or treatment, the ratio, unfortunately, was higher at 1.33. It got even worse for households that relied exclusively on treatment alone or have no strategy at all. In these cases ratios were 1.50 and 2.00, respectively.

These results clearly suggest that the use of bed nets is not only the best strategy for controlling malaria in the study area, but that prevention is better than getting treated after falling sick. The worse a household can do to control malaria is having no strategy at all; this includes receiving no treatment (ratio: 2.00). Overall, children bore the brunt of malaria in northern Uganda in the three months prior to this survey irrespective of actions taken at household level to control malaria.

Table 1
Comparing the effectiveness of malaria coping strategies offered by respondents beyond indoor spraying.

	Cases	**Malaria incidences**			**Ratio**
	n	Children	Adults	Sum (*s*)	*s*/*n*
Bed nets only	27	21	15	26	0.96
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

Primer To Mca Results

Our questionnaire provided a 22 levels categorical data set containing a mixture of integers and factors. Some of these levels were identified statistically not to be informative and were excluded from further analysis. Exclusion was accomplished by using the MCA technique, a statistical tool that decomposes the total inertia (variance in a multivariate data set) into a number of dimensions equal to, or sometimes less than, the total number of levels in the data set (17 were obtained in this study by decomposing the total inertia). Delineating the dimensions to exclude usually come after factoring into the decomposed values the individual contributions to the observed inertia, hence exposing the less contributing dimensions. In normal practice, this collection of weighted dimensions would lead to excluding all but the first 2 to 5 dimensions. Here, the last step was assumed and skipped to chose the first five dimensions (accounting for 14.41%, 9.70%, 7.92%, 6.35% and 5.88% of uncorrected inertia, respectively) for further analysis. The basis of our assumption here is that (i) the five dimensions had most of the variations contained in the data [23, 28] and that (ii) the kind of information we expected from MCA – the locations of points in the 'cloud of individuals' – are unaffected by correction [23, 29].

Having said that, MCA identified eight intervention strategies out of the 22 by the quality of their representation along the chosen five dimensions as the most significantly related to malaria in both children and in adults in northern Uganda. These were the number of individuals staying overnight in a household (*O.N.LstNight*), the number of bed nets in the households (*Number.BedNet*), the number of individuals who actually used the bed nets (*Use.BedNet*), the number of households that do practice indoor residual spraying (*In.Res.Spr* and *IRS*), the number of households that test bed nets before use (*Test.BedNet*)), the number of households that impregnate or treat bed nets with insecticides before use (*Treat.BedNet*) and a collection of additional strategies offered by respondents assembled here under *malaria.control*. The overall qualities of how well the original 22 categories of predictors are represented by the first five MCA dimensions are displayed graphically in Fig. 2. This assessment of quality is needed here to support our contentions 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.

In Fig. 2a are 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). The further from 0 a coordinate of a predictor is (negative or positive direction) a coordinate of a predictor along a dimension, 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 Fig. 2b and Fig. 2c, 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. 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). The 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 these representations were low (Fig. 2b) hence the low contributions of the predictors to those dimensions (Fig. 3c). On the other hand, variables associated for example with *In.Res.Spr.*, *Test.BedNets* and *Treat.BedNets* which are lowly represented in relative terms by Fig. 2a, their presentations were actually of high quality (Fig. 2b) 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 Fig. 2 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 the focus of attempts to understand malaria in the study area ought to be on the representation of bed nets, their treatment and indoor residual spraying along the first two MCA dimensions, and perhaps the third as well (Dim 1, Dim 2 and Dim 3). With this in mind, below are the MCA results with potential interpretations.

Mca Results – Factor Map

The outputs of MCA applied to the mixed categorical data set assembled here in the manner described above are presented in Fig. 4 and Fig. 5. 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, II) to none (*In.Res.Spr_no*: negative loading, I). 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; *In.Res.Spr_no* and *IRS_no*: loading negatively) do test bed nets before use (*Test.BedNet_yes*) and/or used bed nets impregnated or treated with insecticides (*Treat.BedNet_yes*). These households are split 1:1 between non-bed nets users (who score strongly along the dimension) and bed nets users (who score less strongly along Dim 1). The trend could be explained perhaps on the basis of perception that (i) insecticides are not acceptable to 100% of the 24 households which MCA has identified to be similarly predisposed if given a choice between spraying residual insecticides indoors and using treated bed nets or to a minor extent that (ii) bed nets are not a requirement once indoor spraying has taken place. Lack of a bed net therefore would be the driving force to spraying insecticides indoor.

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Figure 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. 1 caption. (b) Vectors showing the relationships between malaria

incidences in children or adults and either the number of people who spent the night before in residential house (*O.N.LstNight*; surrogate for continual residency), the number of bed nets in households, or the usage of bed nets.

The locations of the households that scored strongly along Dim 1 (positively or negatively) 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 on the basis of 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 (*Number.BedNets* and *Use.BedNets* vectors pointing 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 house (*O.N.LstNight* vector pointing 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 is longer than that representing adults). These two findings encourage usage of bed nets, especially when children are involved.

Dimensions 3 and 4 (Dim 3 and Dim 4) represent differences among the additional control strategies offered by respondents under the *malaria.control* category (Fig. 5). From Figs. 2a and 3b, the coordinates of predictors (*A*-*Z*) are furthers from 0 along these two dimensions. MCA results here suggest for households that use bed nets in combination with IRS, there is a difference between a segment accept treatment after getting sick (*A*,*H*,*G*; blue) and those who did not include treatment after the onset of malaria (*A*, *H*; pink).

Hcpc Results

HCPC was recruited here to assess similarities/dissimilarities among the 193 households surveyed on the basis of the limited malaria data on hand. It is our belief that such analysis could help inform a uniform public outreach on malarial control or detect localized misinformation or misperception of (i) activities that households are being asked to engage in or (ii) the kind of surrounding they are subjected to live with at night. The data source for HCPC was the first five MCA dimensions. The results are displayed in Fig. 6 which shows that the households in our survey do group naturally into four clusters (Fig. 6a) with the cluster labeled 1 being the most distinct from the rest (longer 'arm' in Fig. 6b). Cluster 1 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 types of households exist in northern Uganda in relation to malaria intervention: one that relies only bed nets control malaria, a second which relies on residual insecticides indoor, a third which relies on indoor residual spraying along with bed nets pretreated with insecticides, and the last type which relies on indoor residual spraying along with bed nets pretreated with insecticides or not (Fig. 6c).

For quality assurance, the links between 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 the impact of household structure and malaria intervention strategies on incidences of malaria in northern Uganda. The goal was to gain insight into impact of current malaria control intervention on the dynamics of malaria transmission. This information is relevant in informing uniform public outreach on malaria control, and in detecting localized misinformation or misperception of activities that households are being asked to engage in for health reasons. In general, our results show that 86% of the population in study area slept under bed nets during the study period with an average of two bed nets per household. We slightly see increment of 4.2% from studies conducted in 2010 of 81.8% bed net coverage in same study areas in northern Uganda [22]. This increment could be attributed to Uganda national malaria control program interventions of universal coverage of bed nets in the region as recommended by World Health Organization policy on ITN and accompany by free nets to pregnant women and infants in the country [5, 30, 31]. Our findings are consistent with reports carried out in Tanzania with 80% bed net coverage [32, 33] and other parts of the world [3] but higher than those reported in Kenya and other parts of Tanzania [33–35]. Our results also show that the incidence of malaria in children and adult were strongly related to lack of bed net or lack of use thereof and directly associated with the number of individuals spending a night together in a house which is similar to that observed in other studies in Africa [36, 37]. This is not surprising given that bed nets are known to be highly protective against malaria as reported in other studies in the world [38, 39].

In this present study households without bed nets controlled 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 pool where mosquitos lay their eggs, trimming mosquito covers around homestead (grass) and/or receiving treatment after malaria incidences. Generally, there is overall appreciation for taking measures against the spread of malaria in the study area using IRS with 84% of household using IRS to control malaria vectors which is higher than most countries in Africa [40]. This result suggests that households in the study area have achieved the successful campaign threshold of 85% of using IRS as recommended by WHO [2]. We feel that this high coverage of IRS in the study area can be attributed to the long history of IRS and LLINs usage for management of malaria vectors in the region [41]. IRS activities were introduced in the area in 2005 as a result of malaria epidemics in refugee camps [8, 41]. From 2007 to 2009, all the IRS activities in the study area was done biannually using pyrethroid insecticide, alpha-cypermethrin [41]. However, by 2010, there was a shift to a carbamate insecticide called bendiocarb because of the high insecticide resistance recorded in the area [11, 41]. In 2015, there was cessation of IRS activities in the region [42]. This cessation of IRS activities led to the worst epidemic of malaria affecting ten districts of Lamwo, Gulu, Kitgum, Oyam, Agago, Apc, Amuru, Kole, Nowya and Pader with an average of 5000 cases per district and 40,000 cases per week [42, 43] Since then, IRS activities have continued to be implemented in the study area using Acetellic 300CS (an organophosphate insecticide) [44] much as there is insecticide resistance currently seen in the region [12].

The high usage of IRS and bed nets by households in northern Uganda are similar to those observed within East Africa region [45, 46]. It’s important to note that ITNs is the first major malaria vector tool used to prevent malaria in Africa followed by IRS. Therefore the high usage of IRS and bed nets in study area could be explained perhaps on the basis of perception: that (i) given a choice between residual insecticides sprayed indoors and treated bed nets, insecticides are not acceptable to 100% of the 24 households which MCA has identified to be similarly predisposed, or to a minor extent that (ii) bed nets are not a requirement once indoor spraying has taken place. Lack of a bed net therefore would be the driving force to spraying insecticides indoor. 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. There appears to be a perception that bed nets are unnecessary once IRS was applied

What was very surprising is that despite achieving high coverage of IRS and ITNs in the study area, there was still high malaria incidence reported among the local communities which is similar to what has been observed in other African countries [34, 35]. Of the 605 total number of individuals, 255 had malarial in the three months prior to this study, 171 of which were children (67%, a ratio of 3:2). The high and severe malaria in children can be explained by lack of acquired immunity to the disease in children as compared to adults who acquire this immunity through their childhood especially in the high transmission areas like those in northern Uganda. WHO [4] recommends a number of interventions in such cases of high malaria transmission in children. These recommendations include prompt diagnosis and effective treatment, use of LLINs, intermittent preventive therapy for the children and seasonal malaria chemoprevention to concede with peak seasons in malaria transmission areas.

As in other studies, malaria has been recorded in areas where there is high intervention of IRS and ITN [34, 35] and this could be attributed to a number of factors among which could be attributed to high mosquito insecticide resistance [47, 48] sharing bed nets that end up reducing the protective efficiency since humans are known to attract more mosquitoes per person when they aggregates into groups [34]. This is evident by results that show high incidence of malaria strongly related to lack of bed nets or use thereof and also linked directly to the number of individuals in a house. Recent studies by Echodu et al. [12], in the same study area show high mosquito insecticides resistance. We also think that the high malaria burden in the study area could be attributed to communities in northern Uganda who always spend a lot of time outdoors in the evenings when preparing family meals, drinking, during cultural marriages, cultural festivities and burial ceremonies that pre-exposes them to outdoor mosquito bites.

Among other households predictors, we found the significant relation between malaria in both children and adults with the number of individuals staying overnight in a household, the number of bed nets in the households, the number of individuals who actually used the bed nets and the number of households that do practice indoor residual spraying. The clearest predictors of incidence of malaria in northern Uganda from the MCA results are the number of bed nets (or the lack of it) in a household and how many individuals use them at night. These factors have been shown here to strongly influence the extent of malaria incidences, especially in children, in the region. High usage of bed nets correlates with low incidences of malaria. Complementing this finding is the number of individuals that sleep in the same house at night. This is shown here to correlate directly with incidences of malaria in northern Uganda, more so in households that do not practice any form of malaria prevention.

The HCPC in our case here was about detecting similarities or natural clustering of households on the basis of data collected. It was meant to find aggregation of similar responses to malaria across some villages which could signal the presence of localized misinformation, disinformation, differential perception of how to handle or prevent malaria and the like. This approach could be important in unearthing disparity across villages/districts especially if such clusters are concentrated in a region. In the absence of extenuating factors (i.e., if perception, behavior, approaches to containing malaria or resources were uniform), all households would belong to only one cluster. In this context, HCPC clusters households into four types in northern Uganda. First, there are households that use bed nets and sleep in houses sprayed with insecticides. These are households that seem to rely extensively on the use of insecticides. Then there are households that use bed nets but no indoor residual spraying with insecticides. This second cluster of households differs from the first in that insecticides are preferred in the nets only. The third cluster of households are those that have neither bed nets and nor indoor residual spraying. In other words, the characteristic of the households in this cluster are diametrically different from those of the first cluster. The last HCPC cluster groups households who take one extra step in controlling malaria; they test bed nets before use. The importance of this extra step is debatable. Overall, HCPC reveals that malaria control is not conducted uniformly in the study region. There is therefore a need to address the root causes of this non-uniformity. The least that can be done at this time is to tailor malaria messages to each household cluster since the clustering appears not to be random.

Conclusion

The major household predictor of incidence of malaria in northern Uganda include bed nets, their treatment and indoor residual spraying with households not practicing bearing the heaviest burden of malaria. Malaria incidence was higher in children as compared to the adults that necessities having guidelines for management of interventions in local community setting. HCPC clusters households into four types in northern Uganda, 1) household that use bed nets and sleep in houses sprayed with insecticides; 2) households that use bed nets but no indoor residual spraying with insecticides; 3) households that have no bed nets and no indoor residual spraying; and 4) test bed nets before use. An opportunity therefore arises for tailoring malaria messages to fit each cluster of households given that clustering here appears not to be random.

Limitations

We acknowledge the limitations of the current study including:

- The time constraints of conducting this research during.
- Our questionnaire did not capture a couple of questions including levels of education and socioeconomic data of households that could have given us more information.

Declarations

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 reviewed formal analysis and edited manuscript, OO conceptualization, formal analysis, review and editing the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

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

Consent for publication

Not applicable.

Ethics approval and consent to participate

This study was approved by 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). Community leaders in Oyam, Gulu, Pader, Lamwo, Kitgum and Agago districts provided written informed consent.

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Figures

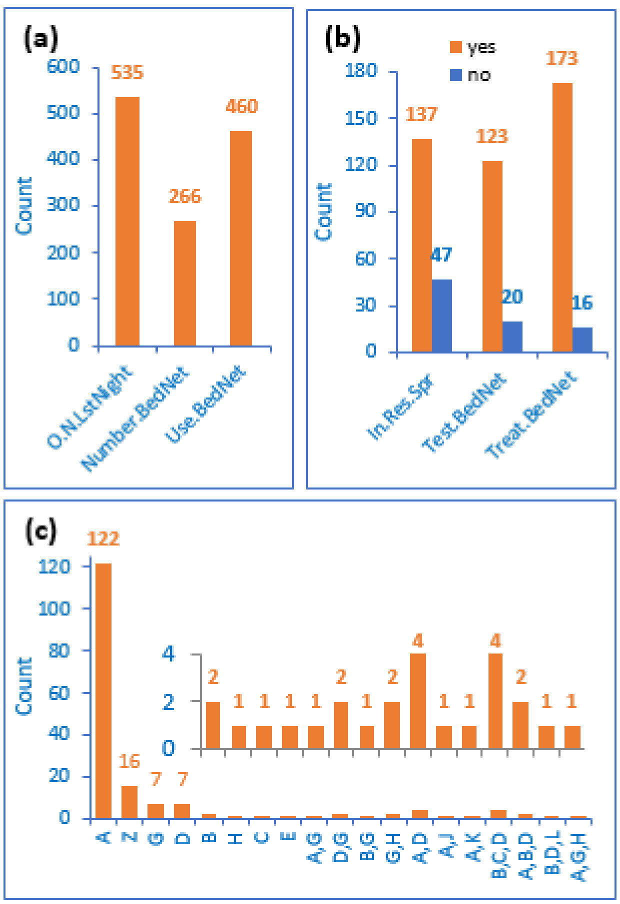

Figure 1

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). (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) Coping with mosquito (malaria.control). 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.

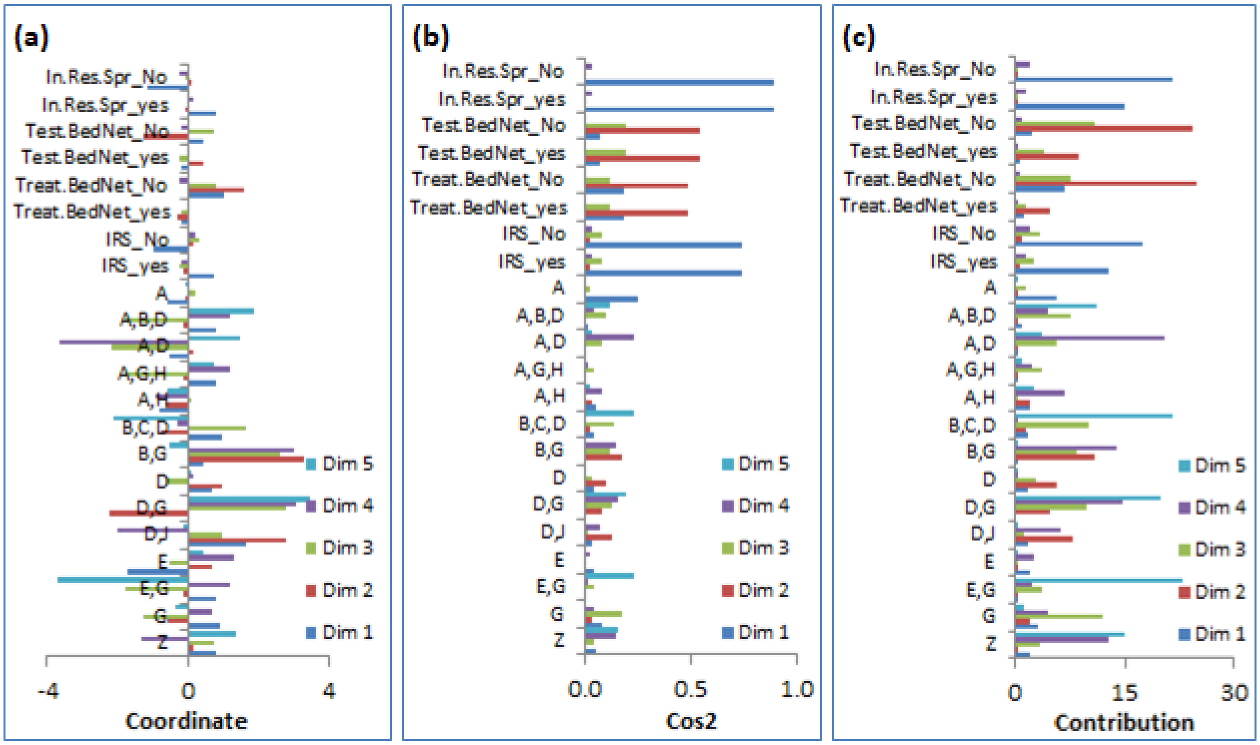

Figure 2

Qualities of predictors representation along the first five MCA dimensions. (a) Coordinates of each variable category showing how far they are from the origin. (b) The quality of representation, given as cosine square. (c) The contribution of each variable along the dimensions. The abbreviations representing predictors are defined in Fig. 1 caption. The ‘_No or ‘_Yes’ in some abbreviations are binary levels of a category.

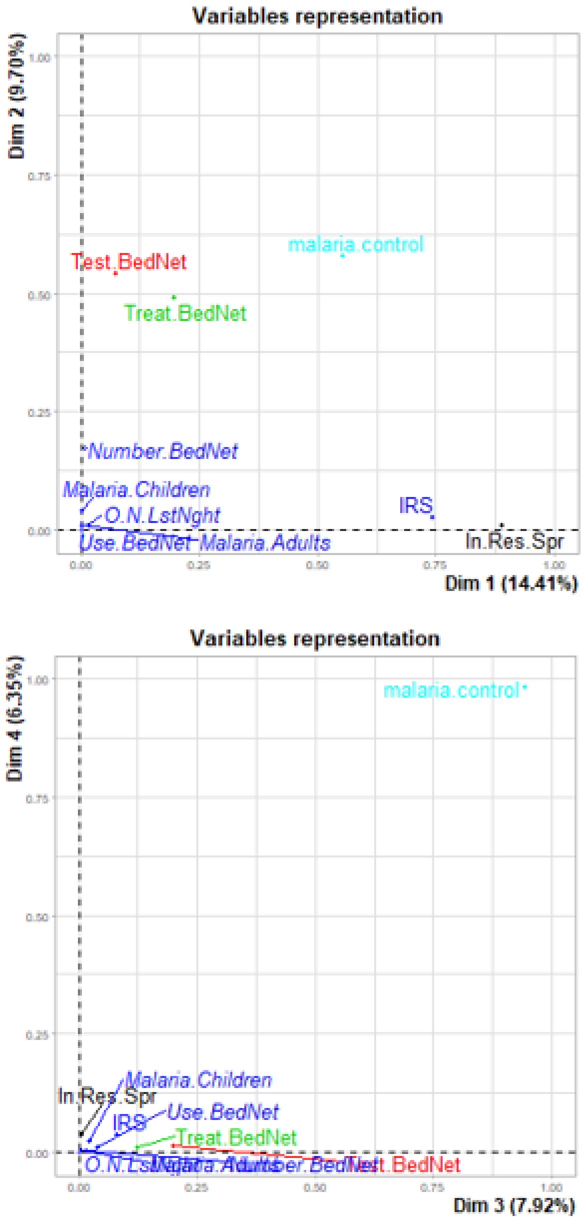

Figure 3

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).

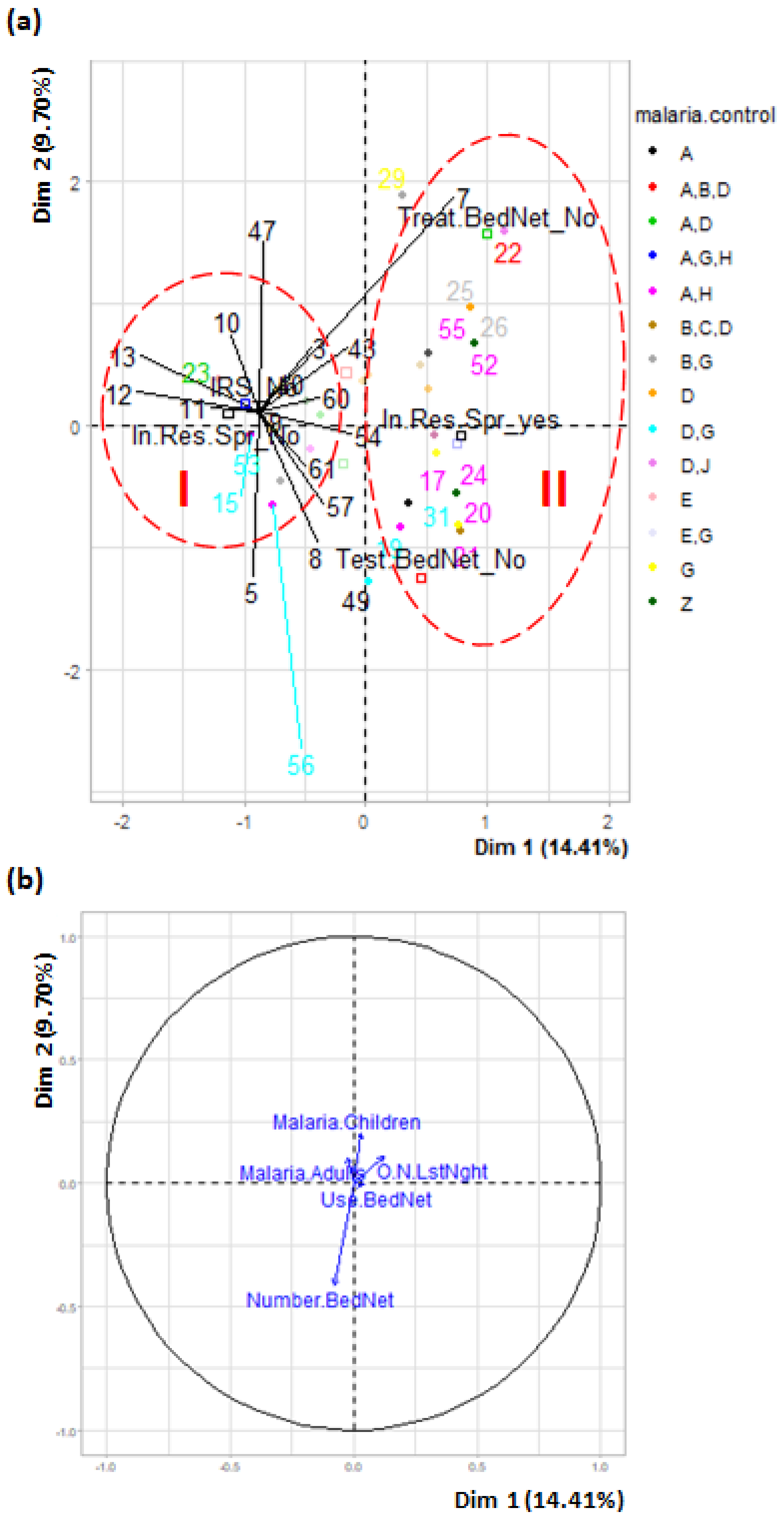

Figure 4

(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. 1 caption. (b) Vectors showing the relationships between malaria incidences in children or adults and either the number of people who spent the night before in residential house

(O.N.LstNight; surrogate for continual residency), the number of bed nets in households, or the usage of bed nets.

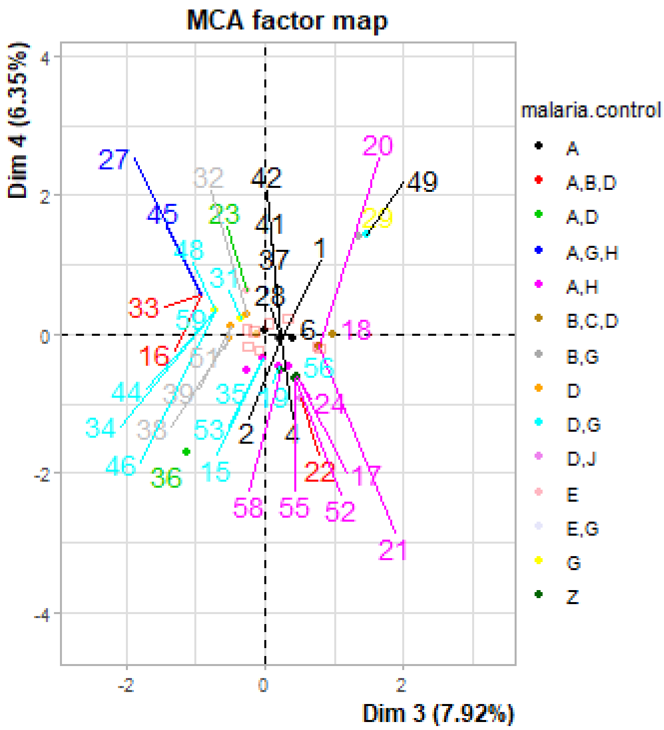

Figure 5

Factor map showing correlations of the third and fourth dimensions which are mainly with the additional malaria control strategies defined in Fig. 1 caption (A to Z) and not with the major drivers of malaria in northern Uganda.

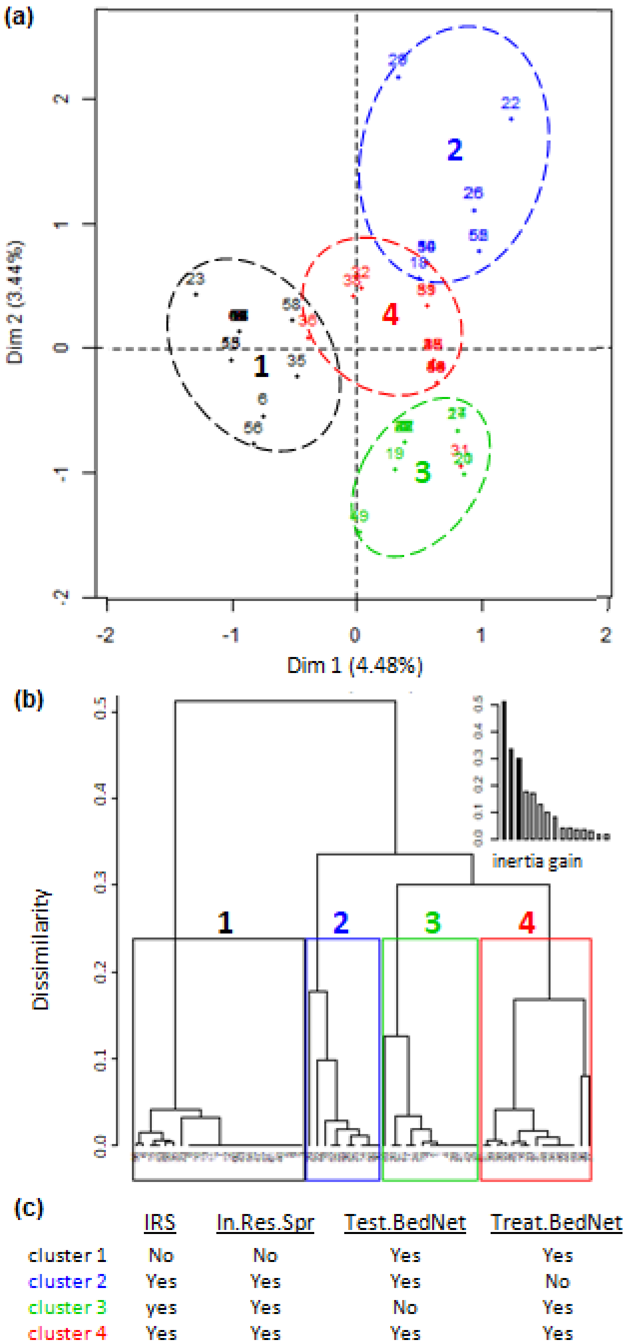

Figure 6

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, Table 1). Euclidean matrix was used.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementalmaterials.docx