Predictors of Insecticide-Treated Mosquito Net Use in Malaria-endemic regions; a Meta-analysis

Saranya Rajagopal

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Committee:
Ann Duerr
Anna Wald
Amalia Magaret
Emily Bancroft

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Abstract

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Saranya Rajagopal

Chair of the Supervisory Committee:
Professor Ann Duerr
Departments of Epidemiology and Global Health

Background: Malaria remains a leading cause of morbidity and mortality globally. Recommended prevention strategies in the general population include indoor residual spraying and the use of insecticide-treated nets. However, current progress towards the adoption and implementation of these strategies has been slow and several countries lag behind the 2010 Roll Back Malaria Partnership target of 80% uptake. We undertook a systematic literature review and meta-analysis to examine the predictors of net use among the general population in malaria-endemic regions and explore the associations between bed net use and household and individual-level factors.

Methods: We systematically collected published literature on factors affecting the use of insecticide-treated nets among the general population in malaria-endemic settings. We searched the Global Health Database, Medline, Pubmed, Embase, Web of Science and the Cochrane Database of Systematic Reviews for studies published in English between January 1, 1990, and September 30, 2013, that examined the association between net use and any of the following factors like socioeconomic status, location of residence, knowledge of malaria transmission, education level, gender, age and the number of nets in a household. Adjusted effect estimates were analyzed using random-effects meta-analyses, with sub-group analyses to evaluate potential sources of variability between studies such as study populations, countries, season of data collection and exposure to mass media campaigns. We used funnel plots and Egger's linear regression to test for publication bias.

Findings: Of 867 articles reviewed, 21 met the inclusion criteria for the meta-analysis. Knowledge of malaria, education level, number of nets in a household and gender were found to be significant predictors of net use in the general population. Household members who had some knowledge of malaria transmission/ITN (versus no knowledge) and households in possession of more nets (compared to those with fewer nets) were the most likely to use an ITN; the summary estimate of the associated OR was 1.47 (95%CI, 1.29 – 1.66) for the knowledge of malaria and 2.35 (95%CI, 1.80 – 3.07) for households with more vs. fewer ITNs. Men were significantly less likely to use an ITN than women (OR, 0.75; 95%CI, 0.69 – 0.82). Not surprisingly, educated individuals were 23% more likely to sleep under a net compared to those with no education (95%CI, 4% - 44%). Pooled summary estimates suggested little or no influence of factors such as socioeconomic status, age and location of residence. However, the effect of age on ITN use varied significantly by study location ($p = 0.03$); with older age groups significantly more likely to use nets than younger household members in countries such as Malawi and Nigeria.

Conclusions: Findings from our analysis have significant policy implications particularly for countries reporting wide disparities between ITN ownership and use by households in possession of ITNs. Significant barriers to ownership like socioeconomic status and place of residence were not found to impact net use among households in possession of nets suggesting that factors affecting ITN ownership may differ from those influencing net use. Achievement of the MDG target of universal ITN uptake by 2015 relies on the successful implementation of policies that address barriers to both ITN access and utilization; strategies that solely focus on only one of those components are limited in their potential to reduce malaria burden.

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Introduction

Malaria is a global health priority occurring in nearly a hundred countries and affecting the lives of over 200 million people worldwide. The World Malaria Report-2012 reflects the enormity of this burden; 80% is concentrated in Sub-Saharan Africa and South-East Asia. The World Health Organization (WHO) reported that in 2010 there were an estimated 219 million cases of malaria leading to 660,000 deaths globally[1]. As a result, the reversal of increasing malarial incidence remains one of the key targets of the United Nations Millennium Development Goals (MDG). Due to the expansion of malaria control programs, malaria mortality rates have fallen by 25% globally since 2000. In line with the MDG, almost fifty percent of the countries with ongoing transmission are on track to reduce their malaria incidence by seventy-five percent by 2015[1]. Despite continued efforts, international financing for malaria has leveled off since 2009; with funding in 2011 reaching half of the estimated 5.1 billion dollars required globally[1]. In addition, tracking progress has been a significant challenge with surveillance being the weakest in countries with the highest number of malaria cases. Since malaria is both preventable and curable, there is an urgent need to scale up and sustain control efforts particularly in endemic regions where malaria continues to remain a social and economic burden.

In regions of stable transmission, the WHO recommends a multipronged approach to malaria prevention. This includes a package of intermittent preventive treatment in pregnancy (IPTp) and the use of insecticide-treated nets (ITNs) combined with effective case management of clinical malaria. The renewed interest in malaria elimination and the expanding evidence base on the effectiveness of ITNs[2-7], triggered an intensive scale-up of net distribution programs in Africa since the early 2000s. This resulted in a significant increase in bed net ownership in 44 African countries from an average of 2.2% of the at-risk population in 1999 to 32.8% in 2008[8]. A WHO Position Statement in 2007[9] recommended a strategic shift from targeted to universal coverage of ITNs in order for their full potential to be realized as a vector control intervention. Understandably, a top priority of ITN programs has been the provision of adequate number of nets to households in malaria prone regions. However, achievement of high utilization of ITNs for many countries in sub-Saharan Africa remains elusive. National surveys among pregnant women in 37 malaria endemic countries estimated that the median use of an ITN the night before the survey was only 35.3% (range 5.2% - 75.5%)[10]. Similarly, a Malaria Indicator Survey (MIS) in Senegal reported poor usage (39%) among all women of reproductive age living in households that owned an ITN[11]. Likewise, a recent cross-sectional survey of 2800 households in Eastern Ethiopia revealed that while two-thirds possessed a net, only a third of the households actually used an ITN the previous night[12]. Patterns of ITN use across age groups demonstrate that two groups least likely to sleep under the nets are children aged 5 – 14 years and adult males[13,14]. Ironically, owing to targeted coverage campaigns, children in the above age group are most likely to live in a household with a deployed ITN. Reduction in malaria mortality through vector control strategies necessitates the successful implementation of two components – provision of nets through routine services to 'keep-up' coverage and regular utilization of nets constituting the 'hang-up' component.

Several studies have examined the socioeconomic, demographic and cultural determinants of insecticide-treated net (ITN) ownership and use.[15-18] However, evidence on the reasons for poor uptake of ITNs is limited. In addition, core ITN indicators employed by the Roll Back Malaria partnership (RBM) measure coverage and uptake among vulnerable populations alone. Likewise, a recent meta-analysis examined the determinants of uptake among pregnant women[10]. Furthermore, many relevant reviews[19-21] focus on effective delivery strategies but do not address the low utilization of nets in general communities. We therefore undertook a meta-analysis to quantitatively integrate findings on the determinants of mosquito net use in the general population in malaria-endemic regions. Achieving high coverage of ITNs without sustained use lowers the effectiveness of malaria control strategies. We therefore aimed to identify critical gaps in the knowledge required to bridge this divide.

Methods

Search Strategy

We followed reporting guidelines and recommendations made by the Meta-analysis of Observational Studies in Epidemiology[22] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses groups.[23] We performed a comprehensive and systematic literature search of electronic databases including Medline, Web of Science, Embase, the Global Health Database[24] and the Cochrane Database of Systematic Reviews to identify studies published between Jan 1, 1990 and September 30, 2013. We identified synonymous terms for *insecticide treated net* AND *utilization* and used these to tailor the search strategy. A full account of the search syntax is provided in Appendix 1. Bibliographies of retrieved articles were reviewed for additional publications. The search strategy was limited to articles published in English.

Study Inclusion Criteria

Studies were eligible for inclusion if they satisfied the following criteria: conducted in the general population, examined the determinants of bed-net use or evaluated the impact of an intervention to increase bed-net use; and the outcome of interest was use of bed-nets in households that possessed at least one net. Only studies conducted in the local populations of malaria endemiccountries[25] were included. Studies in which the outcome (bed-net use) was singularly assessed in vulnerable populations like pregnant women or under-five children were excluded. Systematic synthesis of published literature and meta-analysis related to insecticide-treated nets were excluded. No other restrictions were placed on study design or publication type; both peer-reviewed articles and grey literature were included.

Data Extraction

The title and abstract of all retrieved studies were screened for preliminary eligibility. This was followed by a full-text review of preliminary eligible studies for assessment of their definitive eligibility. Data on study characteristics and crude and adjusted odds ratios with 95% confidence intervals (CI) were recorded in a standardized spreadsheet. Data on the following study characteristics were extracted: title, author, year of publication, country, study population, study design, sample size and endpoint (measurement of ITN use). Information on the following predictors of net-use was abstracted: socio-economic status (SES), education, location of residence, gender, age, number of ITNs in the household and knowledge of malaria.

Data Quality

We assessed methodological study quality utilizing criteria recommended by Wells et al. for non-randomized studies[26]. Each study was assigned a score based on the modified Newcastle-Ottawa Scale and studies that failed to report three or more criteria were flagged as low-to-moderate quality.

Statistical Analysis

Eligible studies that reported adjusted odds ratios (ORs) with 95% CIs were included in the meta-analysis. Studies that only presented crude ORs were excluded. The generic inverse-variance method was used to calculate the overall estimate of effect size, using the below formula. The weight, w_i given to each study is inversely proportional to the variance of the study-specific OR.

$$\ln(\theta) = \frac{\sum_{i=1}^{k} w_i \ln(\theta_i)}{\sum_{i=1}^{k} w_i} \quad ,$$

Firstly, we used the random-effects model proposed by DerSimonian-Laird[27] to estimate the overall impact of each predictor on ITN use. In random-effects analysis the weight assigned to each study is a function of both within-study as well as between-study variance. In contrast to fixed-effects estimates, random-effect models provide a more conservative estimate of the variance (of overall effect size) as the standard errors of each study include two sources of variation. These are more appropriate when substantial heterogeneity in the effect sizes exists between individual studies; with respect to the observed association between predictors and net use.

Secondly, in order to measure the impact of and quantify heterogeneity in our analysis, the I^2 statistic was used and supplemented with p-values from the test of heterogeneity using Cochran 's Q-statistic (χ^2 statistic)[28]. The I^2 statistic is interpreted as the proportion of total variation in study estimates that is due to the between-study variation in effect sizes; above that expected by chance. Values of I^2 have been expressed in terms of percentages and directly estimated from Cochran's Q-statistic using the below scale transformation[28]. A significance level of 5% was used to test for statistical heterogeneity.

$I^2 = \frac{Q-df}{Q} * 100$, where df = k – 1 (and 'k' is the number of studies in the meta-analysis)

Next, we explored sources of heterogeneity in the overall meta-analysis using subgroup analyses[29]. Specifically, eligible studies were stratified by study characteristics chosen a priori like study population (general community or households with target groups like pregnant women and under-five children), study location, season of data collection (rainy or dry) and exposure to mass-media or information-exchange-communication campaigns prior to or during survey administration (yes or no). Table 1 below outlines each predictor examined in the meta-analysis and the corresponding subgroups used to explore sources of heterogeneity. The I^2 statistic was used as a measure of residual heterogeneity within subgroups. High values of I^2 (> 60%) within a subgroup imply considerable heterogeneity in the measure of effect (from the overall meta-analysis) that is not explained by any of the aforementioned study characteristics.

Lastly, random-effects meta-regression models were used to investigate whether the association of a given predictor with net use was modified by study characteristics.[30] Specifically, we tested for differences in effect sizes between subgroups defined by study characteristics outlined in Table 1. Study specific estimates (ORs) were log transformed and regression coefficients (where statistically significant) were presented as ORs with 95% CIs. Sensitivity analysis was conducted to assess the potential effect of study quality on the examined associations with ITN use. Study subgroups were defined on the basis of quality scores assigned to each study. We used random-effects meta-regression to assess whether effect sizes (aORs) for each predictor varied by the two subgroups; namely high vs low-to-moderate study quality.

Forest plots were produced to graphically assess the ORs and 95% CIs for each study. Additionally, funnel plots were used to visually assess the potential for publication bias[31]. We used Egger's linear regression method to test for funnel plot asymmetry (ie. to quantify the bias captured by the funnel plot).[32]

Data abstraction and organization was done in Microsoft Excel 2010 and Stata ver 12.0 was used for the meta-analysis and graphs.

Table 1. Predictors of net use and study characteristics examined in subgroup analyses and meta-regression models

Predictors of net use	*Study characteristics used to define subgroups and assessed as potential effect-modifiers*
Socioeconomic status	Season of survey (rainy or dry)
Education	Country
Knowledge of malaria transmission	Exposure of study population to mass media or IEC campaigns prior to or during the study (yes or no)
Gender	Type of households surveyed (households with high risk groups or random selection of households)
Number of ITNs in the household	
Age group	
Location of residence	

Results

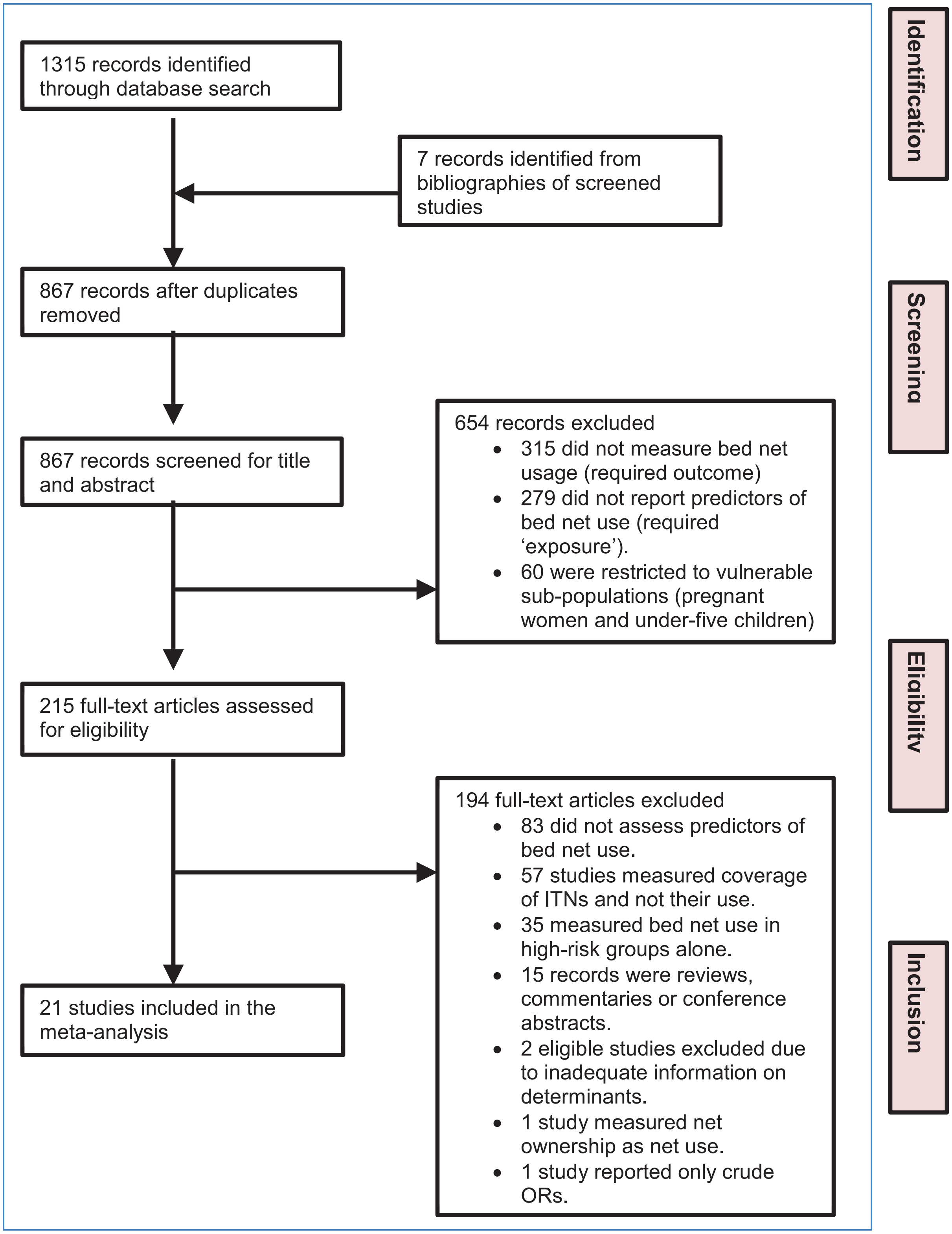


Figure 1. Study selection

The primary search yielded 1315 records of which 867 remained after removal of duplicates (figure 1). An additional 654 records were excluded based on the preliminary screening of titles and abstracts. The remaining 214 full-text articles were assessed for their definitive eligibility. This yielded 23[33-51] records that met our inclusion criteria for the meta-analysis. 2 studies were excluded from the final subset of studies, as they did not examine any of the determinants reported in the other studies.[52,53] Table 2 summarizes key characteristics and endpoints of the 21 studies included in the meta-analysis[33-51].

Study Characteristics

Information about the coverage and uptake of ITNs was available for 12 of the 45 malaria-endemic countries in sub-Saharan Africa. 20 studies (95%) were conducted in this region while 1 study by Vanlerberghe et al.[51] was conducted in the Indian sub-continent (table 2). All studies were conducted between 1994 and 2011; 14 (66%) of them collected data during peak malaria transmission seasons. The vast majority of studies from sub-Saharan Africa were in Ethiopia (n = 8), two each in Cameroon and Nigeria followed by singular contributions from Mozambique, Eritrea, Benin, Malawi, Ghana, Sierra Leone, Kenya and Eritrea. Twenty (95%) articles included in the meta-analysis reported studies that were cross-sectional in nature; the remaining study was a cluster randomized controlled trial. Two cross-sectional studies were implemented as repeated cross-sections; follow-up data were abstracted from with the Malaria Indicator Survey (MIS) in 2007. Eight surveys examined net use among rural households only, while one study was restricted to two Kenyan cities and the remaining eleven were community-based surveys in a combination of rural, urban and peri-urban areas.

Study population

Four studies targeted households with high-risk or vulnerable groups (pregnant women and children under-five); the median sample size was 1097 respondents (range 191 - 10724). The remaining seventeen studies recruited participants from a random sample of households (with and without high-risk groups); with a median sample size of 1879 participants (range 341 - 22344). In eight of these studies which provided data on household demographics, pregnant women and children under-five were present in 2% (range 1 - 10%) and 19% (12 – 72%) of the sampled households. Among the few surveys that reported demographic characteristics of respondents, 51% of all respondents (total 44159) were women; ages ranged from 15 to 50 years. Survey respondents varied across study settings, with nine surveys being administered to the head of household or the spouse and seven surveys targeted any adult (over 18 years of age) in participating households. The remaining five surveys targeted either women of reproductive age, pregnant women or mothers of children under-five.

Study end-point and quality assessment

Eighteen of the twenty-one studies examined predictors of net use as their primary outcome; five of these captured data on coverage and utilization of nets as part of routine monitoring efforts like DHS (Demographic and Health Surveys) and MIC (Malaria Indicator Cluster) surveys. Eight studies obtained contextually specific information regarding ownership and use following the implementation of specific interventions or programmes like mass distribution campaigns and Knowledge Attitude and Practices (KAP) interventions. While the definition of ITN use was fairly consistent across all studies, its measurement at the household level differed across study settings. For instance eight studies examined 'net use' by any (at least one) household member the night preceding the survey. In contrast, five studies measured uptake among all members of the household (table 2). However, few studies discussed the potential influence of social desirability bias. We, therefore, assessed the methodological quality of all studies and ranked them on the Newcastle Ottawa Scale[26] which assigns quality scores to studies based on the ascertainment of exposure (or determinants), study comparability and outcome measurement (Table 3). In addition, studies were evaluated on whether they reported recall and social desirability bias and discussed potential sources. Of the twenty-one studies, 11 were assessed to be of moderate quality (score 2-3/5), with the remaining studies receiving higher scores (4-5/5; n=10). Eight studies reported on sources of bias such as social desirability and recall and potential techniques to minimize them. All studies employed multivariate analysis, while accounting for the cluster sampling of households by communities or districts. Overall, the above quality assessment yielded a median score of three, which reflects moderate quality with scores ranging from two to five.

Coverage and utilization of insecticide-treated nets

Recently published articles on ITN ownership in sub-Saharan Africa have reported a wide variation in rates of coverage (defined as the proportion of households that own at least one ITN), however the general trend showed improvements in the ownership of nets especially among vulnerable populations like pregnant women and children under five.[54,70] Among papers included in this meta-analysis, the coverage varied widely ranging 8% through 88% with a median of 66%. At a national level, the poorest performing country in terms of coverage was Nigeria; with only 8% of households in possession of at least one net (DHS data from 2008).[34]

In addition, a sub-optimal coverage of 37% was reported in parts of rural Mozambique (Household survey, 2007).[38] In contrast, coverage was close to 90% in Sierra Leone, as measured in a national representative survey in 2011.[36] Other countries or regions with high coverage included Cameroon (82%), parts of Northern India (82%) and Zambia (81%). Coverage within certain countries like Ethiopia was heterogeneous across the different states or regions (range 22-71%). Sub-optimal national coverage (55%; MIS 2007 data) was reported in Ethiopia in 2007 with below-average ownership (49%) in parts of central Ethiopia (Household survey 2009). In contrast, coverage was as high as 87% in southern Ethiopia (Household survey 2006). It is important to note that the above estimates imply a declining trend in ITN ownership across different regions of Ethiopia. However there is limited data regarding temporal trends in coverage within a given region. Additionally, Singh et al.[55] have reported that the above trend also corresponded to an overall decline in available ITN use in Ethiopia; from 84% in 2006 to 59% in 2009, although net use varied considerably between different regions.

Figure 2. below is a graphical representation of the relationship between overall ITN use, coverage and conditional use of bed nets. Overall use is defined as the proportion of all households in a given survey where any household member used a bed net the night before the survey. This includes all households; with and without an ITN. On the other hand, conditional or available ITN use is the proportion of households reporting net use solely among households in possession of at least one net.

In our analysis, overall ITN use was positively correlated with both coverage and conditional use of bed nets. Parts of Nigeria and Ethiopia reporting the lowest overall use of 3% and 11%, respectively. In contrast, some of the highest overall use was observed in Zambia (55%) and Sierra Leone (60%). A vast majority of countries reported sub-optimal ITN use (< 50%) owing to a combination of low coverage and poor ITN use in households with available nets. Among all the 23 studies taken together, conditional use of nets ranged from 22% through 76% with a median of 51%. As reflected in Fig 2b., there was little to no correlation observed between ITN coverage and conditional use of nets. For instance, despite having one of the lowest coverage rates of 8%, conditional use in parts of Nigeria was found to be moderately high; 41%. In comparison, the reported usage in parts of India was surprisingly lower for near universal coverage of 80% (Fig 2b.). As observed with ITN coverage, the conditional use of nets was also found to vary considerably between and within countries. For instance in Ethiopia, available use ranged from 22% through 71%; with poorest usage reported in central (22%) and eastern states (34%) the night before the survey. There was less discrepancy between coverage and conditional use in southern Ethiopia where households that possessed ITNs were also likely to use them. The above figures and summary estimates on ITN coverage and usage indicate that, while ownership is a pre-requisite for use, it may not be a suitable proxy for estimating ITN uptake owing to the disparity in ownership and conditional use.

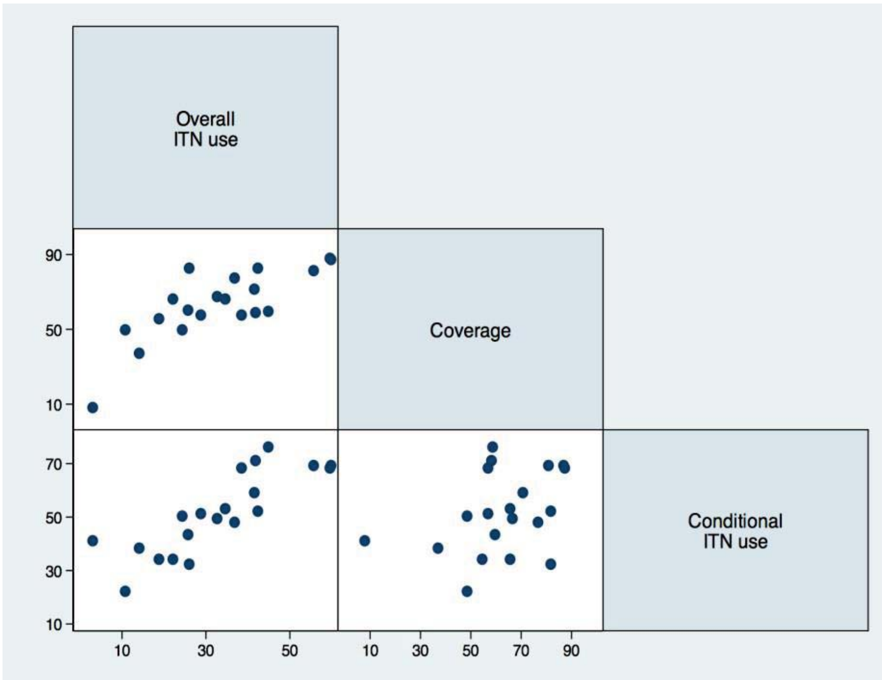


Fig 2a. Scatterplot matrix of the association between ITN coverage, overall and conditional ITN use

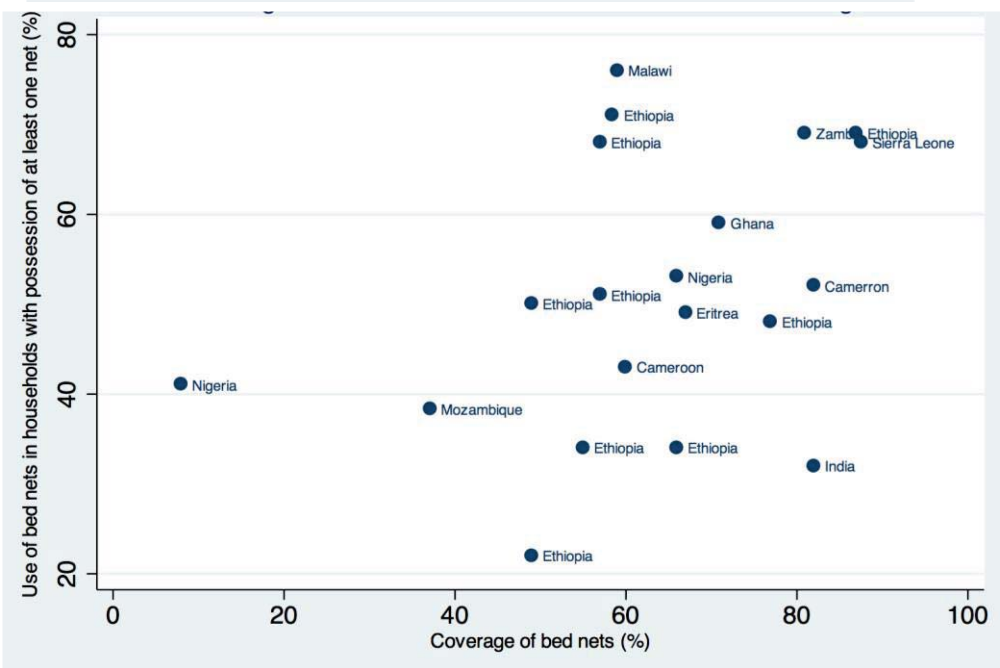


Fig 2b. Coverage and conditional ITN use in malaria-endemic regions

Predictors of ITN use

Summary estimates of OR: The key predictors of ITN use in the general population from 21 studies were education, knowledge of malaria/ITNs, gender and number of ITNs in the household (Fig 3a-g). Household members who had some knowledge of malaria transmission/ITN (vs. no knowledge) and households in possession of more nets (compared to those with fewer nets) were the most likely to use an ITN; the summary estimate of the associated OR was 1.47 (95%CI, 1.29 – 1.66) for the knowledge of malaria and 2.35 (95%CI, 1.80 – 3.07) for the association of the number of nets in a household and the likelihood that at least one net was used the previous net. Men were significantly less likely to use an ITN than women (OR, 0.75; 95%CI, 0.69 – 0.82; Fig 3c). Not surprisingly, educated individuals were 23% more likely to sleep under a net compared to those with no education (95%CI, 4% - 44%; Fig 3a). Pooled summary estimates suggested little or no influence of some factors as reflected in the lack of association between use of ITNs and socioeconomic status, location of residence and age of household members. However, substantial heterogeneity was observed between studies, as shown by the high I^2 values (Fig.3a-g). Among the key predictors, more heterogeneity was noted for education (I^2 = 76%; $p < 0.001$) and number of ITNs (I^2 = 90%; $p < 0.001$) than other factors. Notably, between studies there was minimal variability in the association of ITN use with the knowledge of malaria transmission (I^2 = 33%; $p = 0.13$) implying that the latter is a consistent predictor of net use in several settings. In the overall meta-analysis, the heterogeneity across studies tended to be higher when examining the influence of factors like socioeconomic status, age group and location of residence that were not found to be associated with net use. While socioeconomic status did not seem to have an effect on ITN use in the overall analysis; among four studies richer households were at least 27% less likely to use a net compared to poorer households. However, both the direction and magnitude of this association varied significantly between studies as observed in the substantial heterogeneity of 88% (Fig 3f).

A sensitivity analysis was conducted to assess the effect of study quality on the overall OR estimates associated with each predictor. Random-effect meta-regression was used to test for differences in the ORs between sub-groups of studies defined by their quality scores (high or low-to-moderate; Table 4). Study quality was not found to modify the association between any of the above predictors and ITN use as shown by the non-significant *p*-values between sub-groups in table 2. Sensitivity analysis indicated that education was significantly associated with ITN use only among studies of low-to-moderate quality (OR, 1.28; 95%CI, 1.04 – 1.59).

However, there were few studies of higher quality (n = 5) that examined education as a predictor of net use.

Sources of heterogeneity: In order to explore sources of variability between studies, we tested for heterogeneity within subgroups. The subgroup analysis was conducted for each of the seven predictors as outline in Table 1. Subgroups were defined on the basis of study location (country), season of survey (rainy or dry), household type (sample of households with high-risk groups alone or random sample of all households) and contextual factors that favor ITN use (exposure to mass media and information exchange communication campaigns; IEC or no campaigns before/during survey administration; Table 1). There was significant heterogeneity ($p \leq 0.05$) within each of the above subgroups for factors like socioeconomic status, age, location of residence and number of nets in the household (Tables. 5a-c, Table 5f). Season of survey (rainy or dry) was found to be a potential source of heterogeneity between studies when examining the impact of predictors like education, gender and knowledge of malaria, on net use. For instance, when examining the association between education and net use there was minimal variability between studies conducted in dry seasons (p = 0.84) but significant heterogeneity in estimates from rainy seasons (I^2 = 80%, p < 0.001). In addition to season, exposure to mass media campaigns was also a driver of between-study variance for predictors like gender and education. Furthermore, the heterogeneity in the association of education and gender with ITN use dropped by 28% and 65%, respectively, when restricting the analysis to studies recruiting from the general population compared to the overall meta-analysis of each of the above predictors (Table 5d).

In the subgroup analysis, age was found to be a significant predictor of net use upon stratification by household type (Table 5f); older individuals were 36% more likely to use nets than younger age groups among studies that randomly sampled households with and without target groups (95%CI, 2% - 82%). In contrast, age was not associated with use of ITNs in the survey by Tchinda et al. where households with high-risk groups were purposively sampled (Fig. 3g).[50] Similarly, higher socioeconomic status while not a significant predictor in the overall meta-analysis, was found to be negatively associated with net use among households with vulnerable groups (aOR = 0.58, p = 0.015; Table 5a). While the impact of education on net use varied significantly between studies conducted in rainy seasons (p < 0.001), it was a consistent predictor of use during dry seasons; with more educated individuals 33% more likely to use a net compared to their counterparts (95% CI, 19% - 49%; Table 5d). In contrast, gender was significantly associated with ITN use within all subgroups defined by season and exposure to IEC campaigns.

Characteristics that defined study subgroups as shown in Table 1, were examined in meta-regression models to investigate their potential effects on the association between each predictor and ITN use.[56,57] Covariates like study location, season of survey etc. alluded to previously were not found to modify the association between ITN use and most of the above predictors. However, the effect of age on ITN use varied significantly by study location (p = 0.03); with older age groups significantly more likely to use nets than younger household members in countries such as Malawi and Nigeria. However, the number of studies in each subgroup was small.

Publication bias: Visual assessment of funnel plots (Fig 4) showed that the studies were distributed fairly symmetrically about the combined effect size, suggesting little publication bias. Additionally, Egger's test for funnel plot asymmetry was not statistically significant for any of the determinants, confirming that there was little evidence for publication bias among the studies included in this meta-analysis. However, funnel plots may not be as effective in detecting bias when significant heterogeneity exists between studies.[32]

Discussion

Key Findings

Our meta-analysis of available literature on ITN use indicates that knowledge of malaria, education, number of nets in a household and gender are significant predictors of use in the general population of malaria-endemic regions. Household possession of more nets is associated with roughly doubled odds of net use by any member compared with households that own fewer nets. Likewise, women and individuals with some knowledge of malaria are 25% and 50% respectively, more likely to use a net compared to their counterparts. These findings were supported by the methodologically strongest studies (studies with a quality score greater than 3) where knowledge, gender and number of nets were significant determinants of use. In contrast, our analysis did not find a consistent association between ITN use and factors like socioeconomic status, location and age. However the effect of age on ITN use varied substantially across countries. For example, age was a significant predictor of net use only in Malawi and Nigeria, where older age groups were more likely to use an ITN compared to younger age groups. In contrast, gender and knowledge of malaria were consistently associated with ITN use in a large majority of countries and study settings.

Study findings in relation to other studies

To our knowledge, this is the first meta-analysis of factors affecting ITN use in the general population of malaria-endemic regions. Several studies have assessed targeted coverage and usage of nets among high-risk populations like pregnant women or under-five children, in response to the WHO guidelines in 2007 focusing on vulnerable populations.[55,59] Most recently, two independent meta-analyses evaluated determinants of ITN ownership and use among pregnant women alone.[10,54] Studies examining barriers to net use have identified maternal characteristics like knowledge of malaria, education and age as consistent predictors of ITN use among pregnant women. These findings are corroborated by the results from our analysis, which imply that factors like knowledge of malaria and education are universal determinants in both general and high-risk populations alike. In contrast, we did not observe a consistent association between age and ITN use, potentially due to the nature of comparison groups. Most studies included in this meta-analysis compared net use among adults (25-49 yrs) with under-five children. Due to the organization of shared sleeping structures in a household, children under five often sleep with their parents or mothers, who will most likely be 20-44 years of age. Following recent efforts to scale up coverage and use among vulnerable populations, both young children and their mothers would be expected to report high ITN use. Hence a comparison of the two age groups above will likely yield a poor association if any, between age and net use. On the other hand, Noor et al. draw attention to the higher levels of use in under-five children and their mothers versus older children or adolescents.[14] In our analysis, this is reflected from two studies in Nigeria and Malawi; Nigerian adults over 25 years were roughly twice as likely to use nets compared to those in the 15-25 years age category. Similarly, in Malawi there was a 4-fold increase in likelihood when comparing non-pregnant persons over 15 years with children between 5-15 years. These differences may reflect the fact that while children under the age of five often sleep with their mothers, adolescents do not. Such findings suggest that the number of nets needed should reflect the number of sleeping spaces in a household.

Gender, like the number of nets, was a significant predictor of net use in most settings; with men less likely to use nets than women. This is not surprising since ITN delivery programmes have historically focused on women and young children. Additionally, similar gender-specific trends have been observed for other health programmes such as antiretroviral therapy (ART) and compliance for HIV/AIDS and anti-smoking campaigns.[60-63] However, studies examining gender disparities in net use have reported conflicting results; with use being higher among men in some settings.[64,65] These studies suggest that household decision-making power is largely in favor of men, who choose to use the net in households with low net density thereby precluding other members from sleeping under a net. Such contradictory findings necessitate further research in order to delineate gender disparities in net use.

Study strengths and limitations

This is the first extensive attempt at examining determinants of use only in households with available ITN(s) thereby permitting a clearer examination of factors associated solely with net use. Furthermore, this analysis evaluates the use of ITNs by all household members, which is often overlooked as pregnant women and under-five children are often the primary focus of studies.[10,54] Despite significant heterogeneity between studies, our analysis has identified factors like knowledge of malaria, education and gender as consistent predictors of ITN use in several countries. Although we did investigate sources of between-study variance using subgroup analyses and random-effects meta-regression, these are unlikely to have fully accounted for the variability in the measure of effect between studies. This is not surprising given our attempt to integrate the results from varied study settings within and across malaria-endemic regions. Our study has several limitations, many of which are intrinsic to the existing methods of data collection on ITN use. A vast majority of studies included in this meta-analysis comprise national and regional cross-sectional surveys on ITN coverage and utilization. These rely on self-reported data on the use of bed nets and we did not identify alternative data sources to validate study findings. Due to the rapid scale up of ITN coverage campaigns, self-reported data on net use is liable to social desirability bias. Few studies included in this meta-analysis reported on or addressed this issue. In addition, cross-sectional surveys do not capture fluctuations in ITN use during the period prior to the surveys because of rapid scale-up of coverage, decay of nets or seasonality in use. In addition, the single time-point of cross-sectional survey data limits causal inferences.[54] In this meta-analysis, egger's test did not suggest publication bias however statistical tests for forest plot asymmetry tend to have low power in the presence of substantial heterogeneity.[66] Likewise, meta-regression models may not be sufficiently powered to detect effect modification by covariates like season of survey as sample sizes of subgroups were quite small.

Implications for policymakers

Findings from this analysis can help policymakers identify key bottlenecks in the use of ITNs in order to prioritize interventions that are likely to have the greatest impact in the short or long term. Barriers to ITN use identified in this review like poor knowledge of malaria and low number of nets in a household are potentially modifiable factors. For example, ITN delivery programmes or interventions with an educational component have reported promising results; with individual net usage increasing to 70 to 95% post-intervention.[67,68] These studies suggest that net use can be improved by incorporating an educational component into net distribution campaigns. For some predictors like gender, women and children under-five have historically been the focus of most coverage efforts. The ensuing gender disparities in ITN use may be more effectively addressed through targeted campaigns disseminating gender-neutral messages after taking into account gender roles and norms.

The number of ITNs in a household is a strong determinant of use of at least one net.[36,70] This was noted in a mass distribution campaign in Sierra Leone in 2010 where households were limited to a maximum of three nets. Hence larger households with more than 5 people had low net densities and reported poor usage.[36] More research is needed to determine the optimal number of nets needed to ensure universal coverage of sleeping spaces without misuse of nets .In addition to the aforementioned factors, our analysis also identified education as a significant predictor of net use. This finding calls for the incorporation of development programmes in malaria control strategies.

Unanswered questions

This review aimed at an evidence-based investigation of the gap between net access and net use. In addition to identifying predictors of use, this analysis draws attention to the lack of consistent association of use with factors like socioeconomic status (SES) and age. In a recent meta-analysis, Tusting et al. have emphasized the inverse relationship between SES and risk of malaria.[69] However findings from our analysis indicate that the association between SES and ITN use may be contextual, that is it varies by country. Although households in upper wealth quintiles might be expected to have higher net use, studies in parts of Malawi, Nigeria and Cameroon reported the opposite finding – net use was lower in high SES households. This raises the possibility that, although higher SES and older maternal age may be associated with ITN ownership, further research is needed to evaluate whether these factors affect net use in the general population.

Additionally, use of bed nets is known to be highly seasonal as well as vary by perceived mosquito density. Few studies have examined the barriers to and facilitators of ITN use in the context of such factors. Hence future synthesis of evidence involving utilization of ITNs would benefit from the evaluation of individual level predictors, contextual factors and the interplay between the two.

In our analysis, there was unanimous agreement across several studies on the significance of the number of nets in a household as a predictor of net use. However the impact of net density (number of nets per person in a household) on use is less clear. As a marker for universal coverage used by the WHO, the recommended net density is one ITN for two people in a household. Few studies have examined the adequacy of this definition towards achieving the Millennium Development Goal target of 100% universal coverage by 2015. In this meta-analysis Bennett et al. and Garley et al. have demonstrated that households in possession of more than 1 net per two members were thrice as likely to use a net compared to households with lower net densities.[36,42] Moreover, analysis of DHS survey data from several countries in 2008 found household size as well as the number of nets to be consistent predictors of ITN use; the likelihood of use decreasing sharply with increasing household size. This is a clear indication that ITN ownership is often insufficient to meet the needs of the household. Future studies of ITN uptake should examine the impact of net density as well as the overall number of nets in a household on usage.

Conclusion

It is simplistic to interpret the findings of this analysis as providing a singular policy recommendation on strategies to improve the use of ITNs. Reducing the high malaria burden in developing countries will not depend solely on the elimination of one factor like poverty or poor education. Rather, understanding the specific ecological requirements of the malarial parasite in combination with overcoming barriers to malaria control will determine the success of these efforts. Importantly, our analysis suggests that factors affecting ITN ownership may differ from those influencing its usage. Factors considered to be significant barriers to ownership like costs of nets and place of residence were not found to impact net use among households in possession of nets. Findings from our analysis in combination with other reviews on ITNs suggest that the Millennium Development Goal marker for universal uptake is in fact composed of two components - universal coverage of ITNs and conditional usage of nets (net use conditional on ownership). Consequently, achievement of the MDG target for 2015 relies on the implementation of policies that address barriers to both components rather than solely focusing on delivering ITNs to scale. Hence predictors of net use identified in this review should not be thought of as standalone determinants, but should rather be used for informed decision-making by policymakers when formulating targeted or multifaceted interventions to improve universal ITN uptake. With an ever-present threat like donor fatigue, the timely and ongoing measurement of net use and associated factors could prove fundamental for sustaining malaria control efforts.

Table 2. Characteristics of 23 studies eligible for inclusion in the meta-analysis of predictors of ITN use

Author	Location	Study design	Sample size	Participants	Primary Outcome	Determinants of ITN use in multivariate analysis
Astatkie et al.,[33] 2009	Ethiopia	Cross-sectional	341	One respondent (HOH, husband or wife) from each randomly sampled HH	Net used by any HH member on the night preceding the survey.	Income and gender of the HOH, presence of radio in the HH
Auta et al.,[34] 2012	Nigeria	Cross-sectional	10724	Women (aged 15-49 yrs) living in HHs with children under-five yrs of age.	Net used by children and respondents on the night preceding the survey.	Location, education, wealth quintile.
Baume et al.,[35] 2011	Ghana	Cross-sectional	1852	Pregnant women or mothers/guardians of a child under five years of age in each HH.	Net used (for each net owned by a HH) on the night preceding the survey.	Urban-rural, SES, used coils in past 12 months, number of nets in HH, free or purchased net, age of net, condition of net, color of net, respondent years of education and knowledge of malaria transmission.
Bennett et al.,[36] 2012	Sierra Leone	Cross-sectional	22344	All individuals residing in randomly sampled HHs.	Self-reported last-night net use by a HH resident.	Age, gender, location, wealth quintile, knowledge of malaria transmission, education, exposure to malaria messages, misuse of ITNs and the ratio of ITNs and number of people in the HH.
Bowen et al.,[37] 2013	Cameroon	Cross-sectional	1717	One respondent from each randomly sampled HH.	Self-reported last-night net use by respondents.	Exposure to national mass-media campaign, age, gender, education, religion, children, location, region, SES, number of nets, knowledge of bed nets.
Chase et al.,[38] 2009	Mozambique	Cross-sectional	980	HHs within the demographic surveillance system (DSS) catchment area.	Net used by any HH member the night preceding the survey.	Formal schooling, SES quintile and HH received indoor residual spray (IRS).
Dagne et al.,[39] 2008	Ethiopia	Cross-sectional	638	HOH from each randomly sampled HH	Net used by any HH member the night preceding the survey.	Age, location, education, type of housing construction, shape, color, number and age of ITNs, knowledge of malaria transmission, exposure to ITN messages.
Deressa et al.,[40] 2011	Ethiopia	Cross-sectional	1411	Female HOH from each randomly sampled HH	Net used by any HH member the night preceding the survey.	Region, location, number of ITNs per HH, ITN deployment in HH, number of ITNs in good condition, knowledge of malaria prevention and problems experienced whilst using an ITN (yes/no)

Author	Location	Study design	Sample size	Participants	Primary Outcome	Determinants of ITN use in multivariate analysis
Deribrew et al.,[41] 2010	Ethiopia	Randomized-control trial	2101 HHs in intervention communities and 2030 HHs in control communities.	HOH residing in sampled HHs in the intervention and control communities.	Net used by any HH member on the night preceding the survey.	Age, gender, women of reproductive age (pregnant vs not pregnant). Income, gender, education of HOH and his/her knowledge about malaria transmission.
Garley et al.,[42] 2013	Nigeria	Cross-sectional	3056	All individuals residing in HHs that owned at least one ITN.	Net used (for each net owned by a HH) on the night preceding the survey.	Age, gender, wealth quintile, location, education of HOH, polygamous HH, ratio 1 ITN per 2 persons (yes or no).
Gobena et al.,[12] 2012	Ethiopia	Cross-sectional	1879	All women residing in randomly sampled HHs.	Net used by any HH member the night preceding the survey.	Location, altitude, HH with under-5 children, HH size, education of HOH, education of women, Highest education of HH member, number of sleeping rooms, roof types, Knowledge about malaria prevention, color preference for ITN, number of ITNs.
Graves et al.,[43] 2011	Ethiopia	Baseline and Endline cross-sectional surveys	12678 (baseline). 14663 (endline)	HOH or available adult from each randomly sampled HH.	Net used by each HH member the night preceding the survey.	Age, gender, proportion of good nets, net density, altitude, number of sleeping spaces in HH, proportion of nets older than 12 months and malaria knowledge.
Hwang et al.,[44] 2007	Ethiopia	Cross-sectional	3902	HOH and women of reproductive age (15-49 yrs) living in randomly sampled HHs.	Self-reported last-night net use by respondents.	Women's knowledge of malaria, school attendance, HH with under-5 children, location, HH size, number of ITNs in the HH and HH sprayed in the past 12 months.
Ngondi et al.,[45] 2011	Ethiopia	Baseline and Endline cross-sectional surveys	3784 (baseline). 5413 (endline)	HOH or available adult from each randomly sampled HH.	Net used (for each net owned by a HH) on the night preceding the survey.	Age, condition and type of net, net density, HH wealth quintile, altitude and HH sprayed with insecticide.

Author	Location	Study design	Sample size	Participants	Primary Outcome	Determinants of ITN use in multivariate analysis
Macintyre et al.,[46] 2006	Eritrea	Cross-sectional	1650	One adult per randomly selected HH	Net used by all HH members the night preceding the survey	Knowledge about malaria transmission, presence of health clinic within village, location of HH and at least one malaria case in HH in past 3 yrs.
Macintyre et al.,[47] 2002	Kenya	Cross-sectional in two cities	Kisumu (512) Malindi (480)	One adult per randomly selected HH	Net used by all HH members the night preceding the survey	Wealth, education, drainage system in each HH.
Macintyre et al.,[48] 2012	Zambia	Cross-sectional	341	Mothers of under-five children living in randomly sampled HHs.	Net used by any HH member the night preceding the survey.	HH wealth, number of ITNs, ownership of net with mother's preferred shape and color, net condition, more than one ITN per sleeping space. Mother's characteristics include education, knowledge about malaria, exposure to messages about ITNs.
Rashed et al.,[15] 1999	Benin	Cro3ss-sectional	191	HOH living in HHs with one child under 6 yrs of age.	Net used by any HH member the night preceding the survey.	Men's level of education, women's income, women's participation in a community organization and use of medicinal tea.
Skarbinski et al.,[49] 2011	Malawi	Cross-sectional	18967	Random selection of HHs in urban and rural communities	Net used (for each net owned or deployed) on the night preceding the survey.	Location, SES index, presence of target groups (pregnant women, children under 5), number of ITNs in the HH.
Tchinda et al.,[50] 2012	Cameroon	Cross-sectional	1822	HOH from each randomly selected HH	Net used by any HH member the night preceding the survey.	Net density in HH, age groups, HH with children under 5 yrs, education level, house construction characteristics and environment suitable for mosquito proliferation (yes/no).
Vanlerberghe et al.,[51] 2002	India, Nepal	Cross-sectional	848	HOH from each randomly selected HH	Net used by any HH member the night preceding the survey.	Gender of HOH, wealth quintile, highest level of education of HOH, religion, family size, location and history of visceral leishmaniasis (VL).

Figure 3a. Summary of pooled odds ratios from random-effects meta-analysis of education as a predictor of ITN use

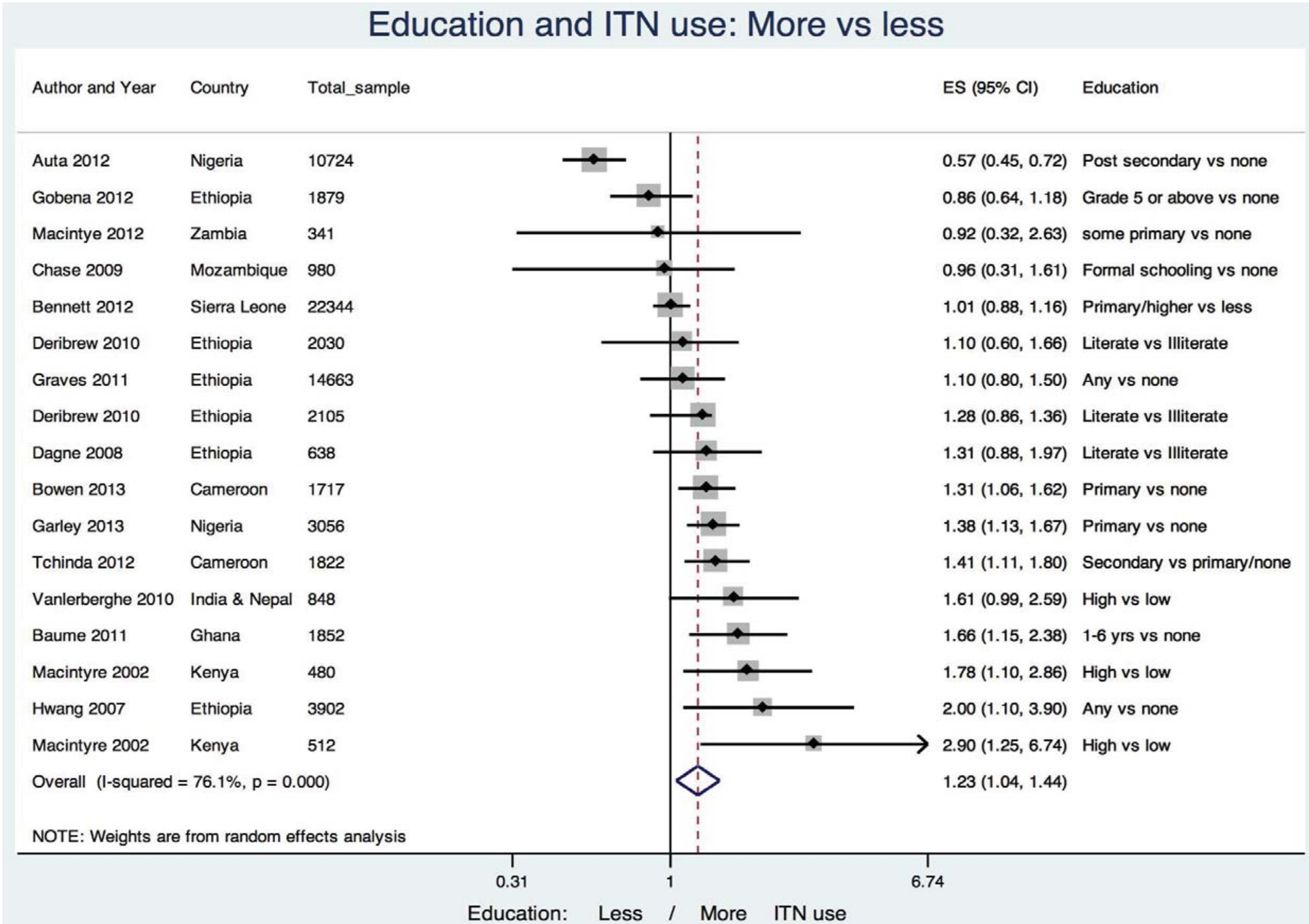


Figure 3b. Summary of pooled odds ratios from random-effects meta-analysis of knowledge of malaria as a predictor of ITN use

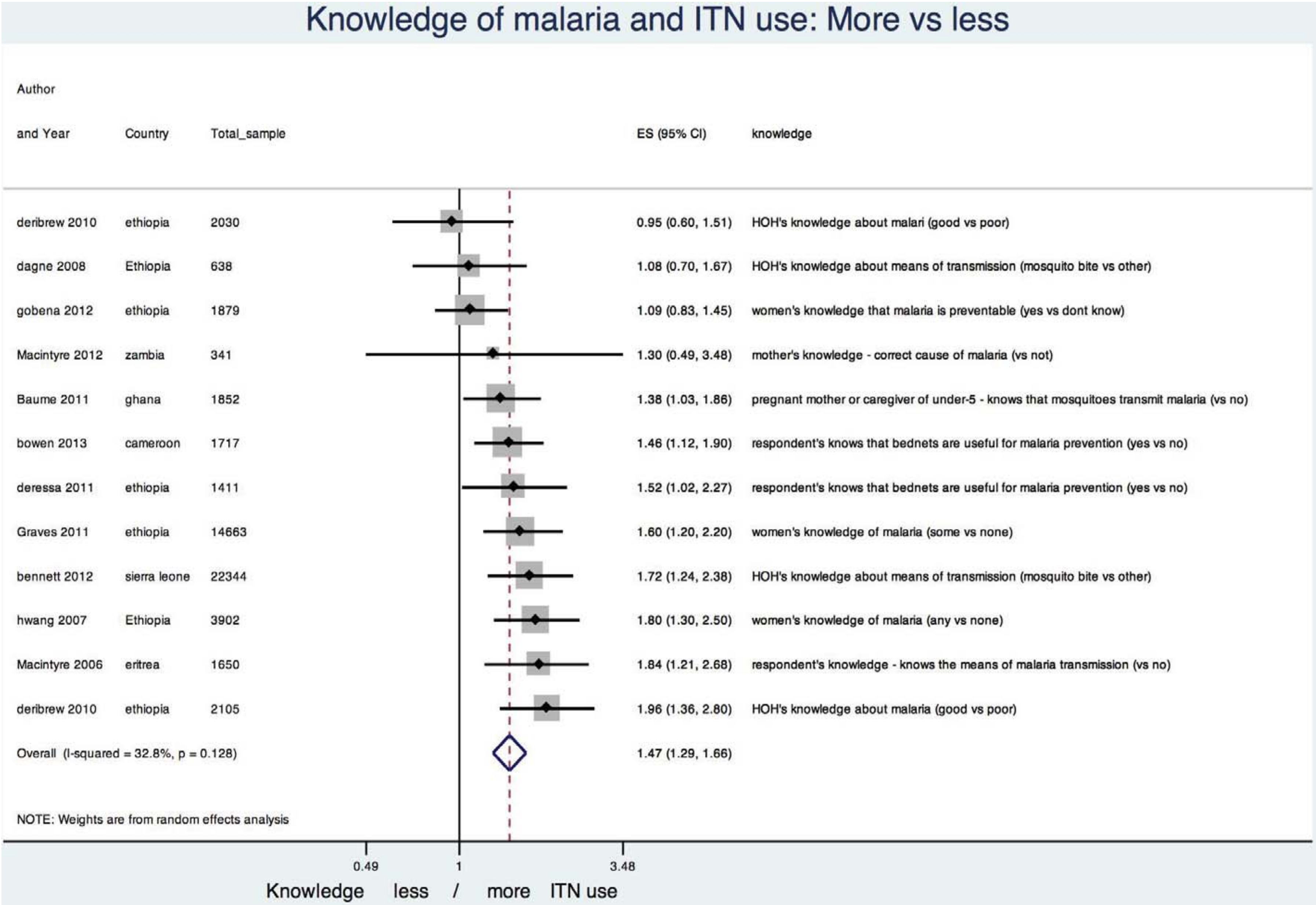


Figure 3c. Summary of pooled odds ratios from random-effects meta-analysis of gender as a predictor of ITN use

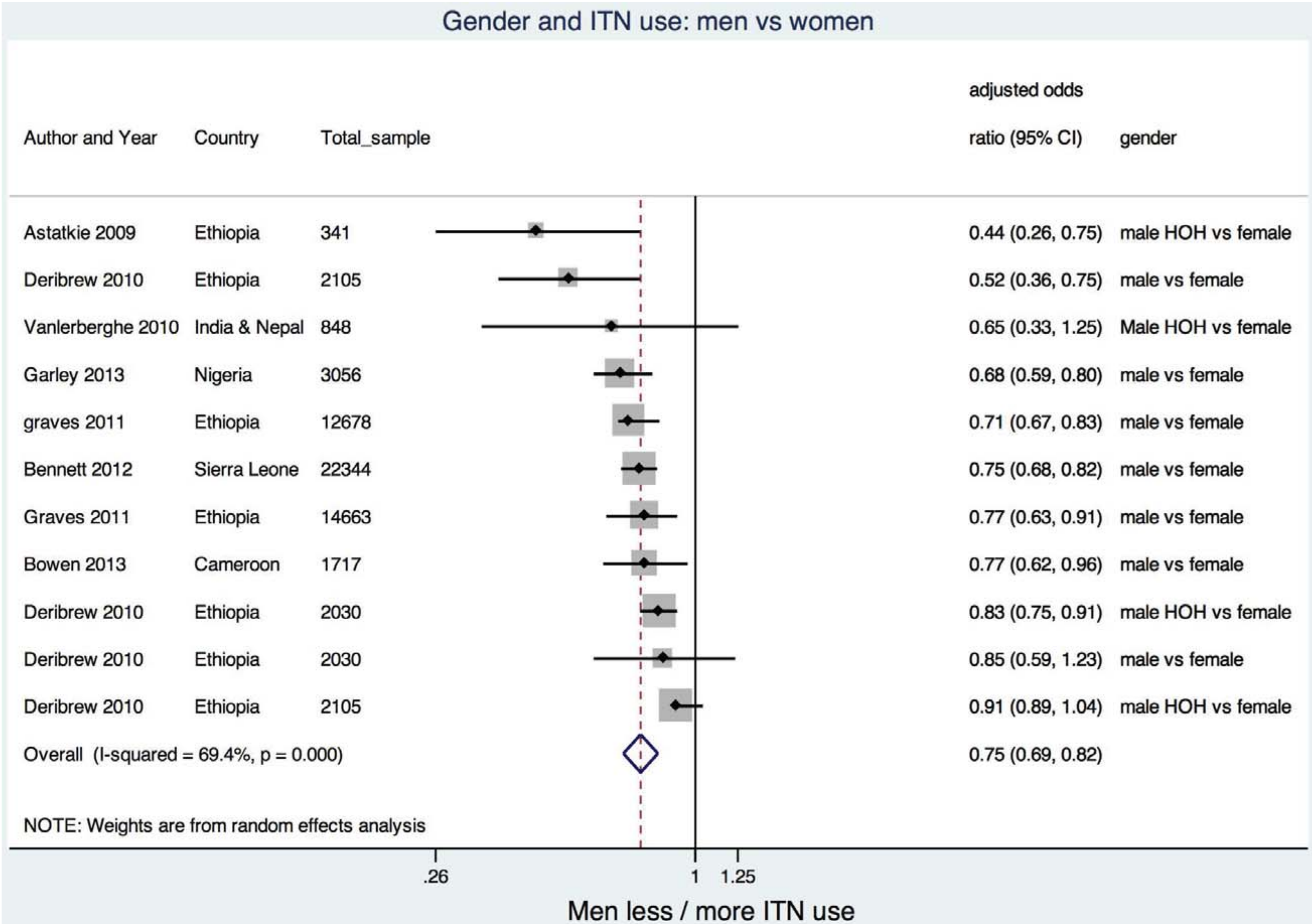


Figure 3d. Summary of pooled odds ratios from random-effects meta-analysis of number of nets in a household as a predictor of ITN use

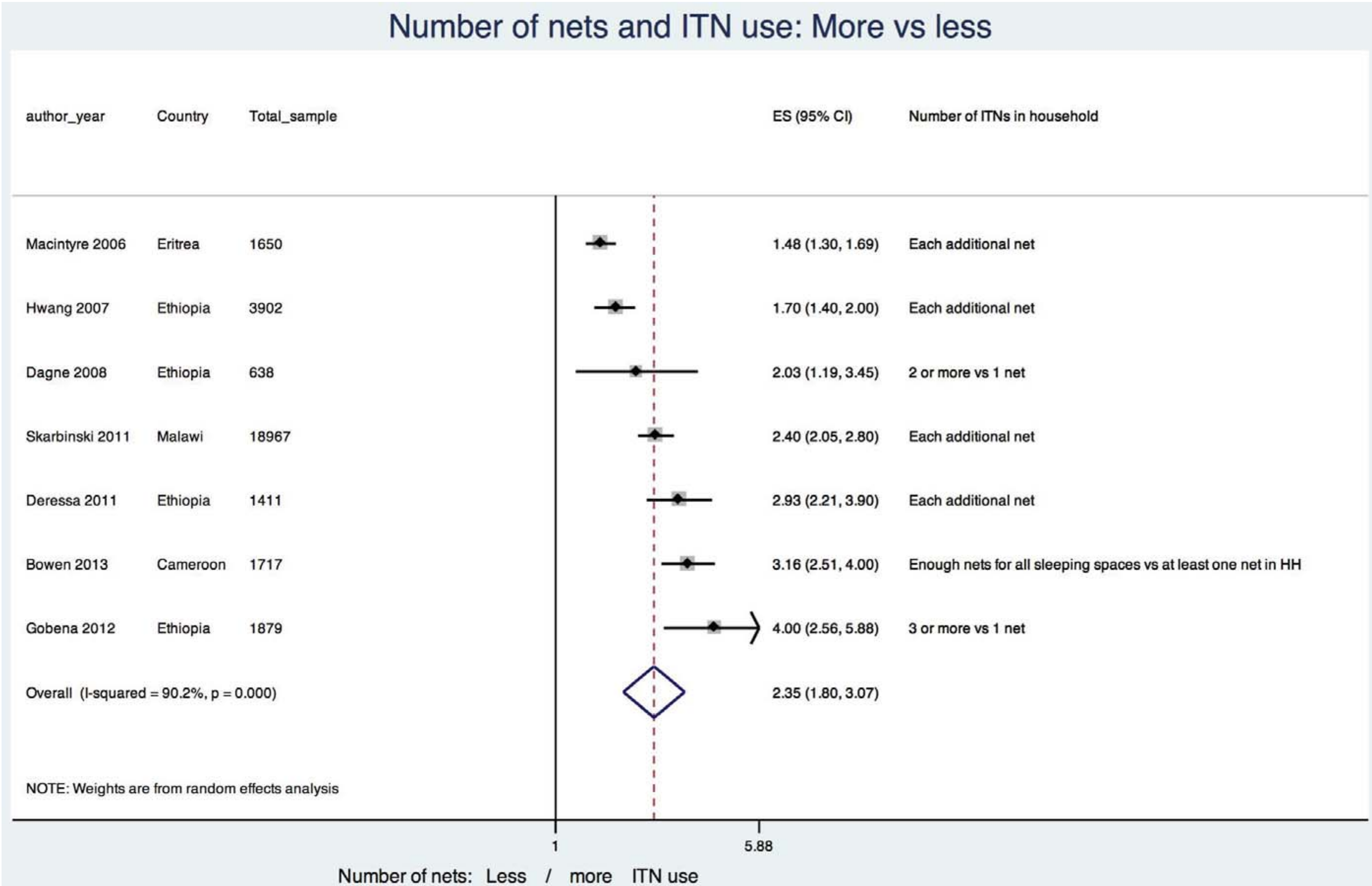


Figure 3e. Summary of pooled odds ratios from random-effects meta-analysis of location of residence as a predictor of ITN use

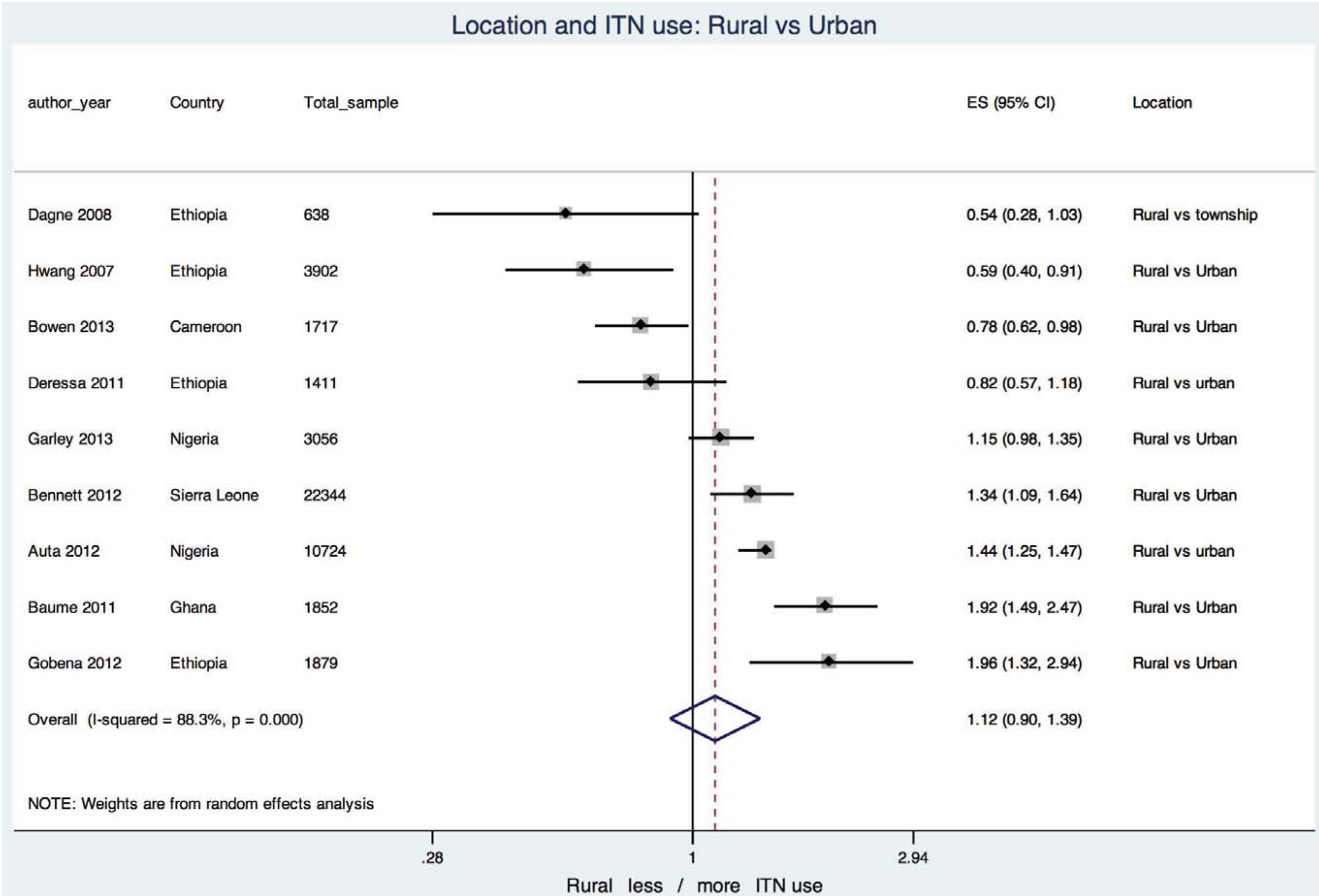


Figure 3f. Summary of pooled odds ratios from random-effects meta-analysis of socioeconomic status as a predictor of ITN use

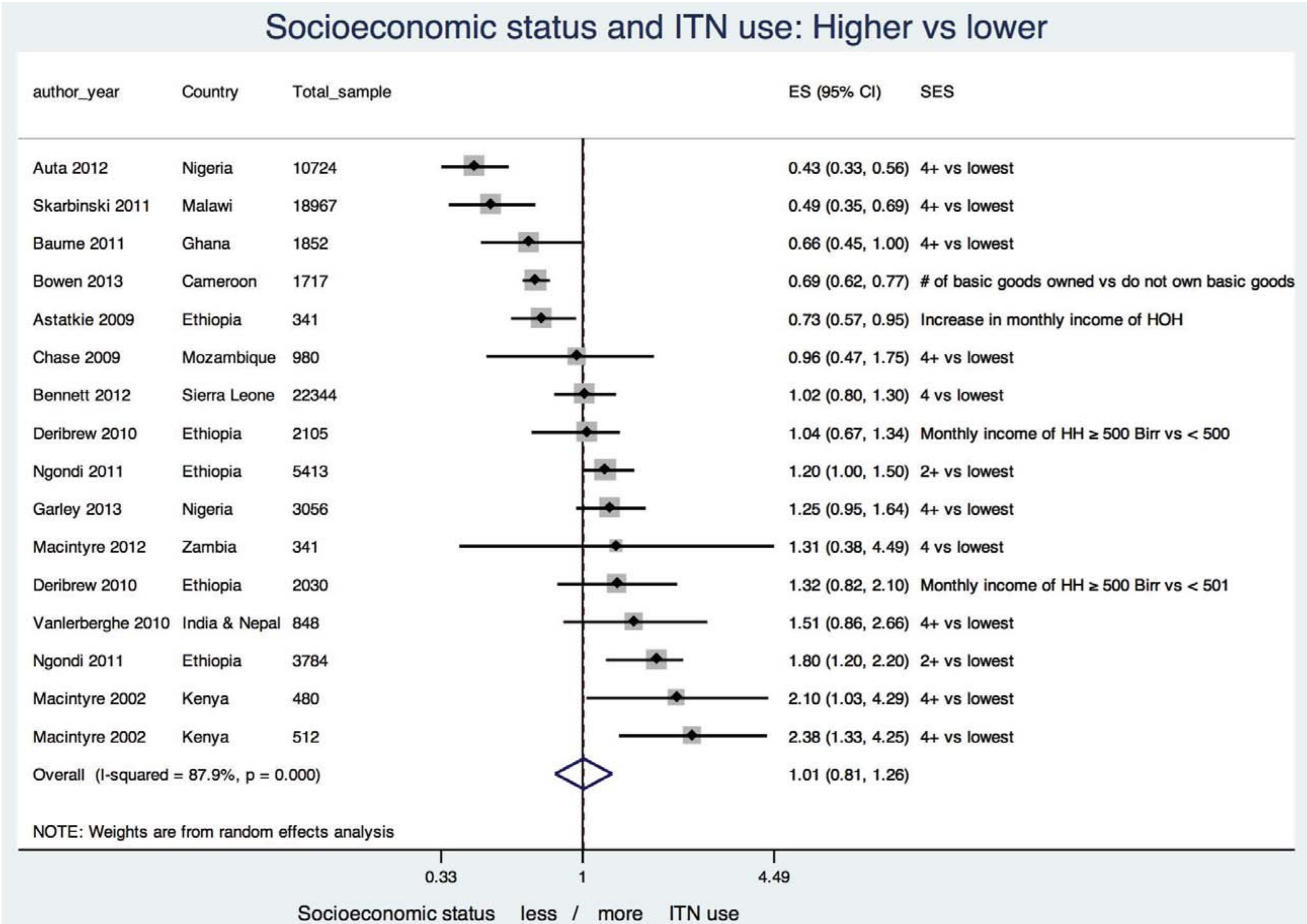


Figure 3g. Summary of pooled odds ratios from random-effects meta-analysis of age as a predictor of ITN use

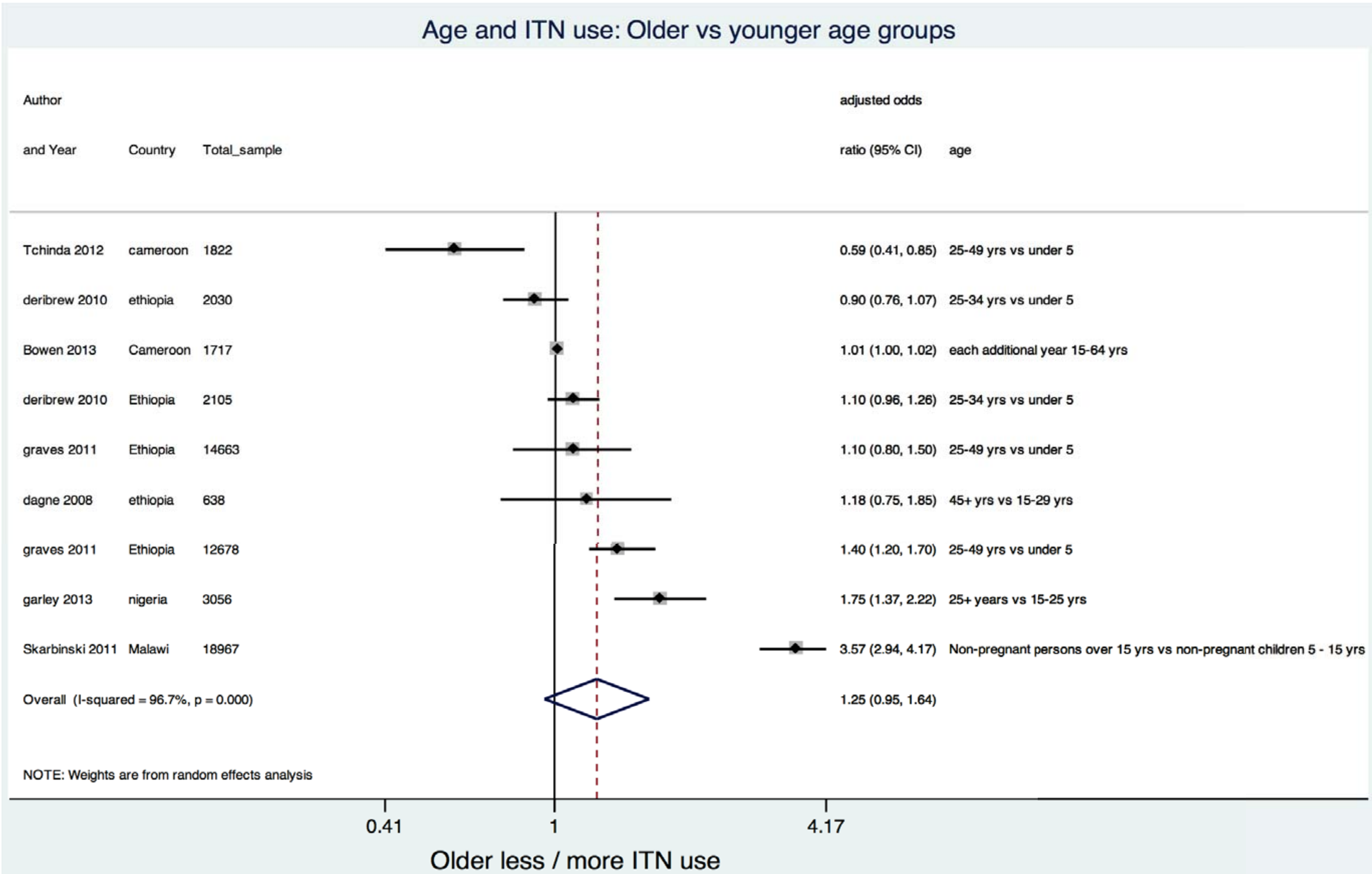


Table 3. Risk of bias assessment for studies included in the meta-analysis

Reference	Selection		Comparability of users and non-users on the basis of study design or analysis	Outcome	Steps to reduce bias discussed (social desirability, recall)	Overall assessment score (max. of 5)
	Representativeness of the surveyed households	Ascertainment of determinants (exposure)		Measurement of ITN use		
Astatkie, 2009	☐ somewhat representative	☐ Structured interview	☐ Multivariate Analysis	☐ Verification of ITN deployment	✕	4
Auta, 2012	☐ truly representative	☐ DHS survey	☐ Multivariate Analysis	Self-reported	✕	3
Baume, 2011	☐ somewhat representative	☐ Structured interview	☐ Multivariate Analysis	Self-reported	✕	3
Bennett, 2012	☐ truly representative	☐ Structured interview	☐ Multivariate Analysis	☐ Verification of ITN deployment / presence	☐	3
Bowen, 2013	☐ truly representative	☐ MICS survey protocol	☐ Multivariate Analysis	Self-reported	☐	4
Chase, 2009	☐ somewhat representative	☐ Structured interview	☐ Multivariate Analysis	Self-reported	☐	4
Dagne, 2008	☐ somewhat representative	☐ Structured interview	☐ Multivariate Analysis	Self-reported	✕	3
Deressa, 2011	☐ somewhat representative	☐ Structured interview	☐ Multivariate Analysis	☐ Verification of ITN deployment / presence	☐	5
Deribrew, 2010	☐ truly representative	☐ Structured interview	☐ Multivariate Analysis	Self-reported	✕	3
Garley, 2013	☐ truly representative	☐ MICS survey protocol	☐ Multivariate Analysis	☐ Verification of ITN deployment / presence	✕	4
Gobena ,2012	☐ somewhat representative	☐ Structured interview	☐ Multivariate Analysis	☐ Verification of ITN deployment	☐	5
Graves, 2011	☐ truly representative	☐ MICS survey protocol	☐ Multivariate Analysis	Self-reported	✕	3
Hwang, 2007	☐ truly representative	☐ MICS survey protocol	☐ Multivariate Analysis	Self-reported	✕	3

Reference	Selection		Comparability of users and non-users on the basis of study design or analysis	Outcome	Steps to reduce bias discussed (social desirability, recall)	Overall assessment score (max. of 5)
	Representativeness of the surveyed households	Ascertainment of determinants (exposure)		Measurement of ITN use		
Macintyre, 2002	□ truly representative	□ Structured interview	□ Multivariate Analysis	Self-reported	X	3
Macintyre, 2006	□ truly representative	□ Structured interview	□ Multivariate Analysis	Self-reported	□	4
Macintyre, 2012	□ truly representative	□ MICS survey protocol	□ Multivariate Analysis	□ Verification of ITN deployment / presence	X	4
Ngondi, 2011	□ truly representative	□ MICS survey protocol	□ Multivariate Analysis	□ Verification of ITN deployment / presence	□	5
Rashed, 1999	□ somewhat representative	Semi-structured interview	□ Multivariate Analysis	Self-reported	X	2
Skarbinski, 2011	□ truly representative	□ Structured interview	□ Multivariate Analysis	□ Verification of ITN deployment	□	5
Tchinda, 2012	□ somewhat representative	□ Structured interview	□ Multivariate Analysis	Self-reported	X	3
Vanlerberghe, 2010	□ truly representative	□ Structured interview	□ Multivariate Analysis	Self-reported	X	3

Table 4. Sensitivity Analysis to assess the effect of study quality

Determinant of ITN use	Study Quality	# of studies	OR (95% CI)	Within subgroups I^2	Between subgroups p-value
SES	Good	8	0.95 (0.7, 1.28)	89.7%	0.64
	Moderate to low	8	1.09 (0.74, 1.62)	87.5%	
Education	Good	5	1.17 (0.95, 1.44)	47.2%	0.59
	Moderate to low	12	1.28 (1.04, 1.59)	80.9%	
Location	Good	4	1.08 (0.77, 1.5)	84.1%	0.55
	Moderate to low	5	1.15 (0.85, 1.55)	87.4%	
Number of ITNs	Good	5	2.59 (1.82, 3.69)	92.9%	0.12
	Moderate to low	2	2.35 (1.8, 3.07)	90.2%	
Gender	Good	3	0.68 (0.56, 0.82)	47%	0.26
	Moderate to low	8	0.78 (0.71, 0.86)	70.3%	
Age	Good	3	1.84 (0.78, 4.35)	90%	0.09
	Moderate to low	6	1.03 (0.84, 1.26)	78.9%	
Knowledge	Good	5	1.4 (1.16, 1.69)	22.6%	0.65

Table 5a Socioeconomic status and ITN use sub-group analyses: Higher vs lower socioeconomic status

Covariate	Subgroup	N studies	Adjusted Odds Ratio (95% CI)	Within group I^2 (p-value)
Country	Zambia	1	1.31 (0.38, 4.5)	--
	Malawi	1	0.49 (0.35, 0.69)	--
	Kenya	2	2.26 (1.44, 3.55)	0.0% (p = 0.88)
	Ghana	1	0.66 (0.45, 0.98)	--
	India & Nepal	1	1.51 (0.86, 2.66)	--
	Nigeria	2	0.73 (0.26, 2.29)	96.7%[a]
	Ethiopia	5	1.16 (0.85, 1.57)	81.2%[a]
	Cameroon	1	0.69 (0.62, 0.77)	--
	Sierra Leone	1	1.02 (0.8, 1.3)	--
	Mozambique	1	0.96 (0.47, 1.75)	--
Season	Rainy	8	0.92 (0.96, 1.4)	87.1%[a]
	Dry	8	1.11 (0.84, 1.47)	89.1%[a]
Exposure to IEC campaign	Yes	9	0.87 (0.67, 1.13)	85.9%[a]
	No	7	1.26 (0.83, 1.91)	84.1%[a]
HH type	HH with target groups	3	0.58 (0.37, 0.91)	63.2% **(0.07)**
	Random selection	13	1.11 (0.88, 1.4)	87.2%[a]

[a] $p < 0.001$ for test of heterogeneity within subgroup

Table 5b. Location and ITN use sub-group analyses: Rural vs Urban

Covariate	Subgroup	N studies	Adjusted Odds Ratio	Within group I^2 (p-value)
Country	Ghana	1	1.92 (1.49, 2.47)	--
	Nigeria	2	1.3 (1.04, 1.62)	83.4%[a]
	Ethiopia	4	0.86 (0.48, 1.54)	85.8%[a]
	Cameroon	1	0.78 (0.62, 0.98)	--
	Sierra Leone	1	1.34 (1.09, 1.64)	--
Season	Peak	7	1.17 (0.9, 1.53)	86%[a]
	Dry	2	0.96 (0.65, 1.4)	86.5%[a]
Exposure to IEC campaign	Yes	5	1.08 (0.84, 1.38)	88.4%[a]
	No	4	1.17 (0.65, 2.1)	91%[a]
HH type	HH with target groups	3	1.35 (0.96, 1.91)	85.9%[a]
	Random selection	6	1.0 (0.74,1.34)	85.2%[a]

[a]$p < 0.001$ for test of heterogeneity within subgroup

Table 5c Number of ITNs in the household and ITN use sub-group analyses: More vs less nets in a household

Covariate	Subgroup	N studies	Adjusted Odds Ratio	Within group I^2 (p-value)
Country	Eritrea	1	1.48 (1.3, 1.69)	--
	Ethiopia	4	2.5 (1.65, 3.76)	85.5%[a]
	Cameroon	1	3.16 (2.5, 3.99)	--
	Malawi	1	2.4 (2.05, 2.8)	--
Season	[a]Peak	6	2.23 (1.7, 2.93)	88.0%[a]
	Dry	1	3.16 (2.5, 3.99)	--
Exposure to IEC campaign	[a]Yes	5	2.32 (1.66, 3.22)	91.5%[a]
	[a]No	2	2.55 (1.1, 5.9)	92%[a]

[a]$p < 0.001$ for test of heterogeneity within subgroup

Table 5d. Education and ITN use sub-group analyses: More vs less education

Covariate	Subgroup	N studies	Adjusted Odds Ratio	Within group I^2 (p-value)
Country	Zambia	1	0.92 (0.32, 2.64)	--
	Kenya	2	2.0 (1.32, 3.04)	0.0% (p = 0.24)
	Ghana	1	1.66 (1.15, 2.39)	--
	India & Nepal	1	1.61 (1.0, 2.6)	--
	Nigeria	2	0.89 (0.37, 2.11)	96.9%[a]
	Ethiopia	6	1.17 (0.97, 1.4)	35.3% (p = 0.17)
	Cameroon	2	1.35 (1.15, 1.59)	0.0% (p = 0.33)
	Sierra Leone	1	1.01 (0.88, 1.16)	--
	Mozambique	1	0.96 (0.42, 2.19)	--
Season	Rainy	12	1.2 (0.95, 1.5)	80.1%[a]
	Dry	5	1.33 (1.19, 1.49)	0.0% (p = 0.84)
Exposure to IEC campaign	Yes	8	1.0 (0.87, 1.36)	83.2%[a]
	No	7	1.4 (1.13, 1.73)	56.5% (p = 0.02)
HH type	HH with target groups	4	1.06 (0.58, 1.94)	91.6%[a]
	Random selection	13	1.25 (1.1, 1.43)	52.1% (p = 0.01)

[a] $p < 0.001$ for test of heterogeneity within subgroup

Table 5e. Gender and ITN use sub-group analyses: Male vs Female

Covariate	Subgroup	N studies	Adjusted Odds Ratio	Within group I^2 (p-value)
Country	Sierra Leone	1	0.75 (0.68, 0.82)	--
	Nigeria	1	0.68 (0.58, 0.79)	--
	Ethiopia	7	0.76 (0.67, 0.86)	76.5%[a]
	Cameroon	1	0.77 (0.62, 0.96)	--
	India & Nepal	1	0.65 (0.33, 1.27)	--
Season	Peak	3	0.74 (0.69, 0.79)	0.0% (p = 0.66)
	Dry	8	0.75 (0.66, 0.85)	71.6%[a]
Exposure to IEC campaign*	Yes	7	0.78 (0.7, 0.86)	73.2%[a]
	No	3	0.71 (0.62, 0.81)	23.9% (p = 0.27)

[a] $p < 0.001$ for test of heterogeneity within subgroup

Table 5f. Age and ITN use sub-group analyses: Older vs younger age groups

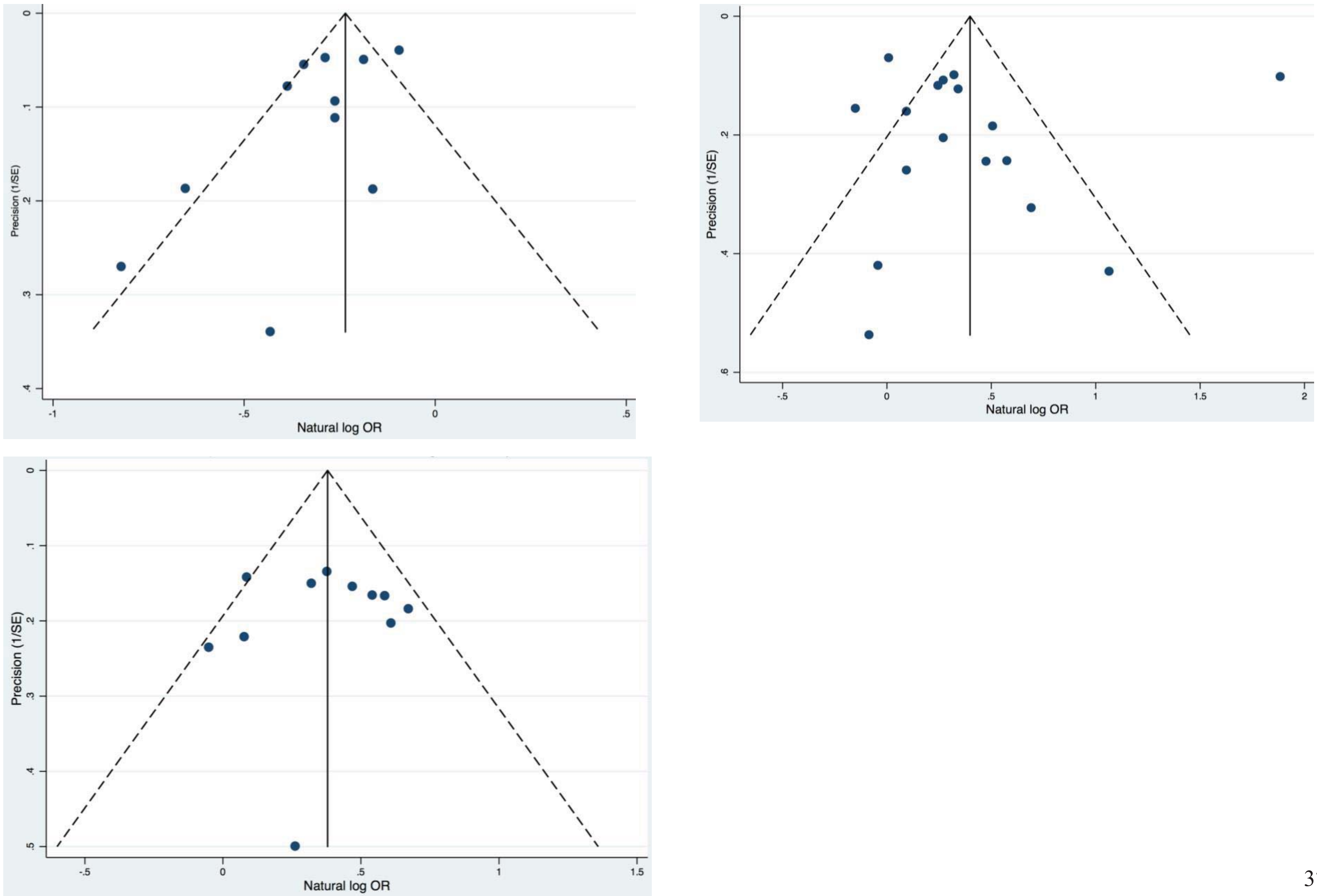
Covariate	Subgroup	N studies	Adjusted Odds Ratio	Within group I^2 (p – value)
Country	Malawi	1	3.57 (3.0, 4.25)	--
	Nigeria	1	1.75 (1.37, 2.23)	--
	Ethiopia	5	1.12 (0.94, 1.32)	68.5%[a]
	Cameroon	2	0.8 (0.47, 1.35)	88.2%[a]
Season	Peak	5	1.32 (0.71, 2.45)	96.5%[a]
	Dry	4	1.12 (0.94, 1.33)	86.9%[a]
Exposure to IEC campaign	Yes	6	1.4 (0.97, 2.02)	97%[a]
	No	3	0.99 (0.61, 1.6)	88%[a]
HH type	HH with target groups	1	0.59	--
	Random selection	8	1.36 (1.02, 1.82)	87%[a]

[a] $p < 0.001$ for test of heterogeneity within subgroup

Table 5g. Sub-group analyses: Knowledge of malaria and ITN use, any vs no knowledge of malaria or ITNs

Covariate	Subgroup	N studies	Adjusted Odds Ratio	Within group I^2 (p-value)
Country	Zambia	1	1.30 (0.49, 3.46)	--
	Eritrea	1	1.84 (1.24, 2.74)	--
	Cameroon	1	1.46 (1.12, 1.9)	--
	Sierra Leone	1	1.72 (1.24, 2.38)	--
	Ghana	1	1.38 (1.03, 1.85)	--
	Ethiopia	7	1.4 (1.14, 1.72)	56% (p = 0.04)
Season	Peak	9	1.47 (1.28, 1.68)	23% (p = 0.23)
	Dry	3	1.43 (1.01, 2.04)	66% (p = 0.05)
Exposure to IEC campaign	Yes	7	1.48 (1.22, 1.8)	39.2% (p = 0.18)
	No	5	1.44 (1.21, 1.72)	32.8% (p = 0.13)
HH type	HH with target groups	3	1.42 (1.13, 1.79)	0.0% (p = 0.92)
	Random selection	9	1.47 (1.25, 1.73)	50.4% (p = 0.04)

Fig 4. Funnel plots of studies included in the meta-analysis of the association between ITN use and gender (Fig 4a), education (Fig 4b), knowledge of malaria (Fig 4c). SE = Standard Error.



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