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

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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 northern part of Uganda as mitigating strategies for malaria episodes. Unfortunately, the region still records the highest malaria prevalence of 63%. This study assesses household predicators of malaria in the region and their impact on malaria episodes at the household levels.

Methods: A cross-sectional study was conducted in four districts of Gulu, Oyam, Kitgum and Agago covering sixteen villages in northern Uganda. In total, 193 households were surveyed. Data was collected through pre-tested structured questionnaire and systematically coded for analysis using *R* software.

Results:

Women headed 58% of the 193 households surveyed. Six hundred and five (605) individuals were declared to have spent the previous night in these households. On average, there were two bed nets per household and 502 (86%) spent the night prior to interview under a bed net. Overall, malaria episodes were strongly related to lack of bed nets or lack of 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. When given a choice between insecticides (IRS) and treated bed nets, 1 in 3 households preferred treated bed nets. At the same time, data suggests that 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. Malaria incidence was higher in children as compared to the adults.

Background

Malaria remains a major public health concern worldwide, more seriously in the sub-Saharan Africa. With 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] reported declining rates of malaria episodes from 76 to 57 cases per 1000 population at risk globally in the period of 2010 to 2018 [1, 3]. 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 still 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]. Pregnant women and children in Africa are the hardest hit with malaria; over eleven million being infected and close to 1 million neonates born with low birth weight as a result [1]. The high infection rate in pregnant women particularly (over 40% in 2018 for example) is mainly attributed to not sleeping under an insecticide treated nets (ITN) and the fact that two thirds of these expectant mothers 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 ranks 9th and 10th highest in mortality and morbidity due to malaria worldwide, respectively [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].

To achieve global strategy reduction plan of at least 40% in malaria case incidence by 2030, Uganda has adapted several 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, malaria remains the number one leading cause of morbidity and mortality in Uganda mainly due to delayed health seeking, clinical judgment without laboratory confirmation, widespread insecticide resistance in mosquito populations [5, 9–12]. Transmission of malaria is endemic and perennial throughout the country, and picks up following the end of rainy seasons with the peaks being seen in December to Feb and May to July [8].

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 [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]. 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].

In this study, we look at possible predictors of malaria episodes 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. 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 system 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 the planning and implementation of appropriate malaria control strategies [13].

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 former camp internees are engaged in crop production, while a small percentage rear livestock, including Ankole and Zebu cattle in the mid-north [21].

Northern Uganda 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 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 [28]

The households here 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

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. 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 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 structured questionnaire in multiple choice questions format. 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 episodes 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 during that time. 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

To answering such real-life question as to whether an association exists between predicators and episodes of malaria among residents of northern Uganda is best addressed by modeling joint behavior of multivariate predictors using an appropriate multivariate statistical tools. Usually the kinds of data collected to answer this question are categorical in nature (as is the case here) for which multiple correspondence analysis (MCA) technique is becoming the accepted standard for analyzing them. MCA, an unsupervised multivariable method of 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 this study, the proportions of variance accounted for by MCA dimensions were used uncorrected for two reasons: (i) our focus was only on 2-D presentation of results which does not change with correction [23], 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 [23].

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 much details as possible to allow for a 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). Applying HCPC we had to first organize multiple categorical data in our possession into continuous predictors. In this regards, MCA was also used to pre-process data as well, the principal components of which were then passed on to the HCPC tool. Only the first five of seventeen dimensions generated by MCA were kept for this purpose (although evidently the first three dimensions contained most information and 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 episodes of malaria in northern Uganda. A total of 193 households were surveyed for the study. From responses to survey questions, the average number of individuals per household was 3 (±2). This average was determined by extrapolating the declared number of individuals who spent the night before the survey to one (1) household. Of the 193 households surveyed, 111 with 388 individuals were headed by women and 82 with 217 individuals by men. Additionally, of the 605 total number of individuals captured in our data ($\sum$ 388 and 217), 255 had malaria in the three months prior to this survey (42% of samples), 171 of which were children (67%).

Among the malaria intervention strategies included in our survey questionnaire were the availability of bed nets (coded as *Number.BedNet* for analysis), the number of individuals who used the nets at night (*Use.BedNet*) and extent of usage as measured by a count of individuals that spent the previous night to the interview day in a 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*). Furthermore, household were asked the question: how do you control malaria vectors in the family to which several intervention strategies were offered in addition to, or as the only means of, controlling malaria. These included the followings: 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 questionnaire with all questions answered was possible for only 159 of the 193 households. That being said, to have had 80% of an indigent community in a sub-Saharan Africa country to respond to all questions asked here was remarkable, and has no bearing on management or data quality.

In Fig. 1 are provided brief descriptions of the data collected in this study. It can be seen that each of the 159 households which responded to all questions on the questionnaire had at least two bed nets (317/159) under which a total of 460 individuals (out of 535; 86%) slept the night before this survey (Fig. 1a). The observed 86% usage is empirical large from experience 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 $r = 0.654$, $p = 8.96e^{-21}$).

In computing the correlation above, (i) 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 households, and (ii) 21 responses were excluded because they were 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 interview.

Overall we believe the data collected here shows 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. 1b, the number of households whose malaria controlling mechanism involve insecticides was 433 (i.e. sum: 137+123+173) 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 malaria controlling mechanism adopted for controlling 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. By the number of times these additional control mechanisms were provided (Fig. 1c), 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 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, a simple ratio of the number of malaria episodes *s* and number of times a control mechanism was offered by respondents *n* was computed for each category for comparison (column *s*/*n* in Table 1). 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 show 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 worse 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.

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Table 1
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

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 little information for inclusion into the final data matrix used in further analysis. Classically, identifying these five dimensions would require factoring into the decomposed values the individual household contributions to the observed inertia. In normal practice though, these steps are assumed and all but the first 2 to 5 MCA dimensions are excluded from further analysis since many studies have shown that the five dimensions have most of the variations contained in data [23]. In line with that practice, (i) we further reduced the number of MCA dimensions for inclusion into further analysis from 12 (i.e., 17-5) to the first five dimensions (accounting for 14.41%, 9.70%, 7.92%, 6.35% and 5.88% of uncorrected inertia, respectively), and (ii) uncorrected inertia was used since the kind of information we expected from MCA, which was the locations of points in the 'cloud of individuals', are unaffected – corrected or not [23, 29].

Identifying The Most Important Malaria Intervention Strategies By Mca

Out of the 22 intervention strategies tested, we identified eight 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 eight 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 test bed nets before use (*Test.BedNet*)), (vii) the number of households that impregnate or treat bed nets with insecticides before use (*Treat.BedNet*) and (viii) 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 Fig. 2. 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 Fig. 2a. 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 **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 (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 (**Fig. 2b**) and hence the predictors did not contribute much to those dimensions (**Fig. 2c**). On the other hand, variables such as those associated with *In.Res.Spr.*, *Test.BedNets* and *Treat.BedNets* which are lowly represented in relative terms (**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 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 Fig. 4 and Fig. 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) – 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). This trend could perhaps be explained speculatively on the basis of perception that (i) insecticides are not acceptable to 100% of the 24 households 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. Further study is required to explain this observation.

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 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 (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 is longer than that representing adults). These two findings provide ground for concerted effort to encourage 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. 2a and 3, 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 the impact of household structure and 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 are 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 interview. The 86% represents a 4.2% (within errors) over bed nets usage recorded 10 years ago in same areas of northern Uganda (81.8%) [22]. Furthermore, this finding is consistent with the findings of similar studies carried out in parts of Tanzania (80% bed net coverage) [32, 33, 45, 46], and elsewhere in the world [3] although is higher than those reported in Kenya and the remaining 20% of Tanzania [33–35].

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, 30, 31].

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 previous studies in Africa [36, 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 [38, 39].

In details, the present study show 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 pool where mosquitos lay their eggs, trimming mosquito covers around 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. For, 84% of household were found to be more likely to use IRS to control malaria vectors than the percentages of households in most countries in Africa [40]. 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]. And as stated earlier here, the high coverage is attributable to the long history of IRS and LLINs usage in the region [41].

It’s important to note that ITNs is the first major malaria vector tool used to prevent malaria in Africa, followed by IRS. And because this serial introduction, the high but non-overlapping usage of IRS and bed nets here could be based on 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 indoor. We do not have definitive data to show that people who had their houses sprayed were less likely to use their nets, or vise 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 relies 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 African [34, 35]. 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 acquire this immunity by a certain age through their childhood in the high transmission areas like northern Uganda. WHO recommends a number of 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 [34, 35]. It is believed that factors such as high mosquito insecticide resistance [47, 48] is responsible for the observed persistence of malaria in such areas as was recently shown by Echodu et al. in the study area [12]. 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 [34] as evident by the strong relationship between 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 time had more than 3 residents at night (> 605/193). Furthermore, the high malaria burden in northern Uganda could be attributed to the cumulative 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 on the basis of 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 unearthed 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, behavior, approaches to containing malaria or resources were uniform), all households would belong to only one large cluster. In this context, four clusters were detected by HCPC, meaning that there were four types of households in northern Uganda at the time of this study (see HCPC results subsection for description). At the minimum here, HCPC has provide incontrovertible evidence supporting a notion that malaria control in northern Uganda is not conducted uniformly. There is 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.

Conclusion

In this study, we shown the link between malaria and (i) the number of bed nets a household owns in northern Uganda, (ii) the number of individuals staying overnight in a household, (iii) the number of individuals who actually used bed nets at night and (iv) the number of households that do practice residual insecticides spraying indoors.

The clearest predictors of incidence of malaria in northern Uganda were two statistically: the number of bed nets in a household, and the lack of using bed nets at night. High episodes of malaria were correlated strongly, more so in children than in adults, with low usage of bed nets and high number of individuals sleeping in the same household at night.

Four households clusters were revealed to exist in northern Uganda malaria by studying the combinations of strategies used by households to contain malaria. This revelation provide an opportunity to tailor-make preventive/intervention malaria messages to fit the individual household clusters.

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 performed formal analysis, reviewed and edited manuscript, OO carried out statistical analysis, review and edited manuscript drafts. 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).

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 (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.

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Figures

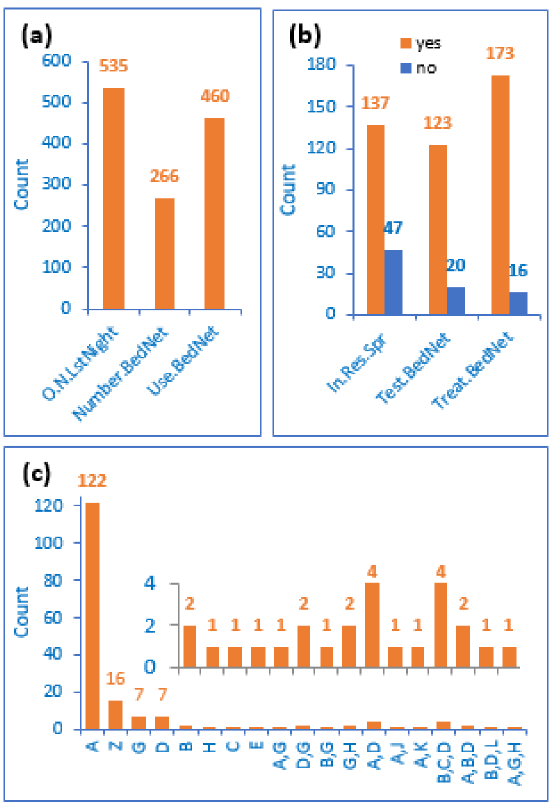

Figure 1

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) Controlling 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.

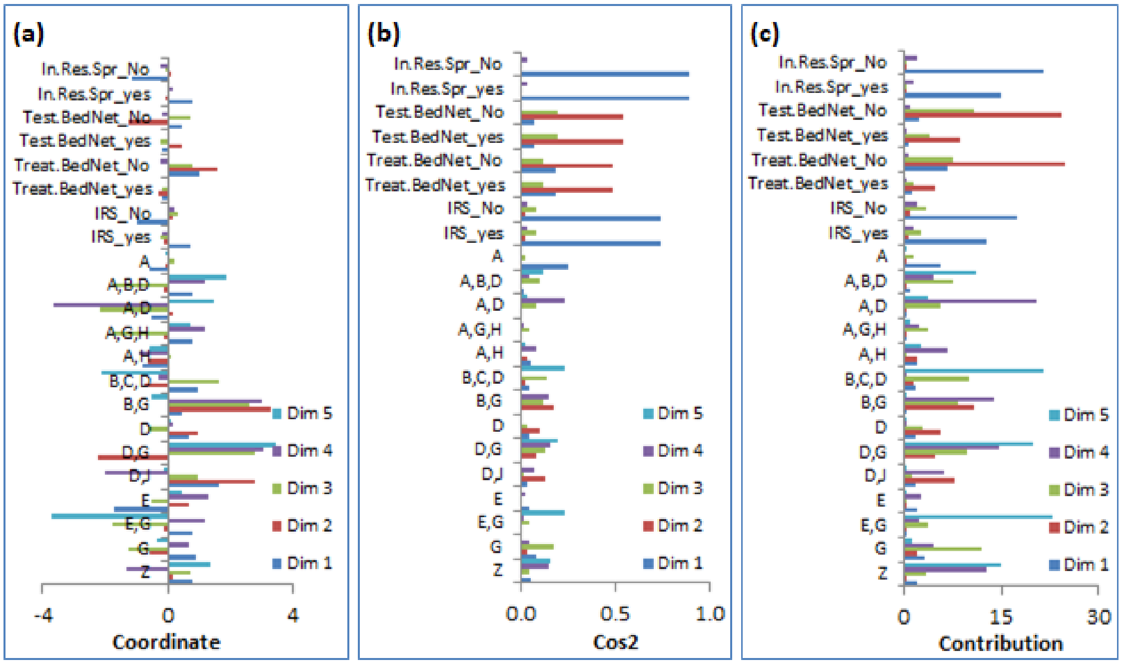

Figure 2

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.

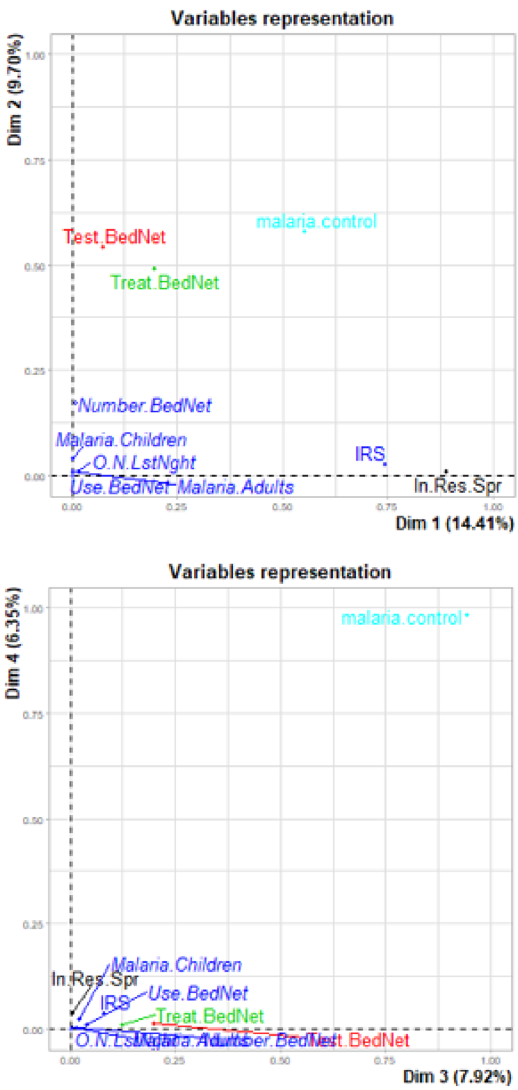

Figure 3

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).

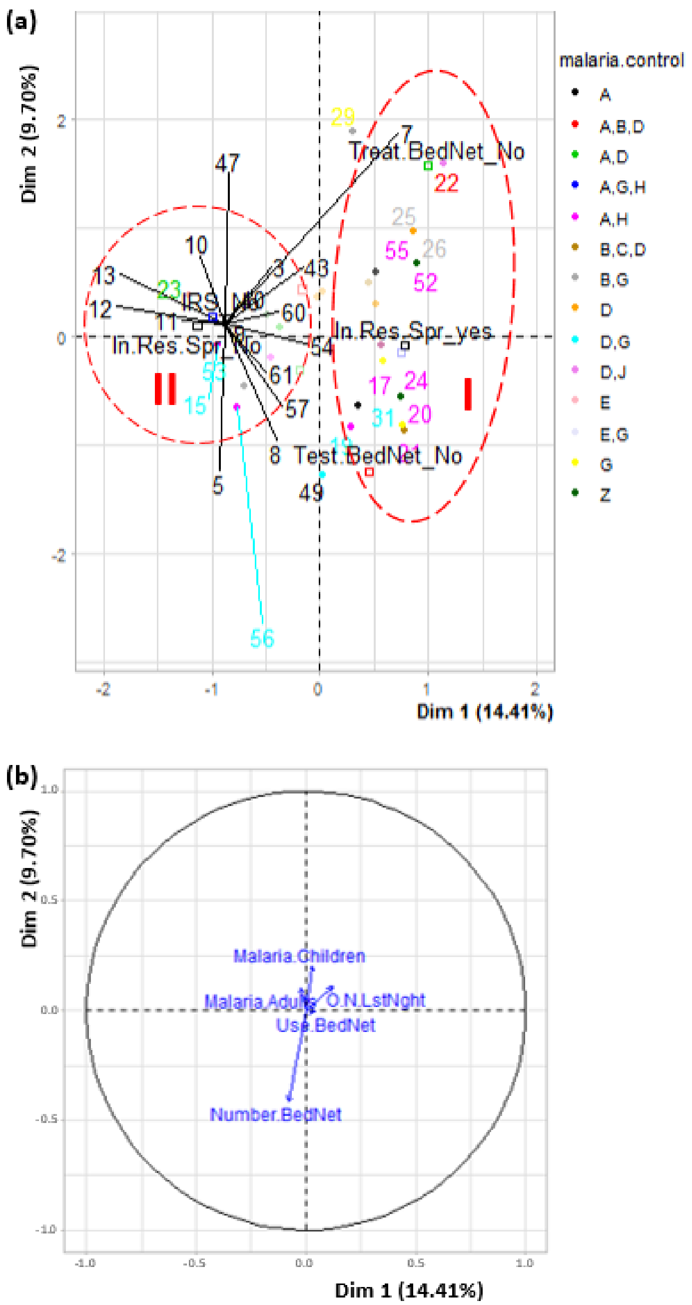

Figure 4

(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 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.

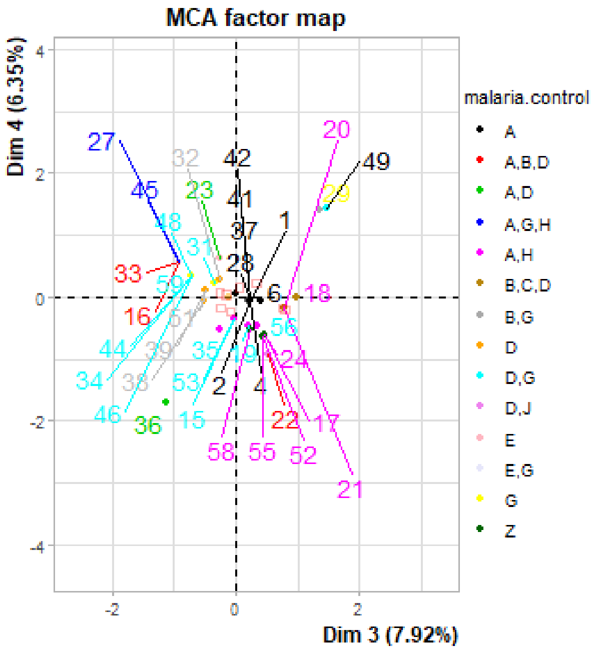

Figure 5

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.

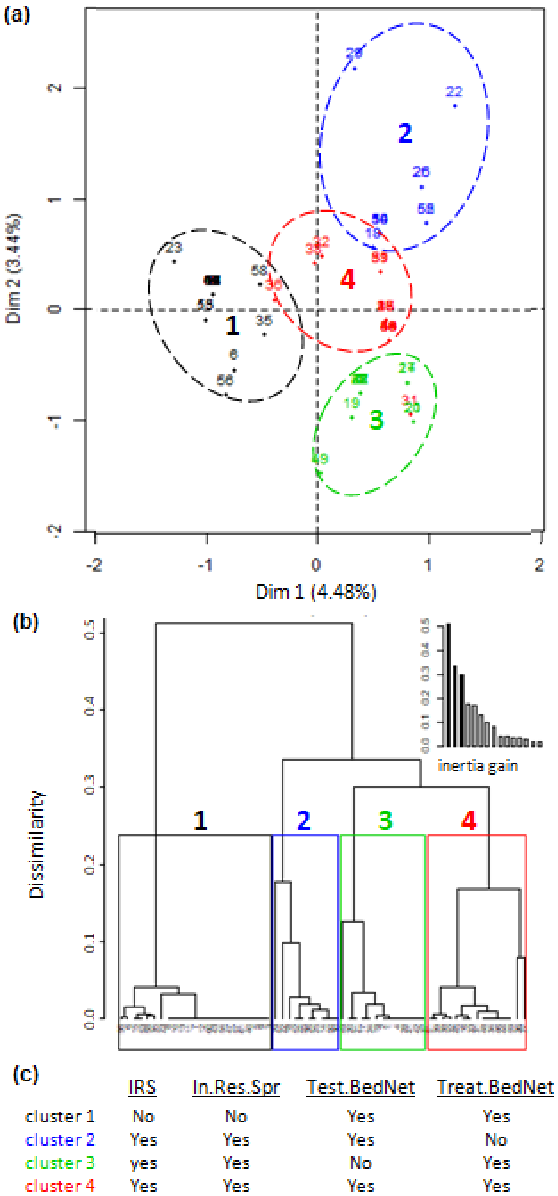

Figure 6

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.pdf