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# Individual, household and environmental risk factors for malaria infection in Amhara, Oromia and SNNP regions of Ethiopia

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**Summary** We assessed malaria infection in relation to age, altitude, rainfall, socio-economic factors and coverage of control measures in a representative sample of 11 437 people in Amhara, Oromia and SNNP regions of Ethiopia in December 2006—January 2007. Surveys were conducted in 224 randomly selected clusters of 25 households (overall sample of 27 884 people in 5708 households). In 11 538 blood slides examined from alternate households (83% of those eligible), malaria prevalence in people of all ages was 4.1% (95% CI 3.4—4.9), with 56.5% of infections being *Plasmodium falciparum*. At least one mosquito net or one long-lasting insecticidal net (LLIN) was present in 37.0% (95% CI 31.1—43.3) and 19.6% (95% CI 15.5—24.5) of households, respectively. In multivariate analysis ($n$ = 11 437; 82% of those eligible), significant protective factors were: number of LLINs per household (odds ratio [OR] $_{\text{per additional net}}$ = 0.60; 95% CI 0.40—0.89), living at higher altitude (OR $_{\text{per 100 m}}$ = 0.95; 95% CI 0.90—1.00) and household wealth (OR $_{\text{per unit increase in asset index}}$ = 0.79; 95% CI 0.66—0.94). Malaria prevalence was positively associated with peak monthly rainfall in the year before the survey (OR $_{\text{per additional 10 mm rain}}$ = 1.10; 95% CI 1.03—1.18). People living above 2000 m and people of all ages are still at significant risk of malaria infection.


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## 1. Introduction

Malaria is a major problem in Ethiopia, being the leading cause of outpatient visits, admissions (excluding those for normal deliveries) and deaths in the country in 2005—2006, and accounting for over 20% of deaths at all ages.[1] There are estimated to be 5—6 million malaria cases per year. However, exposure to malaria varies markedly by location and season.

Ethiopians live at altitudes ranging from −100 to >3500 m, with consequent variation in minimum and maximum temperatures. In general, the peak of malaria incidence follows the main rainfall season in July, August and September each year. However, many areas in the south and west of the country have a rainfall season beginning earlier in April and May or have no clearly defined rainfall season. 'Usual' rainfall by zone varies from about 50 to >1000 mm per year.[2]

Over the whole country there is also large inter-annual variation in rainfall and temperature superimposed on the seasonal variation, leading to a persistent risk of devastating epidemics.[3,4] Thus the country experiences a wide range of malaria transmission patterns, varying from stable endemic malaria in the western lowlands to no malaria at all in highland urban areas.

Malaria stratification, a scheme by which geographical areas are demarcated by levels of malaria exposure, is essential for optimal planning of preventive interventions (especially nets and spraying) and for health service provision. At least nine different stratification schemes for Ethiopia have been proposed, which fall into two broad groups. First, there are schemes that aim to stratify the probability of malaria infection in an 'average' year.[5—9] These are predominantly climate-based predictive models (with altitude affecting climate mainly through temperature), although in some models proximity to water and mosquito species are used as criteria.[7] Secondly, some schemes attempt to define 'epidemic-prone' areas by incorporating inter-annual variation (based on history of where epidemics have occurred as well as environmental factors) superimposed on the underlying 'average' risk of malaria.[5,10,11] A recent scheme of this second type classified the country into seven strata (FMOH, 2007, unpublished).

None of the stratification maps developed to date use actual malaria reported case data or prevalence surveys in a systematic way to validate the climate-based stratification. This is partly because of concern about the reliability and non-representative nature of the case data, but also because cases are reported by administrative units (regions, zones and *woredas*, or districts), and cannot easily be mapped onto the climate- and altitude-based ecological strata. Classification into epidemic-prone areas seems like a false dichotomy, as almost any part of Ethiopia has potential for an epidemic, defined as ''an outbreak of disease affecting or tending to affect a disproportionately large number of individuals within a population, community or region at the same time''.[12] An additional problem is that control measures such as spraying and provision of nets are not taken into account in defining the relative likelihood of malaria infection. Neither are socio-economic factors or urban/rural location of residence, which might influence exposure to infection as well as ability to seek and afford treatment.

The household survey described here is the first rigorous and representative malaria prevalence survey for all ages in the three largest regions of Ethiopia: Amhara, Oromia and SNNPR, where 81% of the population live. The Carter Center has been assisting with onchocerciasis or trachoma control in these regions since 2001. Previous cross-sectional studies of malaria prevalence in Ethiopia have demonstrated the wide range (0—36.7%) of malaria prevalence observed in the country.[13—21] Cox et al.[10] showed a negative relationship between prevalence in a study site (village) and altitude, ranging from >80% positive at 1000 m to 0% at 2000 m, using all available national prevalence data. However, the studies were not necessarily representative samples, were collected over a long time period and may not be relevant today given changes in socio-economic status, population movements, control measures applied and possibly climate. Recently, in three regions studied here, Tilaye and Deressa[19] observed a prevalence of 5.3% in Gondar town, North Gondar Zone, Amhara; Abose et al.[13] observed a prevalence of 6.8% near Lake Ziway in East Shewa zone in Oromia in 1994; and Newman et al.[17] found a prevalence of 1.8% in pregnant women in a sample including Jimma town, in Jimma Zone, Oromia Region (refer to Figure 1 for zone locations).

The analysis described here builds on previously published survey results from Amhara, Oromia and SNNP regions[22,23] by examining the effects on malaria slide positivity of individual, household and cluster-specific environmental risk factors as well as availability and use of preventive interventions (spraying and nets) in a multivariate logistic regression model.

## 2. Materials and methods

### 2.1. Study area and population

The survey was conducted in Amhara, Oromia and SNNP regions of Ethiopia in December 2006 and January 2007. The population in the regions surveyed was 60 846 688 as estimated by the Central Statistical Agency.[24] The timing of the survey was shortly after the peak of the 2006—2007 malaria season, which was not an unusually low or high year for malaria transmission, as judged by routine surveillance reporting of cases.[25]

The sample size estimation, sampling plan and sample selection have been described elsewhere for Amhara Region (where the survey was an integrated malaria and trachoma survey) by Emerson et al.,[22] and for Oromia/SNNPR regions by Shargie et al.[23] The sample size was based on power requirements at both household and individual levels, and we were able to reach required numbers for individuals by testing every other household.

To avoid sampling in areas without transmission, we pre-specified the exclusion of major urban areas and any *woreda* (district) with less than 10% of its population living in malarious areas, as defined by regional health staff. Within the remaining *woredas*, we also pre-specified exclusion of *kebeles* (smaller administrative units roughly equivalent to villages) that were defined as non-malarious. In this context, 'non-malarious' means not targeted to receive long-lasting insecticidal nets (LLINs) in the recent large scale-up of net distribution in Ethiopia. We did not exclude any areas on the

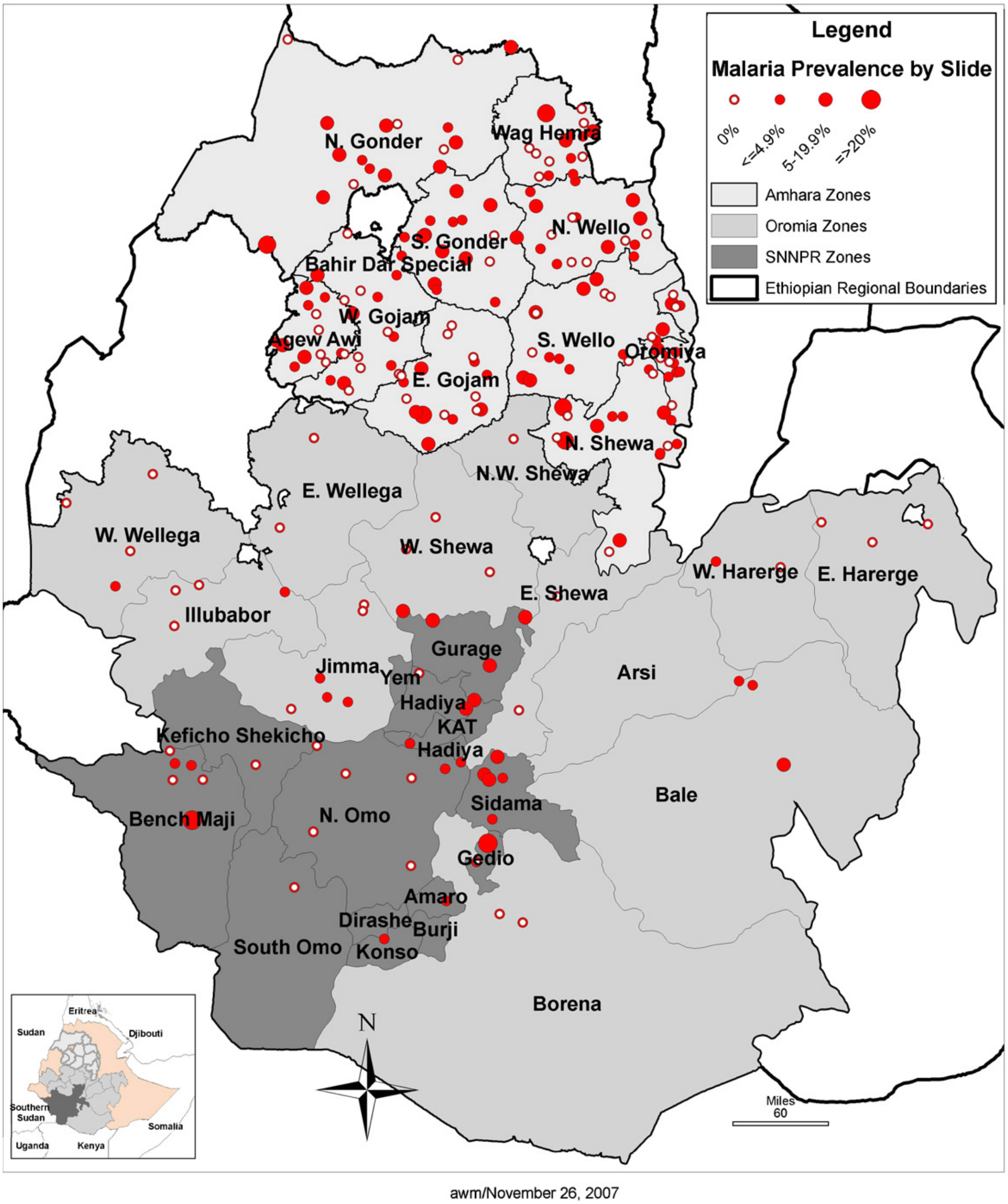


**Figure 1** Map of the survey sites and malaria prevalence estimates by cluster.

basis of altitude. Overall, the percentage of the population excluded due to residing in non-malarious areas was 27% of the total.

Clusters were defined as *kebeles*. The multistage cluster random sampling design used zones and *woredas* in Amhara and 'quadrants' (groups of *woredas*) in Oromia/SNNPR as preliminary sampling stages. The strategy was designed to select 160 clusters (16 per zone) in Amhara and 64 clusters (8 per quadrant) in Oromia/SNNPR, giving 224 clusters in total, each targeted to include 25 households. Clusters were randomly selected from among the malarious *kebeles* in each *woreda* or quadrant. After selection, one cluster in Borena Zone of Oromia Region was replaced due to security concerns. Within clusters, five state teams (divisions of a *kebele*) were randomly selected, and within each state team, five households were selected by the random walk method. Households within a cluster were assigned sequential numbers as they were sampled. All eligible participants (all age groups and both sexes) in even-numbered households were invited to participate in testing for malaria parasites. Locations of the selected clusters are shown in Figure 1. Verbal informed consent to participate in interviews was sought from the heads of the household. Signed informed consent for blood testing was sought from each individual and parents of children aged 17 years and younger. Personal identifiers were removed from the data set before analyses were undertaken.

### 2.2. Household questionnaire

The survey questionnaire was based on the Malaria Indicator Survey Household Questionnaire, modified for the local conditions as previously described.[22,23,26] A wealth index was constructed for each household using principal components analysis using the methods of Vyas and Kumaranayake.[27] This index was based on possession of assets (having electricity in the household, a functioning radio and/or a functioning television), type and location of usual water source, possession of and type of latrine, house construction materials (wall, roof and floor), number of rooms and density of people per room. The first principal component (representing 10.3% of the variance in the sample) was used to generate the asset index, which was then divided into quintiles.

Respondents were also asked about: indoor residual spraying; presence and type of mosquito net (verified by observation); demographic information on residents; and where people slept. Interviewers asked to see each net by room in the house, determined whether it was an LLIN or not, and asked who had slept under it the previous night. It was also determined whether any household residents slept outside, and if so whether they used a net or LLIN. Altitude and location of each household was recorded using the Global Positioning System (Garmin eTrex GPS Personal Navigator; https://buy.garmin.com/shop/shop.do?cID=144&pID=8705 [accessed 4 November 2008]).

### 2.3. Rainfall data

Monthly rainfall data were obtained from the International Research Institute for Climate and Society. The rainfall estimate products are derived from satellite images produced by the National Oceanic and Atmospheric Administration —Climate Prediction Centre using the African rainfall estimation algorithm. The rainfall products are provided every 10 d from December 1999 to the present. The 10 d products were summed to monthly data and averaged over *woreda* boundaries. Rainfall was quantified by *woreda* in various ways, including the annual mean of 2000—2007, the total rain in 2006 (the year prior to the survey), the total rain during the peak season of 2006 (June to October), and the maximum monthly rain in 2006. The latter two variables were included in the regression analysis.

### 2.4. Malaria parasite prevalence

All consenting eligible persons (those in even-numbered households) were tested by a rapid diagnostic test, which detects all malaria species (ParaScreen; Zephyr Biomedical Systems; http://www.tulipgroup.com [accessed 4 November 2008]) and had duplicate blood slides taken by fingerprick. Participants with positive rapid tests were offered immediate treatment according to national guidelines:[28] CoArtem for *Plasmodium falciparum* infection, chloroquine for other malaria infection and clinic-based quinine therapy for self-reported pregnant women. The analysis reported here is based on the results from blood slides stained and examined as described by Emerson et al.[22] and Shargie et al.[23] Parasite density was not quantified. To ensure accuracy, all positive slides and a random sample of 5% of the negative slides were re-examined by a separate microscopist, who was blinded to the diagnosis of the first slide-reader. The overall agreement between the two microscopists was 99.4%. Comparison of the results obtained with rapid diagnostic tests and slides will be reported separately.

### 2.5. Quality control, data entry and analysis

Forms were checked by the supervisor in the field and inconsistencies verified with the respondents. Data were double-entered by different entry clerks and compared for consistency using the Census and Survey Processing System (US Census Bureau, Washington DC, USA). Statistical analysis was conducted using Stata 9.2 (Stata Corp., College Station, TX, USA). Sampling probabilities were calculated for clusters (*kebeles*), and sampling weights derived as the inverse of the product of sampling probabilities. Descriptive statistics were used to examine the characteristics of the sample. Point estimates and confidence intervals were derived using the SURVEY (SVY) routine in Stata, which controlled for clustering in the sample design as well as weighting for sampling probability.[29]

To investigate the association between malaria infection and risk factors, univariate analysis was first conducted for each potentially explanatory risk factor. Multivariable models were then developed by backwards stepwise logistic regression analysis in Stata using weighted data. Starting with all potentially significant variables, explanatory variables were sequentially removed if they satisfied the >15% significance level for exit. After determining the significant variables, the final model was then run with adjustment for survey design. Age and sex were retained in all multivariable models to control for any potential confounding effects. $P < 0.05$ was considered statistically significant.

## 3. Results

### 3.1. Characteristics of study population

The total number of households selected for the survey was 5708 in 224 clusters, and overall 27 884 people were surveyed. In the even-numbered households, there were 13 960 people eligible for malaria testing, of whom 12 212 (87.5%) were tested. Of these, 513 had missing or unreadable slides (including all slides from one cluster in Amhara Region) and 98 had missing age or sex data, leaving a sample size of 11 601 (83.1% of those eligible) for analysis of malaria prevalence by individual characteristics. Household characteristics data were not linkable for a further 63 people, which gave a sample size of 11 538 (82.7% of those eligible) with blood slide results. Due to missing risk factor data, 164 people were excluded, leaving 11 437 people in the final regression analysis.

The mean household size was 4.9 people. The mean age of individuals tested was 20.7 years, with 46.1% being male.

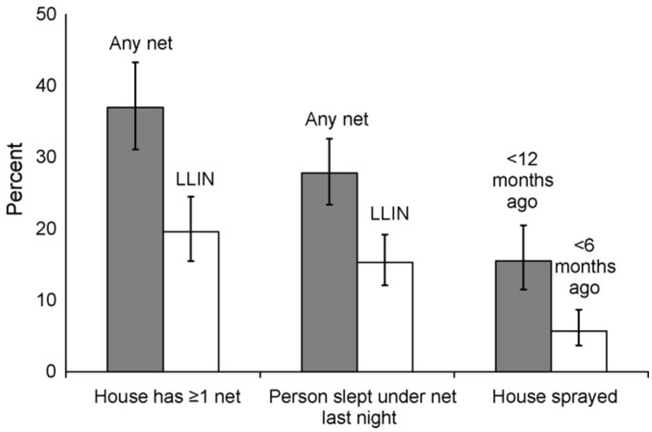


**Figure 2** Household net possession and use by people of all ages, and proportion of houses sprayed. LLIN: long-lasting insecticidal net; bars represent 95% CI.

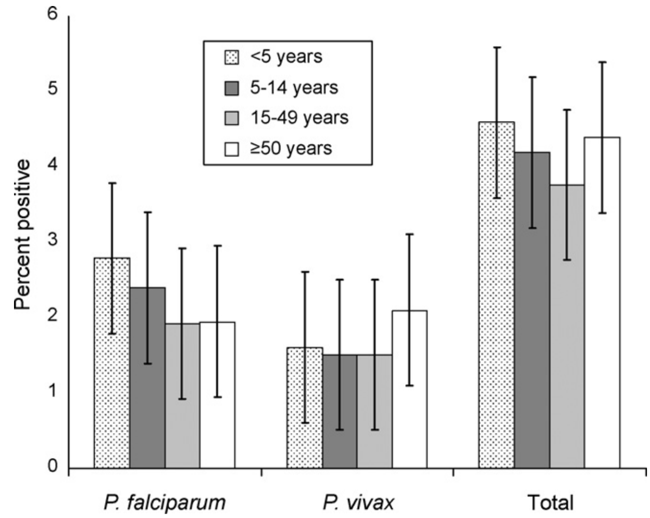


**Figure 3** Malaria prevalence (slide positivity) by species and age group. LLIN: long-lasting insecticidal net; bars represent 95% CI.

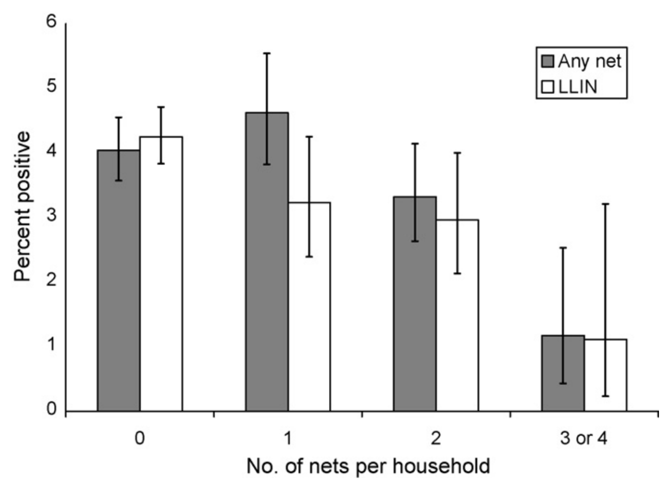


**Figure 4** Malaria prevalence (slide positivity) by number of nets (any type) and long-lasting insecticidal nets (LLIN) per household. Bars represent 95% CI.

The design effect in this survey ranged from 1.6 for the variable representing age group to 4.1 for altitude.

### 3.2. Coverage of malaria control measures

The mean number of nets or LLINs owned per house was 0.6 (95% CI 0.4—0.7) and 0.3 (95% CI 0.2—0.4), respectively. We estimated that 37.0% (95%CI 31.1—43.3) of households had at least one net of any type and 19.6% (95%CI 15.5—24.5) had at least one LLIN (Figure 2). Overall, 27.8% (95% CI 23.5—32.7) of people reported sleeping under a net the previous night, while 15.3% (95% CI 12.0—19.2) slept under an LLIN (Table 1 and Figure 2). The proportions were only slightly higher for under-fives (31.8% net and 17.4% LLIN) and for pregnant women (35.9% net and 18.9% LLIN) (Table 1). Within the last 12 months and 6 months, respectively, 15.5% (95% CI 11.2—20.9) and 5.7% (95% CI 3.7—8.9) of houses had been sprayed (Figure 2). The type of insecticide used is unknown, but DDT is the most commonly used chemical.

### 3.3. Prevalence of malaria infection

The locations and proportions of people positive for malaria in the sampled clusters are shown in Figure 1. Malaria prevalence was 4.1% (95% CI 3.4—4.9) overall. There were 1.3 times as many people infected with *P. falciparum* (2.5%) as *P. vivax* (1.9%) infections, with 0.3% of infections being mixed. There was no difference in parasite prevalence by gender.

There was no difference in prevalence by age group (Figure 3): the apparent declining trend of *P. falciparum* prevalence by age was not statistically significant. However, there was a declining trend of prevalence (both species combined) with increasing numbers of LLINs in the house (Figure 4).

There was a decline in prevalence with altitude (Table 2), although people infected with malaria were found in all

**Table 1** Percentage of sampled individuals sleeping under mosquito nets on the night prior to the survey.

| | *n* | Any net % (95% CI) | LLIN % (95% CI) |
|---|---|---|---|
| All age groups | 27 884 | 27.8 (23.5—32.7) | 15.3 (12.0—19.2) |
| Children aged <5 years | 4387 | 31.8 (26.8—37.4) | 17.4 (13.6—22.0) |
| Women aged 15—49 years | 6510 | 29.0 (24.4—34.0) | 16.0 (12.6—20.1) |
| Self-reported pregnant women | 489 | 35.9 (28.8—43.7) | 18.9 (14.0—25.0) |

LLIN: long-lasting insecticidal net.

Table 2 Malaria (species-specific) prevalence by slide, by altitude, all regions combined.

| Altitude class (m) | *n* | Any positive slide | | *Pf* | *Pv* | *Pf*+*Pv* | *Pf*:*Pv* ratio |
|---|---|---|---|---|---|---|---|
| | | *n* (%) | (95% CI) | *n* (%) | *n* (%) | *n* (%) | |
| ≤1000 | 125 | 11 (7.3) | (1.9—23.8) | 5 (4.1) | 4 (2.2) | 2 (1.1) | 1.6 |
| 1000—1500 | 1529 | 67 (4.7) | (3.1—7.2) | 42 (2.7) | 17 (1.5) | 8 (0.6) | 1.6 |
| 1500—2000 | 5640 | 232 (4.2) | (3.3—5.4) | 122 (2.4) | 102 (1.7) | 8 (0.2) | 1.4 |
| 2000—2500 | 3661 | 121 (3.8) | (2.6—5.4) | 67 (2.0) | 48 (1.5) | 6 (0.3) | 1.2 |
| 2500—3000 | 543 | 18 (3.2) | (2.0—5.1) | 7 (1.0) | 8 (1.6) | 3 (0.6) | 0.7 |
| >3000 | 103 | 7[a] (7.3) | (1.4—30.1) | 6[a] (6.3) | 1 (1.1) | 0 | 6.0 |
| Total | 11601 | 456 (4.1) | (3.4—4.9) | 249 (2.2) | 180 (1.6) | 27 (0.3) | 1.3 |

*Pf*: *Plasmodium falciparum*; *Pv*: *Plasmodium vivax*.
[a] Malaria cases clustered in one family.

altitude bands tested. Surprisingly, although prevalence dropped with altitude in general, the percent positive between 2500 and 3000 m was 3.2% (95% CI 2.0—5.1). Above 3000 m there was one household in which all six household members were infected with *P. falciparum,* accounting for six of the seven positive people in this altitude band and leading to an anomalously high prevalence (the other positive case in a different household had *P. vivax*).

### 3.4. Risk factors for malaria infection

Initial univariate analysis (weighted for sampling probability and adjusted for clustering) suggested the following factors associated with reduction in malaria prevalence (Table 3): having at least one LLIN in the house [odds ratio (OR) = 0.66, 95% CI 0.43—0.96, *P* = 0.03], the number of LLINs per house [OR = 0.76 (95% CI 0.60—0.95) per additional LLIN, *P* = 0.02] and the asset index (OR = 0.80, 95% CI 0.67—0.95, *P* = 0.01). The richest wealth quintile had significantly lower malaria prevalence (OR = 0.44, 95% CI 0.25—0.77, *P* = 0.004). There was a suggestion that house spraying within the previous 12 months reduced prevalence (OR = 0.66, 95% CI 0.42—1.03, *P* = 0.07). Surprisingly, although sleeping under either a net of any type or an LLIN the previous night was associated with reduction in prevalence, the relationship was not statistically significant in either case. Rainfall, expressed as the maximum monthly rain per *woreda* in 2006 (the year before the survey), was significantly positively associated with malaria (OR = 1.09, 95% CI 1.02—1.17). The analysis confirmed the absence of association between age and malaria positivity shown in Figure 3. As Table 3 shows, while increasing altitude reduced malaria positivity in the expected way, the effect was not significant in univariate analysis.

When all potentially important variables were entered into a multivariate logistic regression with stepwise elimination, the significant variables remaining were as shown in Table 4. This shows the effect of altitude in reducing malaria prevalence (OR = 0.95, 95% CI 0.90—1.00, *P* = 0.049, per 100 m increase in altitude) and rainfall in increasing it (OR 1.10, 95% CI 1.03—1.18, *P* = 0.007, per additional 10 mm in the peak rain month prior to the survey). Increase in the asset index (which ranged from −1.90 to 6.29) was significantly associated with reduction in prevalence (OR = 0.79, 95% CI 0.66—0.94, *P* = 0.009). Malaria prevalence was lower if the house had been sprayed within the previous 12 months than if it had not, but this was not statistically significant (*P* = 0.072). The number of LLINs in the house was associated with lower prevalence (OR = 0.60, 95% CI 0.40—0.89, *P* = 0.012, per additional net). It was notable that in contrast to the univariate analysis, the variable 'slept under LLIN last night' was associated with increased likelihood of being infected after adjusting for other factors, although this was not statistically significant (*P* = 0.070).

The model was repeated using infection with *P. falciparum* or *P. vivax* as the outcome. Results were generally similar for *P. falciparum* as for any parasite species (data not shown), although only household possession of an LLIN and the asset index remained statistically significant. The odds ratio for 'at least one LLIN per house' was 0.55 (95% CI 0.32—0.95, *P* = 0.03). For *P. vivax*, by contrast, having an LLIN in the house did not reduce the odds of positivity for this species (OR = 0.84, 95% CI 0.11—1.38, *P* = 0.50), and only rainfall remained a significant factor increasing likelihood of infection with *P. vivax*.

## 4. Discussion

This study uses results from the first extensive population-based malaria prevalence survey in three large regions of Ethiopia. The results provide important information on age-specific and altitude-specific malaria infection rates, as well as an estimate of current (early 2007) intervention coverage and the effectiveness of those interventions. Notably, satellite-derived rainfall estimates were included in our model to control for climate factors in addition to age, gender, altitude, socio-economic status and use of interventions. The survey results can be used to validate suggested malaria stratification schemes and improve the malaria control program's targeting of interventions.

The overall malaria prevalence was low (4.1%), even though the survey was done shortly after the peak transmission season. There was no difference in prevalence by age group or gender. Malaria positivity declined with altitude, but not as steeply as expected based on the previous review by Cox et al.[10], and the results refuted the suggestion therein that 2000 m is the cutoff for malaria transmission. Our sampling frame (which excluded non-malarious areas completely) may have biased the estimate of the protective effect of altitude, but positive individuals were found at all altitudes, with 3.2% of people living at 2500—3000 m

**Table 3** Univariate logistic regression analysis of individual, household and cluster risk factors for malaria slide positivity (any species); weighted and adjusted for survey design.

| Risk factor | *n* | % +ve | Malaria blood slide +ve | |
|---|---|---|---|---|
| | | | Odds ratio (95% CI) | *P*-value |
| Age (per 5 year age group) | 11437 | | 0.99 (0.96–1.02) | 0.47 |
| Age (per year) | 11437 | | 1.00 (0.99–1.00) | 0.44 |
| Sex | | | | |
| Male | 5270 | 3.7 | | |
| Female | 6167 | 4.0 | 1.05 (0.80–1.36) | 0.74 |
| Currently pregnant (of eligible women, $n = 2549$) | | | | |
| No | 2342 | 3.9 | | |
| Yes | 207 | 4.4 | 1.34 (0.60–2.98) | 0.48 |
| Slept under any net last night | | | | |
| No | 7849 | 4.1 | | |
| Yes | 3588 | 3.4 | 0.86 (0.60–1.22) | 0.39 |
| Slept under LLIN last night | | | | |
| No | 9319 | 4.1 | | |
| Yes | 2118 | 3.1 | 0.76 (0.50–1.15) | 0.19 |
| Household size (per additional person) | 11437 | | 0.99 (0.93–1.06) | 0.81 |
| No. rooms in house (per additional room) | 11437 | | 0.84 (0.57–1.22) | 0.36 |
| At least one net (any type) in house | | | | |
| No | 6252 | 4.1 | | |
| Yes | 5185 | 3.7 | 0.91 (0.63–1.33) | 0.63 |
| At least one LLIN in house | | | | |
| No | 8322 | 4.3 | | |
| Yes | 3115 | 2.8 | 0.66 (0.43–0.96) | 0.03[a] |
| No. nets (any type) in house (per additional net) | 11437 | | 0.88 (0.74–1.05) | 0.14 |
| No. LLINs in house (per additional net) | 11437 | | 0.76 (0.60–0.95) | 0.02[a] |
| Household net status | | | | |
| None | 6252 | 4.1 | | |
| ≥1 any net | 2070 | 4.9 | 1.21 (0.78–1.89) | 0.40 |
| ≥1 LLIN | 3115 | 2.8 | 0.67 (0.44–1.04) | 0.07 |
| House sprayed <12 months ago | | | | |
| No | 9470 | 4.0 | | |
| Yes | 1967 | 3.5 | 0.66 (0.42–1.03) | 0.07 |
| House sprayed <6 months ago | | | | |
| No | 10454 | 3.8 | | |
| Yes | 983 | 4.5 | 0.82 (0.48–1.40) | 0.46 |
| Altitude (per additional 100 m) | 11437 | | 0.98 (0.93–1.03) | 0.38 |
| Altitude group (m) | | | | |
| <1000 | 122 | 8.2 | | |
| >1000–1500 | 1510 | 4.4 | 0.68 (0.17–2.75) | 0.59 |
| >1500–2000 | 5577 | 3.9 | 0.57 (0.14–2.34) | 0.44 |
| >2000–2500 | 3598 | 3.3 | 0.53 (0.13–2.23) | 0.39 |
| >2500 | 630 | 4.0 | 0.55 (0.12–2.48) | 0.44 |
| Rainfall (by *woreda*, per additional 10 mm) | | | | |
| Total rain Jul–Oct 2006 | 11437 | | 1.02 (1.00–1.04) | 0.08 |
| 2006 max monthly rain | 11437 | | 1.09 (1.02–1.17) | 0.02[a] |

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Table 3 (*Continued*)

| Risk factor | *n* | % +ve | Malaria blood slide +ve | |
|---|---|---|---|---|
| | | | Odds ratio (95% CI) | *P*-value |
| Asset index | 11437 | | 0.80 (0.67—0.95) | 0.01[a] |
| Wealth quintile | | | | |
| Poorest | 2374 | 3.7 | | |
| Second | 2185 | 3.7 | 0.86 (0.54—1.37) | 0.53 |
| Middle | 2281 | 4.3 | 0.86 (0.53—1.40) | 0.55 |
| Fourth | 2288 | 4.9 | 1.10 (0.63—1.92) | 0.73 |
| Richest | 2309 | 2.8 | 0.44 (0.25—0.77) | 0.004[a] |

LLIN: long-lasting insecticidal net.
[a] $P < 0.05$ was considered statistically significant.

being infected. Altitude was not a significant protective factor in univariate analysis, but became so in the multivariate model after inclusion of the spraying variable. This is not surprising, as spraying is done at defined altitudes, and may possibly be keeping malaria under some control at particular altitudes. Although seven infected people were found even above 3000 m, six of these (all with *P. falciparum*) were in one household and may have traveled recently to lower altitudes. Although we did not obtain travel histories and therefore cannot exclude overnight travel to lower altitudes as an explanation for some of the infections found at higher altitudes, we believe the most likely place of infection in these relatively poor and mostly rural communities is home.

The weak protective effect of indoor residual spraying observed in this study was unexpected, and warrants further investigation through a qualitative and quantitative in-depth study comparing spraying records with respondents' reports of spraying and its timing. Our study design (five households per state team) did not allow assessment of whether the proportion of houses covered in a village was too low for an effect on the mosquito population, nor did we assess insecticide resistance, mosquito behavior or the extent of replastering over sprayed walls. Although targeting of spraying to areas most at risk of malaria will tend to diminish its apparent effect in the analysis, nevertheless our results suggest that current spraying practice needs further assessment and improvement to reach the level of effectiveness demonstrated by LLINs.

The results on coverage with nets and LLINs indicate that major progress has been made in net distribution since the DHS survey of 2005.[30] In that survey, LLINs were not evaluated explicitly; rather, the survey distinguished between untreated nets, ever-treated nets and insecticide-treated nets (ITNs) (either long-lasting or those treated within the last 12 months). At that time, less than 3% of households in Amhara, Oromia and SNNPR had any ITNs, while we found that 19.6% of households in the three regions had at least one LLIN. Although the samples are not directly comparable, as DHS 2005[30] included both malarious and non-malarious areas, there appears to have also been a large increase in use of nets in these regions, from 1.3% of children under 5 years sleeping under an ITN in DHS 2005[30] compared with 17.4% who slept under an LLIN in this study.

A previous risk factor analysis by Deressa et al.[31] in Oromia Region showed that both spraying and household ownership of a mosquito net were associated with lower risk of febrile illness in children. Our results did not support these findings directly, as spraying demonstrated only weak effectiveness and mere possession of a net did not reduce the likelihood of infection with malaria. In our study, ITNs were a crucial factor.

An interesting feature of our results is that possession of each additional LLIN by a house is associated with a 40% lower risk of malaria positivity, whereas sleeping under a net or LLIN the previous night did not appear to provide significant protection in this analysis. This may be due to the timing of the survey after peak mosquito season, or because

**Table 4** Multivariable logistic regression analysis of risk factors for malaria slide positivity (any species) — weighted and adjusted for survey design ($n = 11\,437$).

| Risk factor | Odds ratio (95% CI) | *P*-value |
|---|---|---|
| Age (per additional 5 years) | 0.99 (0.95—1.02) | 0.405 |
| Sex (male) | 1.05 (0.81—1.36) | 0.729 |
| Altitude (per additional 100 m) | 0.95 (0.90—1.00) | 0.049[a] |
| Max monthly rain in 2006 (per additional 10 mm) | 1.10 (1.03—1.18) | 0.007[a] |
| Asset index | 0.79 (0.66—0.94) | 0.009[a] |
| House sprayed within last 12 months | 0.66 (0.43—1.03) | 0.070 |
| Person slept under LLIN last night | 1.79 (0.95—3.36) | 0.071 |
| No. LLINs per house (per additional LLIN) | 0.60 (0.40—0.89) | 0.012[a] |

LLIN: long-lasting insecticidal net.
[a] $P < 0.05$ was considered statistically significant.

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the question regarding net use the single night before the survey did not accurately capture the net use over a longer period. It may also be that the mere presence of an LLIN in the house gives protection. In multivariate analysis, use of an LLIN the previous night was in fact associated with increased malaria prevalence, suggesting that net use is influenced by the householder's estimation of the risk (i.e. nets tend to be used more in areas of greater exposure to malaria).

There may be additional risk factors that we did not address in this study. A study in Tigray region by Gebreyesus et al.[16] is very relevant, although it estimated incidence of malaria in children under 10 rather than prevalence. In multivariate regression there were seven significant risk factors for malaria incidence (earth roof, open eaves, windows, single sleeping rooms, no separate kitchen, animals sleeping in the house and use of irrigated land). Deressa et al.[31] also showed that sharing the house with livestock increased the risk of fever. Some of these factors may be captured in our socio-economic index, but these studies[16,31] suggest that the household asset-related questions in the standard DHS/MIS questionnaire should be evaluated and possibly modified to include additional relevant items. Tilaye and Deressa[19] observed that proximity to breeding sites increased the risk of malaria in Gondar town, Amhara Region, a factor that is difficult to assess in large household surveys but could be investigated further in future.

There was no evidence that increased age reduced the risk of being infected with malaria. Thus control measures in Ethiopia should be targeted to all age groups and not restricted to small children or pregnant women. In addition, people living above 2000 m are still at significant risk of malaria infection even in 'non-epidemic' years. The results indicate that while there has been great progress in net distribution since 2005, there is still a further need, given that we found an average of only 0.3 LLINs per household. This need is being met by additional net distribution to all age groups in 2007 and beyond.

The survey results presented here also contribute to improving and evaluating the malaria control program in Ethiopia. Prevalence survey data can help to validate the stratification systems discussed in the Introduction, and refine the relationship between stratification levels and targeting of appropriate malaria control methods within administrative planning units. Surveys such as this one also assess in a rigorous way the coverage of interventions such as net distribution and spraying, and indicate gaps needing to be filled. Finally, the results provide much-needed clear baselines for follow-up surveys of intervention coverage and prevalence in order to demonstrate the decline of malaria in Ethiopia.

**Authors' contributions:** PMG, FOR, PME, EBS, TG, AWM and AH planned and designed the survey; EBS, TE, YE, AWM, MZ, TT, BA, AM, GY and AT carried out the survey; YE, JN, EBS and AWM managed the data; PC extracted and provided climate data; PMG and JN analyzed the data; PMG and JN wrote the first and subsequent drafts of the manuscript; FOR, EBS, TE, PME, TG, PC, YE and AH commented on drafts. All authors read and approved the final manuscript. PMG, JN and EBS are guarantors for the paper.

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