Impact of Insecticide Treated Nets and Indoor Residual Spraying on prevalence of Malaria Among Women of reproductive age in Ghana: Implication for Malaria Control and Elimination

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Abstract

Background

The Global Fund alone contributed 56% of all international financing for malaria and has invested more than US$13.5 billion in malaria treatment, prevention, and control programs as of June 2021. However, there is paucity of studies assessing whether these investments in different malaria interventions (use of mosquito nets, indoor residual spraying and preventive treatment for children and pregnant women) have contributed to a reduction in malaria prevalence. This study aims to quantify the impact of household access to insecticide treated nets (ITNs) and the indoor residual spraying (IRS) on malaria prevalence among women of reproductive age in Ghana. .

Method

This study analyzed the 2016 Ghana Malaria Indicator Survey (MIS), a nationwide survey among women aged 15 to 49 years. The study employed the Poisson regression model with inverse probability to treatment weighting to determine the average treatment effect estimate of the two malaria interventions on the prevalence of malaria among women in Ghana.

Results

A total sample of 4,861 women interviewed from the 2016 Ghana MIS was used for the analysis. The prevalence of malaria in 2016 was 34.4% (95% CI: [32.4%, 36.4%]). Approximately 80.0% of the women lived in households with access to ITNs (Pr=79.9% , (95% CI: [78.0%, 81.7%])), 12.4% (95% CI: [7.5%, 19.8%]) of the households had access to IRS and 11.4% (95% CI: [7.0%, 18.0%]) of the households had access to both ITNs and IRS. Household access to only ITN contributed to 7.1% (95% CI: [-12.0%, -2.1%], p=0.005) reduction in the prevalence of malaria among women whilst IRS at the households contributed to 6.8% (95% CI: [-13.1%, -0.55%], p=0.033) reduction in malaria prevalence. Households with access to both ITNs and IRS contributed to a 27.1% (95% CI: [-34.9%, -19.25%]) reduction in malaria prevalence among women.

Conclusion

Access to both ITNs and the application of IRS at the household level contributed to a significant reduction of malaria prevalence among women of reproductive age in Ghana. This finding confirms the call for integrating malaria control interventions to facilitate attainment of malaria elimination in Ghana.

Introduction

Malaria is a life-threatening disease caused by parasites transmitted from person-to-person through the bite of female anopheles' mosquitoes. Although preventable, globally, there were an estimated 229 million cases of malaria and 409,000 malaria deaths in 2019 compared to 228 million cases and 411,000 deaths in 2018[1, 2]. The disease disproportionately affects children under the age of five years, accounting for approximately 274,000 (67%) of all malaria deaths globally in 2019. Countries in the World Health Organisation (WHO) African Region have a disproportionately high share of the global malaria burden, accounting for about 94% of malaria cases and deaths. In 2019, the total funding for malaria control and elimination was estimated as USD 3 billion globally, of which about USD 900 million (31%) were contributed from governments of endemic countries[1].

One of the overarching objectives of the sustainable development goals (SDG) is to attain the highest standard of health care for each individual within all communities by preventing the occurrence of diseases [3]. Vector control has been identified as an important preventive strategy for malaria. WHO recommends insecticide-treated nets (ITNs) and indoor residual spraying (IRS) as part of this strategy. These preventive strategies came at a huge cost with an estimated USD 3.1 billion invested in 2017 of which USD 2.2 billion were invested in the WHO African regions [2]. A total of 624 million long lasting insecticide-treated nets (LLINs) were delivered from 2015 to 2017, of which 459 million (83%) ITNs were delivered in sub-Saharan Africa. [2] In 2019, it was estimated that about 46% of all people at risk of malaria in Africa were protected by an ITN, compared to 2% in 2000.[1] However, ITN coverage has plateaud since 2016.[1] In contrast, globally, IRS protection declined from a peak of 5% in 2010 to 2% in 2019, with decreases recorded across all WHO regions. The declines in IRS coverage are occurring as countries switch from pyrethroid insecticides to more expensive alternatives to mitigate mosquito resistance to pyrethroids.

In Ghana, over 13 million ITNs had been distributed as of September 2017 with about 1.5 million of those distributed in 2017 only [4]. Again, over 300,000 households were sprayed against mosquitoes protecting over 840,000 household residents through the indoor residual spraying program [4]. Funding from the US President Malaria Initiative (PMI) over the years which saw an initial annual funding of USD 5 million in 2008 increased to USD 28 million in 2017 cumulating to over USD 275 million within the 10 years period. A budget of USD 26 million was made for the malaria operational plan for the 2018 fiscal year through the PMI [4]. The median cost of distribution of each ITN was estimated as USD 4.34 to 4.55 through mass distribution, USD 3.30 to 3.69 through school-based distribution, and USD 3.90 to 4.55 through health facilities[5]. The median cost of protecting an individual each year using ITNs was estimated as USD 2.20 (range: USD 0.88 to 9.54) whilst IRS was USD 6.70 (range: USD 2.22 to 12.85) [6]. Between May 2010 and October 2012, a total of 12.5 million LLINs were distributed across Ghana with an incurred cost of USD 6.51 per LLIN [7]. However, there is paucity of studies quantifying the impact of these investments in terms of the distribution of ITNs and the application of IRS towards the reduction of malaria prevalence in Ghana. Therefore, this study sought to estimate the impact of the distribution of ITNs and the application of IRS on malaria prevalence among women of reproductive age in Ghana.

Methods

Study design and participants

Data for this study were derived from the Ghana Malaria Indicator Survey (GMIS), a nationally-representative survey conducted by the Ghana Statistical Service from October 2016 to December 2016. For the purpose of this study, we included women of reproductive age 15 – 49 years. Women with responses for all variables considered in this analysis were included.

Participants were selected using a multi-stage cluster sampling procedure across all 10 regions of Ghana. The country was divided into 20 strata (10 regions and residential types – urban/rural). A cluster was defined as a census enumeration area (EA) comprising approximately between 300 to 500 households. In the first stage of sampling, for each stratum, clusters were selected using probability proportion to size. A total of 200 clusters were selected. In the second stage of sampling, a fixed number of 30 households were randomly selected from each selected cluster without replacement. Women aged 15-49 were interviewed from each household if available [8]. In the original survey, 5,150 women were interviewed. However, due to the missing response for some variables, a total of 4,861 women were used for this study representing 94.4% of the sampled women. The data includes information on housing, household, women characteristics, malaria prevention, and knowledge on malaria. Computer-assisted personal interviewing (CAPI) system on tablet computers and paper questionnaires were used to collected data. The Census and Survey Processing (CSPro) system was used for data editing and management by the data curators. [8]

Variable Definition

Primary outcome

The primary outcome for this study was prevalence of malaria among women of reproductive ages 15 – 49 years, defined as women who reported to have experienced at least one episode of malaria within the 12-months preceding the survey.

Intervention

The interventions were household access to ITNs, and application of IRS in households within 6 months prior to the survey. Households which received both interventions were considered as integrated intervention. Household access to ITNs was defined as women who were living in households with access to at least one insecticide-treated net while household application of IRS was defined as women living in households that had been sprayed against mosquitoes within the 12 months preceding the survey.

Potential Confounders

The study considered two main categories of confounding variables, namely; household, and individual characteristics. Household characteristics included; regions, type of residence (rural-urban), sex of household head, household size, household access to

electricity, type of cooking fuel (solid or non-solid), main floor material, main wall material, main roof material, source of drinking water (improved or unimproved), type of toilet facility (improved or improved) and household wealth category (Poor, middle and rich). The categories of the household characteristics were recoded according the DHS reporting standards in the 2016 GMIS and 2014 Ghana Demographic Health Survey (GDHS) reports [8, 9]. Individual characteristics considered were;current age of the woman, highest level of education, pregnancy status at time of survey, health insurance status, religion, exposure to malaria messages in the 6 months prior to the survey and the knowledge level of the woman on malaria issues. The knowledge level of the woman was assessed using five knowledge questions, which includes woman's knowledge on causes of malaria, symptoms of malaria, methods of preventing malaria, treatment of malaria and awareness of the fact that the national health insurance scheme (NHIS) of Ghana covers malaria. Women who scored 0-2 were considered to have low knowledge, those who scored 3 or 4 were considered to have moderate knowledge and those who scored 5 were considered to have comprehensive knowledge on malaria. These selected variables have been found to be associated with access to ITNs, IRS or malaria prevalence in literature [10–18].

Statistical analysis

Background characteristics of women were summarised using frequencies and percentages for categorical variables whereas mean and standard deviation for continuous variables. Background characteristics were summarised by intervention status to examine potential imbalance and population structure, suggestive of potential confounding. Chloropleth maps were used to describe prevalence of malaria among women and coverage of the two interventions by geographical location. The Rao's Scott's chi-square adjusting for survey design characteristics (i.e., stratification, clustering, and sampling weight) was used to assess the association between malaria prevalence and access to the two interventions and background characteristics. Malaria prevalence was calculated as the number of women who experienced at least one episode of malaria in the 12 months preceding the survey divided by the total eligible women interviewed in the survey.

A modified weighted Poisson regression model was used to estimate the impact of access to the malaria interventions on malaria prevalence among women after adjusting for the inverse probability of treatment weight (IPTW) and survey weight using the *"svy linearized"* model in Stata 16 IC (StataCorp, College Station, TX, USA) The inverse probability of treatment weight (IPTW) for intervention *"i"* and woman *"j"* was estimated as:

$$IPTW_{ij} = \frac{i}{pw_{ij}} + \frac{1-i}{1-pw_{ij}}$$

Where:

$IPTW_{ij}$ is the inverse probabilty of treatment weight for intervention i $for\ woman\ j$

pw_{ij} is the estimated probability of woman j having access to intervention i

i is the indicator variable $\begin{cases} 0 & \text{if individual j does not have access to intervention } i \\ 1 & \text{if individual j have access to the intervention } i \end{cases}$

The final weighting variable to be used in the Poisson regression model was then adjusted as follows:

$$fw_i = IPTW_i * sw_i$$

Where:

fw_{ij} is the final weighting variable for individual j and intervention i

sw_{ij} is the sampling weight from the 2016 GMIS for individual j and intervention i

The command "*margins, dydx(intervention_i)*" post estimation command in Stata was then used to estimate the marginal difference (impact) of access to intervention *"i"* on malaria prevalence among women after the modified weighted Poisson regression model was run controlling for all confounding variables.

As a sensitivity analysis, three different regression models, the binary logistic regression, the probit regression and the linear regression models were also used to estimate the impact of each of the malaria interventions on malaria prevalence among women in Ghana. 95% confidence interval was estimated for all prevalence, prevalence ratios as well as impact estimates. All statistical analyses in this study were considered significant at an alpha level of 0.050. Stata IC version 16 was used for statistical analysis.

Ethical statement

The Demographic and Health Survey program approved and granted permission to use the data for this paper. The data were accessed from the program website (http://dhsprogram.com) on 8th September, 2020. The data were de-identified and therefore can not be linked to any individual participant in the survey.

Results

Characteristics of households and women in the study

A total of 4,861women aged 15 to 49 years that were interviewed in the 2016 GMIS survey were used for this study. Majority (53.1%) were from the urban areas of the country. The Ashanti (19.8%) and Greater Accra (18.1%) regions had the highest percentage of participants whilst the Upper East (4.0%) and Upper West (2.7%) regions had the least percentage of partcipants.

About two-thirds (36.1%) of the households were headed by males. The mean (SD) age of the household head was 43.8 (13.5) years . Each household size predominantly had 4-6 members. Majority of the households had access to electricity (79.5%), improved source of drinking water (87.2%), improved toilet facility (71.4%) and uses solid cooking fuel (76.6%). (Table 1)

The mean (SD) age of the women was 29.8 (9.5) years. In most (55.9%) cases, the women had up to secondary level of education while few of them had beyond secondary education. Christianity was the most (77.4%) affiliated religion among the women. Over a quarter (28.6%) of the women had never given birth, another 28.9% had given birth once or twice whilst a fifth (20.0%) had given birth for more than 4 times. About seven in every ten women sampled (68.2%) had a comprehensive knowledge of malaria. However, more than half (54.2%) of the women had been exposed to malaria messages in the past 6 months (Table 1).

Prevalence of malaria and access to malaria interventions

The prevalence of malaria in the last 12 months prior to the survey was 34.4% (95%CI: 32.4%-36.4%). Proprotion of women with access to ITNs was 79.9% (95% CI: 78.0%-81.7%) whereas women living in household sprayed against mosquitoes (IRS) was 12.4% (95% CI: 7.5%-19.8%). Access to only IRS was 1.0% (95% CI: 17.1%-21.2%), only ITNs was 68.5% (95% CI: 62.9%-73.6%) and both IRS and ITNs was 11.4% (95% CI: 7.0%-18.0%). (Fig. 1).

Access to ITNs was significantly associated with region (p<0.001), area of residence (p<0.001), household size (p<0.001), Sex of household head (p<0.001), age o household head (p=0.041), household wealth index category (p<0.001), source of drinking water

(p=0.004), type of toilet facility (p<0.001), access to electricity (p<0.001), type of cooking fuel (p<0.001) and housing characteristics such as main wall material (p<0.001) and main roof material (p<0.001) from the chi-square tests. Also, women characteristics such as education (p=0.009), number of births (p=0.007) and knowledge of malaria (p<0.001) were also associated with access to ITNs. (Table 1)

Household characteristics associated with access to IRS included region (p<0.001), place of residence (p=0.005), household size (p<0.001), sex of household head (p=0.007), wealth index (p=0.011), type of toilet facility (p=0.007), main wall material (p=0.004) and main roof material (p<0.001). The women characteristics associated with access to IRS among the women included education (p<0.001), health insurance status (p<0.001) and religion (p=0.005). (Table 1)

Regional Distribution of malaria prevalence and access to malaria interventions

For malaria prevalence among the women, the Upper East (42.8%) and the Central (45.3%) recorded the highest whilst the Upper West (23.1%) and Ashanti (28.4%) recorded the least prevalence. Access to ITNs was highest in the Upper West (93.6%) and the Upper East (97.7%) regions whilst Greater Accra (70.9%), Western (73.1%) and Ashanti (75.0%) recorded the least percentage access. The percentage of women with access to IRS was highest in the Upper West region (91.7%) followed by the Northern region with 42.7% and Upper East with 25.6% whilst the rest of the southern regions recorded less than 15% each with the Volta and Eastern regions recording 0%. Access to both ITNs and IRS was highest in the three northern regions, Upper West (86.3%), Northern (39.4%) and Upper East (25.4%). (Fig. 2).

Prevalence of malaria among women 12 month before the survey by access to malaria interventions

Prevelence of malaria among women with access to ITNs was 33.3% (95% CI: 31.2%-35.4%) which was significantly lower compared to the 38.7% (95% CI: 33.9%-43.7%) among women with no access to ITNs (χ^2=4.32, p=0.039). Prevalence of malaria did not significantly vary between women with access to IRS (32.3%, 95% CI: 28.1%-36.9%) compared to women with no access to IRS (34.7%, 95% CI: 32.6%-36.8%) (χ^2=0.91, p=0.342). Prevalence of malaria did not significantly differ across the combination of access to the two malaria interventions (χ^2=1.65, p=0.188). (Table 2)

Factors associated with malaria prevalence among women in the past 12 months

Prevalence of malaria was significantly associated with the region of residence of the women (χ^2=4.38, p<0.001). Malaria prevalence was highest among women with access to improved water sources (35.4%, 95% CI: 33.4%-37.5%) compared to the 27.3% (95% CI: 23.5%-31.5%) amon prevalence among women with access to unimproved water sources (χ^2=12.57, p<0.001). Malaria prevalence was lowest among women in the age range 15-19 years (25.4%, 95% CI: 22.3%-28.7%) compared to women in the age groups 20-29 years (35.6%, 95% CI: 31.7%-38.5%), 30-39 years (37.1%, 95% CI: 33.8%-40.6%) and those aged 40-49 years (36.3%, 95% CI: 32.5%-40.3%). The age group of the women was significantly associated with malaria prevalence (χ^2=8.14, p<0.001). Prevalence of malaria was lowest among women with low knowledge on malaria (11.4%, 95% CI: 6.3%-19.7%) compared to women with moderate (33.8%, 95% CI: 30.4%-37.5%) or comprehensive (35.2%, 95% CI: 32.9%-37.5%) knowledge (χ^2=7.03, p=0.002). Also, malaria prevalence was highest among women exposed to malaria messages (40.1%, 95% CI: 37.3%-43.0%) compared to women not exposed to malaria messages (29.5%, 95% CI: 27.1%-32.0%)(χ^2=34.07, p<0.001). (Table 2).

The impact of household access to ITNs and application of IRS on malaria prevalence

From the Poisson regression model, women living in households with access ITNs saw a 7.05% significant absolute reduction in malaria prevelance (ATE: -7.05%, 95% CI: [-11.96%, -2.14%], p=0.005). From the sensitivity analysis, similar estimates were found from the binary logistic (ATE: -7.88, 95% CI: [-13.14%, -2.62%], p=0.004), probit (ATE: -7.16%, 95% CI: [-12.26%, -2.07%], p=0.006) and linear regression models (ATE: -7.39%, 95% CI: [-12.60%, -2.17%], p=0.006). (Table 3)

In addition, from the Poisson regression model, women living in households with access IRS saw a 6.81% significant absolute reduction in malaria prevelance (ATE: -6.81%, 95% CI: [-13.06%, -0.55%], p=0.033). From the sensitivity analysis, 7.34% significant reduction was estimated from the probit model probit (ATE: -7.34%, 95% CI: [-14.10%, -0.58%], p=0.033). (Table 3).

Compared to those with access to only ITNs, access to both ITNs and IRS did not show significant reduction in malaria prevalence among the women in any of the four regression models. Also, compared to those with access to IRS only, access to both ITNs and IRS did not show significant reduction in malaria prevalence in the Poisson regression model although significant in the binary logistic regression model (ATE: -4.12%, 95% CI: [-8.15%, -0.09%], p=0.045).

Compared to those with no access to both ITNs and IRS, access to both ITNs and IRS saw a 27.09% significant absolute reduction in malaria prevelance among the women in the Poisson model (ATE: -27.09, 95% CI: [-34.94%, -19.25%], p<0.001). Similary, in the sensitivity analysis, significant reduction in malaria prevalence was recorded in the binary logistic model (ATE: -27.99%, 95% CI: [-35.58%, -20.41%], p<0.001), Probit model (ATE: -28.66%, 95% CI: [-36.33, -21.00], p<0.001) and the linear regression model (ATE: -27.12, 95% CI: [-35.62, -18.63], p<0.001). (Table 3)

Subgroup analysis of the impact of household access to ITNs and application of IRS on malaria prevalence

Access to ITNs saw significant reduction in malaria prevalence in the central (ATE: -8.71%, 95% CI: [-16.49, -0.92], p=0.029), Greater Accra (ATE: -6.49%, 95% CI: [-11.14, -1.79], p=0.007), Volta (ATE: -6.33%, 95% CI: [-10.51, -2.15], p=0.003), and the Eastern (ATE: -7.89%, 95% CI: [-13.66, -2.07], p=0.008) regions. Also, access to ITNs saw over 7% significant reduction in both the urban (ATE: -7.14%, 95% CI: [-12.13, -2.14], p=0.005) and the rural areas (ATE: -7.88%, 95% CI: [-13.60, -2.16], p=0.007). All the other subgroups of the household characteritics and women individual characteristics also saw varying significant reduction in malaria prevalence among women with access to ITNs ranging from over 2% reduction among women with low knowledge on malaria (ATE: -2.67%, 95% CI: [-5.53, -0.02], p=0.048) to over 8% reduction among women with more than 4 births (ATE: -8.92%, 95% CI: [-15.69, -2.15], p=0.010). (Fig. 3 & 4 and supplementary table)

Access to IRS saw significant reduction in malaria prevalence in the Greater Accra (ATE: -4.10%, 95% CI: [-7.37, -0.83], p=0.014), Volta (ATE: -7.29%, 95% CI: [-12.78, -1.81], p=0.009), and the Eastern (ATE: -8.20%, 95% CI: [-14.89, -1.52], p=0.016) regions. Also, access to IRS saw over 8% significant reduction in both the urban areas (ATE: -8.35%, 95% CI: [-14.96, -1.75], p=0.013) and the rural areas (ATE: -8.30%, 95% CI: [-14.64, -1.96], p=0.011). Results of the impact of IRS on malaria reduction among women by both household characteritics and women individual characteristics is also reported in Fig. 3 & 4 and supplementary table.

Access to both ITNs and IRS saw significant reduction in malaria prevalence in the central (ATE: -25.77%, 95% CI: [-49.52, -2.01], p=0.034), Greater Accra (ATE: -10.84%, 95% CI: [-18.40, -3.28], p=0.005), Volta (ATE: -15.04%, 95% CI: [-22.18, -7.90], p<0.001), the Eastern (ATE: -23.54%, 95% CI: [-35.43, -11.65], p<0.001) and the Ashanti (ATE: -29.34%, 95% CI: [-56.51, -2.18], p=0.034) regions. Also, access to both ITNs and IRS saw significant reduction in both the urban (ATE: -24.22%, 95% CI: [-32.65, -15.78], p<0.001) and the rural areas (ATE: -30.94%, 95% CI: [-39.66, -22.22], p<0.001). All the other subgroups of the household characteritics and women individual characteristics also saw varying significant reduction in malaria prevalence among women with access to both ITNs and IRS ranging from over 11% among women with low knowledge on malaria (ATE: -11.69, 95% CI: [-21.42, -1.96], p=0.019) to over 36% reduction among women living in household with no access to electricity (ATE: -36.96, 95% CI: [-52.52, -21.40], p<0.001). (Fig. 3 & 4 and supplementary table)

Discussion

In this study, the package of vector controlled preventive strategy for malaria showed a significant reduction in malaria prevalence among women of reproductive age in Ghana. Access to both ITNs and IRS among women recorded a 27% reduction in malaria prevalence. This finding is consistent with the results from a randomised controlled trial conducted by Chaccour and colleagues, in which there was evidence of a significant reduction in malaria RDT positivity among IRS users compared to non-IRS users in a high malaria endemic but high standard ITNs access area in Mozambique [19]. In Northern Tanzania, the combination of ITNs and IRS recorded a significant reduction in the anopheles density and entomological inoculation rates [20]. Our finding on an integrated vector-controlled preventive strategy for malaria is further supported by a community-based survey conducted in the Nyanza province in Western Kenya in which Hamel and colleagues found that the combination of indoor residual spraying and insecticide-treated nets provided added protection against malaria compared with insecticide-treated nets alone. [21]

compared to no access to ITN, there was 7% points absolute reduction in malaria prevalence among women with access to ITNs with a 95% confidence reduction of 2%-12%. Similar results were shown from a trend of malaria cases in health sentinel sites in

Papua New Guinea which also recorded a reduction in malaria cases as a result of the repeated distribution of long-lasting insecticide nets [22]. In the Tombel Health District, South West region of Cameroon, the distribution of LLINs recorded a short-lived reduction of malaria cases from 3 health facilities in 2012 (22.7%) following the distribution of ITNs compared to post-distribution cases in 2010 (26.7%) and 2011 (30.7%). However, the cases recorded an increase to 29.5% in 2013 from 22.7% in 2012. [23]. Similar results were recorded for IRS alone. For example, compared to no IRS, we found that women living in households sprayed against mosquitoes or treated with indoor residual insecticide recorded a 7% absolute reduction in malaria prevalence. This was also consistent with findings from a district-level observational study in the northern region of Ghana in which there was a 39%, 26% and 58% relative reduction in confirm malaria cases in 2015, 2016 and 2017 respectively among IRS campaigned districts compared to non-IRS campaigned districts [24]. In another study conducted in the Bunkpurugu-yunyoo district in northern region of Ghana, there was an estimated 5% marginal decline in asexual parasitaemia prevalence among children from 52% in November 2010 to 48% in October 2012 during a high transmission season after application of alpha-cypermethrin IRS between the two periods. There was a further decline in malaria parasitaemia prevalence from 48% in October 2012 to 20.6% in October 2013 after pirimiphos-methyl IRS application [25].

This study estimated that 34% of women had malaria episode 12 months before the survey with a 95% confidence interval estimate of 32%-36%. The prevalence of malaria episode among women living in a household with access to ITNs (33%) was significantly lower than women living in households with no access to ITNs (39%). Similarly, the prevalence of malaria among women living in a household that had been sprayed against mosquitoes was 32% compared to 35% in household that had not been sprayed. Unimproved toilet facilities and poor sanitary conditions can serve as potential sources of breeding ground for mosquitoes, which directly lead to increase in community spread of malaria. Efforts towards the provision of improved toilet facilities and sanitations in households and communities should be strengthen.

Our study had several important limitations. First, the study used data from a cross-sectional survey which makes it difficult to measure causality. To overcome this limitation, we used causal inference statistical methodologies to estimate average treatment effects of the interventions. We have adjusted for the treatment assignment with important variables in estimating potential outcomes of women whose households had the intervention should they not have the intervention as well as those whose households did not have the intervention should they have. Second, we recongnised that access to ITNs does not necessarily mean utilization of ITNs therefore care must be taken in the interpretation of results and conclusions from this study. Third, the outcome for this study, malaria prevalence among women in the past 12 months, is self-reported hence could be biased by the knowledge level of the women on malaria especially the unconfirmed positive cases. Finally, the study did not account for multiple episodes of malaria cases per participants within the 1-year reference period. However, we do not believe that using first or any episode of malaria cases reported by the respondent will bias the impact of the interventions. Given the limitations of the observational study, a more robust randomised controlled trial would be an important consideration for future research study.

Conclusions

Households with access to both ITNs and IRS had a lower prevalence of malaria compared to households with only ITN or IRS. This finding confirms the call for integrating malaria control interventions to facilitate attainment of malaria elimination in Ghana.

Abbreviations

ITNs: Insecticide-treated nets. IRS: indoor residual spraying. WHO: World Health Organization. GMIS: Ghana Malaria Indicator Survey. DHS: Demographic Health Survey. LLINs: Long lasting insecticide-treated nets. NMCP: National Malaria Control Programme.

Declarations

Ethical approval and consent to participate

The study required no consent from participants. Approval for the use of the GMIS data was sought from the Demographic Health Survey (DHS) program through their online portal using the students DHS account.

Availability of Data

The GMIS data is available online at no cost at the online DHS portal. It can be access through the website https://dhsprogram.com/data/ upon request[26].

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Author's contributions

DD, YA & KA developed and designed the concept of the study. YA, DD & KA performed statistical analysis. The discussions section of the manuscript was done by all authours. . HB, SAA, SB, JN, AEY, YA, DD, MT, MK reviewed the manuscript critically for intellectual conent. All authors read and approved the final manuscripts.

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Consent for publication

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Competing interest

The authors declare that they have no competing interests.

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Tables

Table 1: Background characteristics of women by intervention status.

	Number of women (% of total)	Access to ITNs		Household Sprayed (IRS)		Combination of interventions				
						None	IRS only	ITNs only	Both IRS & ITNs	Chi-squared p-value
Variables		% of total	Chi-squared p-value	% of total	Chi-squared p-value	% of total	% of total	% of total	% of total	
Total	**4861 (100%)**	79.91		12.43		19.07	1.02	68.5	11.41	
Region of residence			<0.001		<0.001					<0.001
Western	398 (8.19)	5.99		1.15		2.06	0.14	4.98	1.01	
Central	511 (10.51)	9.42		0.78		1.09	0.00	8.64	0.78	
Greater Accra	882 (18.15)	12.86		0.29		5.29	0.00	12.57	0.29	
Volta	401 (8.24)	6.79		0.00		1.46	0.00	6.79	0.00	
Eastern	451 (9.28)	7.09		0.00		2.19	0.00	7.09	0.00	
Ashanti	964 (19.84)	14.87		2.00		4.59	0.37	13.25	1.62	
Brong Ahafo	420 (8.64)	7.27		0.23		1.35	0.01	7.05	0.22	
Northern	509 (10.48)	9.21		4.47		0.93	0.34	5.08	4.13	
Upper East	192 (3.95)	3.86		1.01		0.08	0.01	2.85	1.00	
Upper West	133 (2.73)	2.56		2.50		0.03	0.15	0.20	2.35	
Place of residence			<0.001		0.005					<0.001
Urban	2579 (53.06)	39.16		3.27		13.62	0.29	36.17	2.99	
Rural	2282 (46.94)	40.75		9.15		5.45	0.73	32.33	8.42	
HOUSEHOLD CHARACTERISTICS										
Household size			<0.001		<0.001					<0.001
<4 members	1448 (29.79)	21.79		2.21		7.60	0.40	19.98	1.81	
4-6 members	2225 (45.78)	37.29		5.28		8.22	0.27	32.28	5.01	
7-9 members	904 (18.6)	15.73		3.61		2.52	0.35	12.46	3.27	
10+ members	284 (5.83)	5.11		1.32		0.73	0.00	3.78	1.32	
Sex of household head			<0.001		0.007					<0.001
Male	3108	53.06		9.87		10.2	0.67	43.86	9.20	

	(63.93)									
Female	1753 (36.07)	26.85		2.56		8.86	0.36	24.64	2.21	
Age of household head (mean ± SD)	43.75 ± 13.46		0.041		0.183					0.054
<30	668 (13.74)	10.14		1.20		3.55	0.05	8.99	1.16	
30-49	2746 (56.49)	45.84		7.60		9.92	0.73	38.97	6.87	
50-69	1206 (24.81)	19.75		3.07		4.84	0.22	16.90	2.85	
>69	241 (4.961)	4.17		0.55		0.76	0.02	3.64	0.53	
Wealth index			<0.001		0.011					<0.001
Poor	1705 (35.08)	30.82		6.48		4.09	0.17	24.51	6.31	
Middle	1000 (20.56)	16.60		2.82		3.66	0.30	14.09	2.52	
Rich	2156 (44.36)	32.48		3.13		11.32	0.56	29.90	2.58	
Source of water			0.004		0.857					0.324
Improved water source	4239 (87.22)	68.87		10.95		17.37	0.97	58.89	9.98	
Unimproved water source	621 (12.78)	11.03		1.48		1.70	0.05	9.61	1.42	
Toilet facility			<0.001		0.007					0.002
Improved toilet facility	3468 (71.35)	55.38		6.73		15.34	0.63	49.28	6.10	
Unimproved toilet facility	1393 (28.65)	24.52		5.70		3.73	0.39	19.22	5.31	
Access to electricity			<0.001		0.524					0.045
No	996 (20.48)	18.29		3.04		2.06	0.13	15.39	2.91	
Yes	3865 (79.52)	61.61		9.39		17.01	0.89	53.11	8.50	
Main floor materials	()		0.058		0.076					0.087
Ceramic/tiles/carpet	1165 (23.97)	18.20		2.05		5.51	0.26	16.41	1.79	
Cement	3051 (62.78)	50.66		8.16		11.55	0.57	43.07	7.59	
Sand/earth/wooden planks	644 (13.25)	11.05		2.22		2.01	0.19	9.02	2.02	
Main wall materials			<0.001		0.004					<0.001
Cement/bricks	3143 (64.66)	48.77		4.97		15.27	0.61	44.41	4.36	
Others (clay, woods etc.)	1718 (35.34)	31.13		7.46		3.80	0.41	24.09	7.05	

Main roof materials			0.002		<0.001				<0.001
Asbestos/shingles/concrete	871 (17.92)	12.90		0.26		4.96	0.06	12.70	0.21
Zinc/aluminium	3810 (78.37)	63.75		11.38		13.68	0.95	53.32	10.43
Thatch/palm leaves/wood	180 (3.709)	3.25		0.78		0.44	0.02	2.49	0.77
Cooking fuel			<0.001		0.064				0.003
Non-solid (LPG, electricity)	1137 (23.39)	16.48		1.55		6.64	0.27	15.21	1.27
Solid (charcoal, woods, etc.)	3724 (76.61)	63.43		10.88		12.43	0.75	53.29	10.13
WOMEN CHARACTERISTICS									
Woman's age	29.80 ± 9.51		0.91		0.439				0.7016
15-19	854 (17.56)	14.20		2.55		3.08	0.28	11.93	2.27
20-29	1610 (33.12)	26.36		3.88		6.47	0.29	22.77	3.59
30-39	1458 (29.99)	23.88		3.66		5.86	0.25	20.47	3.41
40-49	939 (19.33)	15.46		2.33		3.66	0.21	13.34	2.13
Woman's education			0.009		<0.001				<0.001
No education	955 (19.65)	16.46		4.62		2.75	0.44	12.28	4.18
Primary	832 (17.12)	13.91		2.23		2.92	0.28	11.96	1.95
Secondary	2719 (55.94)	44.18		4.80		11.46	0.30	39.68	4.50
Higher / tertiary	355 (7.29)	5.35		0.77		1.94	0.00	4.58	0.77
Number of births			0.007		0.204				0.076
None	1391 (28.61)	21.81		3.12		6.44	0.36	19.05	2.76
1-2 births	1406 (28.92)	22.89		3.39		5.75	0.28	19.77	3.12
3-4 births	1095 (22.52)	18.56		2.73		3.85	0.10	15.93	2.63
>4 births	970 (19.96)	16.65		3.18		3.02	0.29	13.75	2.89
Woman's currently pregnant			0.079		0.134				0.164
No/unsure	4511 (92.8)	73.84		11.28		18.05	0.90	63.47	10.38
Yes	350 (7.2)	6.06		1.15		1.02	0.12	5.03	1.03

Covered by health insurance			0.135		<0.001					0.003
No	2011 (41.38)	32.44		3.98		8.71	0.22	28.68	3.76	
Yes	2850 (58.62)	47.47		8.45		10.36	0.80	39.82	7.65	
Woman's religion			0.277		0.005					0.004
Christians	3760 (77.35)	61.74		6.48		15.12	0.48	55.74	6.00	
Islam	946 (19.46)	15.83		5.71		3.13	0.49	10.61	5.22	
Tradition/No religion/ others	155 (3.19)	2.33		0.24		0.81	0.05	2.15	0.18	
Knowledge of malaria			<0.001		0.1254					0.016
Low knowledge	81 (1.66)	1.25		0.15		0.38	0.04	1.13	0.11	
Moderate knowledge	1464 (30.11)	22.90		3.10		6.89	0.33	20.12	2.77	
Comprehensive knowledge	3316 (68.22)	55.77		9.18		11.80	0.66	47.24	8.52	
Exposure to malaria messages in the past 6 months			0.942		0.167					0.194
Not exposed	2633 (54.17)	43.31		7.67		10.07	0.79	36.43	6.88	
Exposed	2228 (45.83)	36.59		4.76		9.00	0.24	32.07	4.52	

Table 2: Prevalence of malaria among women 12 month before the survey by access to malaria interventions

	Experienced malaria in the past 12 months		Rao Scott's Chi-square	P-value
	No	Yes		
	% [95% CI]	% [95% CI]		
	65.62 [63.63, 67.57]	34.38 [32.43, 36.37]		
INTERVENTIONS				
Insecticide Treated Nets (ITNs)			4.32	0.039
No access to ITNS	61.33 [56.31, 66.11]	38.67 [33.89, 43.69]		
Access to ITNs	66.71 [64.59, 68.76]	33.29 [31.24, 35.41]		
Indoor residual spraying (IRS)			0.91	0.342
Household not sprayed	65.34 [63.18, 67.43]	34.66 [32.57, 36.82]		
Household sprayed	67.63 [63.07, 71.87]	32.37 [28.13, 36.93]		
Both ITNs & IRS			1.65	0.188
No access to both ITNs & IRS	61.31 [56.44, 65.96]	38.69 [34.04, 43.56]		
Access to only IRS	61.65 [39.00, 80.17]	38.35 [19.83, 61.00]		
Access to only ITNs	66.46 [64.27, 68.59]	33.54 [31.41, 35.73]		
Access to both ITNs & IRS	68.16 [62.41, 73.42]	31.84 [26.58, 37.59]		
Region of residence			4.38	<0.001
Western	63.19 [57.76,68.30]	36.81 [31.70,42.24]		
Central	54.72 [48.15,61.13]	45.28 [38.87,51.85]		
Greater Accra	66.59 [61.80,71.07]	33.41 [28.93,38.20]		
Volta	69.30 [64.06,74.08]	30.70 [25.92,35.94]		
Eastern	65.02 [59.91,69.80]	34.98 [30.20,40.09]		
Ashanti	71.64 [65.87,76.78]	28.36 [23.22,34.13]		
Brong Ahafo	60.56 [53.22,67.44]	39.44 [32.56,46.78]		
Northern	67.44 [62.39,72.11]	32.56 [27.89,37.61]		
Upper East	57.25 [50.71,63.54]	42.75 [36.46,49.29]		
Upper West	76.95 [70.86,82.09]	23.05 [17.91,29.14]		

Place of residence			0.00	0.970
Urban	65.59 [62.88,68.20]	34.41 [31.80,37.12]		
Rural	65.66 [62.68,68.53]	34.34 [31.47,37.32]		
HOUSEHOLD CHARACTERISTICS				
Household size			0.89	0.440
<4 members	64.02 [60.42,67.46]	35.98 [32.54,39.58]		
4-6 members	65.52 [62.53,68.39]	34.48 [31.61,37.47]		
7-9 members	67.45 [63.50,71.17]	32.55 [28.83,36.50]		
10+ members	68.81 [62.58,74.43]	31.19 [25.57,37.42]		
Sex of household head			0.63	0.430
Male	66.14 [63.87,68.33]	33.86 [31.67,36.13]		
Female	64.71 [61.47,67.83]	35.29 [32.17,38.53]		
Age of household head (mean ± SD)			0.44	0.702
<30	64.54 [59.04,69.69]	35.46 [30.31,40.96]		
30-49	65.47 [62.57,68.27]	34.53 [31.73,37.43]		
50-69	65.69 [62.45,68.79]	34.31 [31.21,37.55]		
>69	69.99 [62.22,76.76]	30.01 [23.24,37.78]		
Wealth index			2.26	0.106
Poor	67.68 [64.29,70.88]	32.32 [29.12,35.71]		
Middle	61.91 [57.74,65.90]	38.09 [34.10,42.26]		
Rich	65.73 [62.61,68.71]	34.27 [31.29,37.39]		
Source of water			12.57	<0.001
Improved water source	64.59 [62.48,66.64]	35.41 [33.36,37.52]		
Unimproved water source	72.70 [68.54,76.49]	27.30 [23.51,31.46]		
Toilet facility			0.14	0.713
Improved toilet facility	65.39 [62.95,67.74]	34.61 [32.26,37.05]		
Unimproved toilet facility	66.22 [62.45,69.80]	33.78 [30.20,37.55]		

Access to electricity			1.98	0.161
No	68.52 [63.69,72.97]	31.48 [27.03,36.31]		
Yes	64.88 [62.75,66.95]	35.12 [33.05,37.25]		
Main floor materials			2.50	0.083
Ceramic/tiles/carpet	62.18 [58.53,65.70]	37.82 [34.30,41.47]		
Cement	66.35 [63.91,68.71]	33.65 [31.29,36.09]		
Sand/earth/wooden planks	68.41 [63.05,73.33]	31.59 [26.67,36.95]		
Main wall materials			0.49	0.485
Cement/bricks	65.20 [62.70,67.61]	34.80 [32.39,37.30]		
Others (clay, woods etc.)	66.40 [63.63,69.06]	33.60 [30.94,36.37]		
Main roof materials			0.50	0.587
Asbestos/shingles/concrete	66.37 [61.43,70.97]	33.63 [29.03,38.57]		
Zinc/aluminium	65.27 [63.05,67.43]	34.73 [32.57,36.95]		
Thatch/palm leaves/wood	69.50 [62.36,75.81]	30.50 [24.19,37.64]		
Cooking fuel			0.61	0.435
Non-solid (LPG, electricity)	64.47 [60.94,67.84]	35.53 [32.16,39.06]		
Solid (charcoal, woods, etc.)	65.98 [63.73,68.15]	34.02 [31.85,36.27]		
WOMEN CHARACTERISTICS				
Woman's age			8.14	<0.001
15-19	74.63 [71.32,77.68]	25.37 [22.32,28.68]		
20-29	64.45 [60.87,67.87]	35.55 [32.13,39.13]		
30-39	62.91 [59.45,66.24]	37.09 [33.76,40.55]		
40-49	63.67 [59.66,67.50]	36.33 [32.50,40.34]		
Woman's education			0.68	0.537
No education	68.35 [63.02,73.24]	31.65 [26.76,36.98]		
Primary	64.97 [61.44,68.35]	35.03 [31.65,38.56]		
Secondary	64.99 [62.40,67.50]	35.01 [32.50,37.60]		

Higher / tertiary	64.66 [57.68,71.07]	35.34 [28.93,42.32]		
Number of births			2.24	0.087
None	68.29 [65.33,71.12]	31.71 [28.88,34.67]		
1-2 births	64.80 [61.32,68.13]	35.20 [31.87,38.68]		
3-4 births	66.40 [62.68,69.92]	33.60 [30.08,37.32]		
>4 births	62.12 [57.80,66.25]	37.88 [33.75,42.20]		
Woman's currently pregnant			0.07	0.787
No/unsure	65.70 [63.61,67.73]	34.30 [32.27,36.39]		
Yes	64.67 [57.16,71.51]	35.33 [28.49,42.84]		
Covered by health insurance			0.23	0.630
No	66.18 [62.98,69.24]	33.82 [30.76,37.02]		
Yes	65.23 [62.77,67.62]	34.77 [32.38,37.23]		
Woman's religion			1.97	0.143
Christians	65.61 [63.28,67.87]	34.39 [32.13,36.72]		
Islam	64.35 [60.67,67.87]	35.65 [32.13,39.33]		
Tradition/No religion/ others	73.63 [65.73,80.25]	26.37 [19.75,34.27]		
Knowledge of malaria			7.03	0.002
Low knowledge	88.59 [80.26,93.69]	11.41 [6.31,19.74]		
Moderate knowledge	66.17 [62.50,69.65]	33.83 [30.35,37.50]		
Comprehensive knowledge	64.82 [62.50,67.08]	35.18 [32.92,37.50]		
Exposure to malaria messages in the past 6 months			34.07	<0.001
Not exposed	70.47 [67.96,72.87]	29.53 [27.13,32.04]		
Exposed	59.89 [57.03,62.69]	40.11 [37.31,42.97]		
Abbreviations: ITN: Insecticide Treated Net, IRS: Indoor Residual Spraying CI: confidence interval				

Table 3: The impact of malaria control interventions on malaria prevalence among women in the past 12 months

	Impact estimates of the malaria interventions on malaria prevalence among women aged 15-49 years							
	Sensitivity analysis							
	Poisson Regression Model		Binary Logistic regression model		Probit regression model		Linear regression model	
	ATE [95% CI]	P-value	ATE [95% CI]	P-value	ATE [95% CI]	P-value	ATE [95% CI]	P-value
Access to ITNs vs. No access to ITNs	-7.05 [-11.96, -2.14]	0.005	-7.88 [-13.14, -2.62]	0.004	-7.16 [-12.26, -2.07]	0.006	-7.39 [-12.60, -2.17]	0.006
Household sprayed (IRS) vs. Household not sprayed	-6.81 [-13.06, -0.55]	0.033	-6.36 [-13.03, 0.32]	0.062	-7.34 [-14.10, -0.58]	0.033	-5.99 [-12.20, 0.23]	0.059
Access to ITNs & IRS vs. Access to ITNs only	-6.88 [-14.69, 0.93]	0.084	-6.83 [-14.61, 0.94]	0.085	-7.68 [-15.63, 0.28]	0.059	-6.41 [-13.86, 1.03]	0.091
Access to ITNs & IRS vs. Access to IRS only	-4.70 [-9.76, 0.37]	0.068	-4.12 [-8.15, -0.09]	0.045	-3.25 [-7.09, 0.59]	0.095	-19.08 [-38.97, 0.80]	0.060
Access to ITNs & IRS vs. No access to ITNs & IRS	-27.09 [-34.94, -19.25]	<0.001	-27.99 [-35.58, -20.41]	<0.001	-28.66 [-36.33, -21.00]	<0.001	-27.12 [-35.62, -18.63]	<0.001

NOTE:

Household characteristics (region, residence, household size, sex of household head, age of household head, household wealth quintile, household water source, toilet facility, access to electricity, main floor materials, main wall materials, main roof material and type of cooking fuel) and women individual characteristics (age of woman, highest education, religion, number of children, currently pregnant, covered by health insurance, knowledge on malaria and exposure to malaria meeages in the past 6 months) were controlled for.

ATE: Average treatment effect. Percentage difference in malaria prevalence (Intervention – No Intervention).

CI: confidence interval. ITNs: Insecticide Treated Nets. IRS: Indoor Residual Spraying

Figures

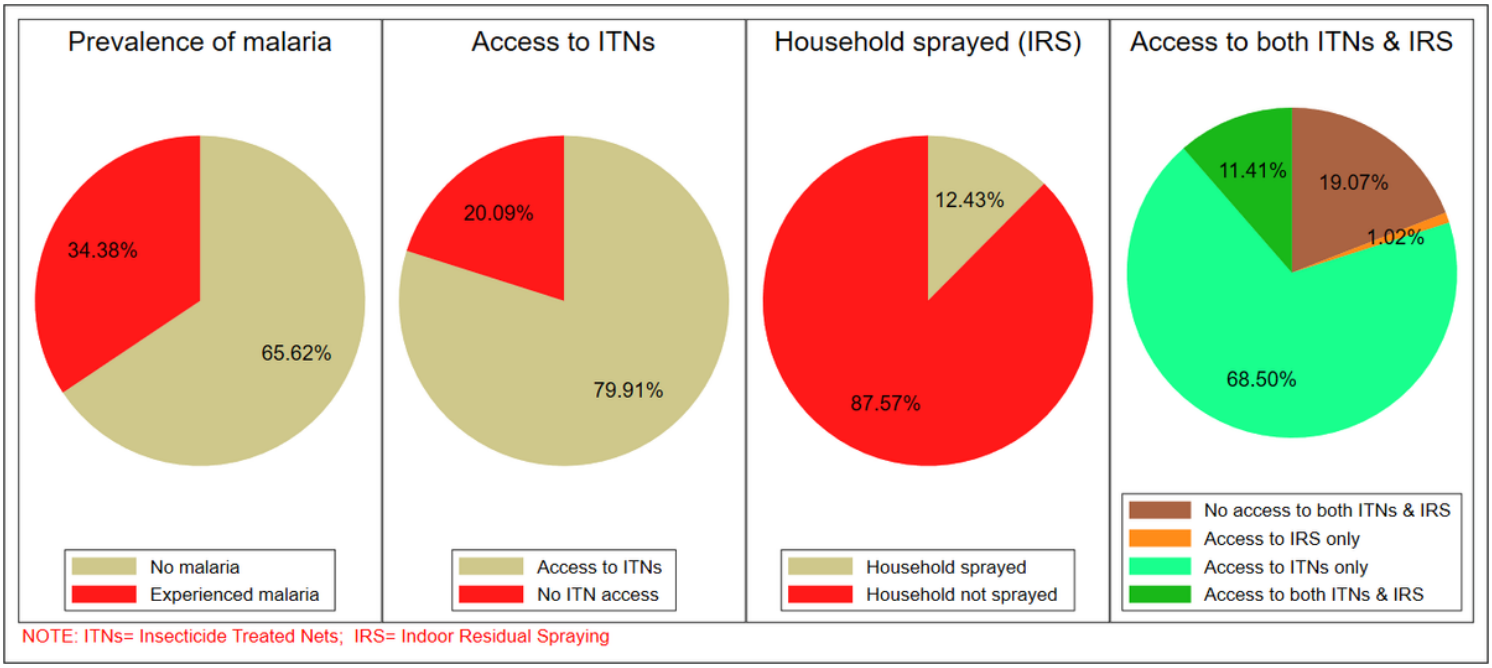

Figure 1

Prevalence of malaria and access to malaria interventions among women aged 15-49 years in Ghana.

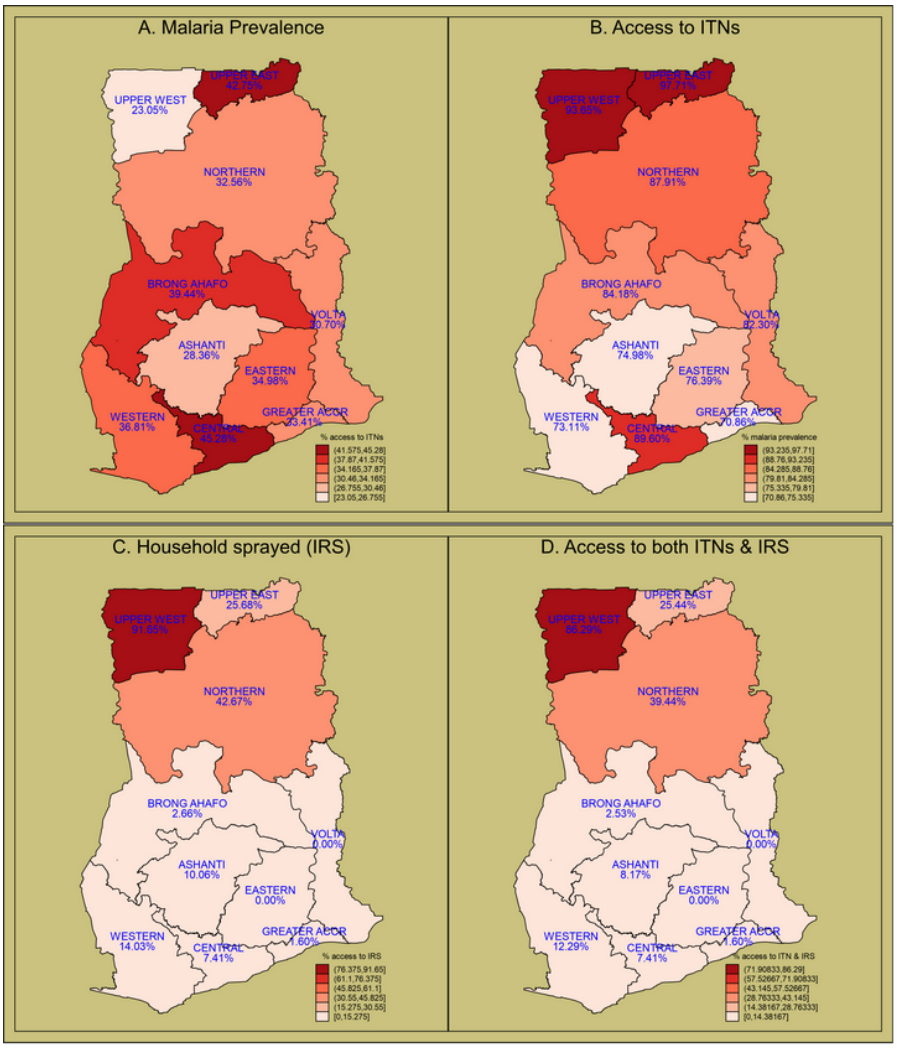

Figure 2

Prevalence of malaria and access to malaria interventions among women by regions

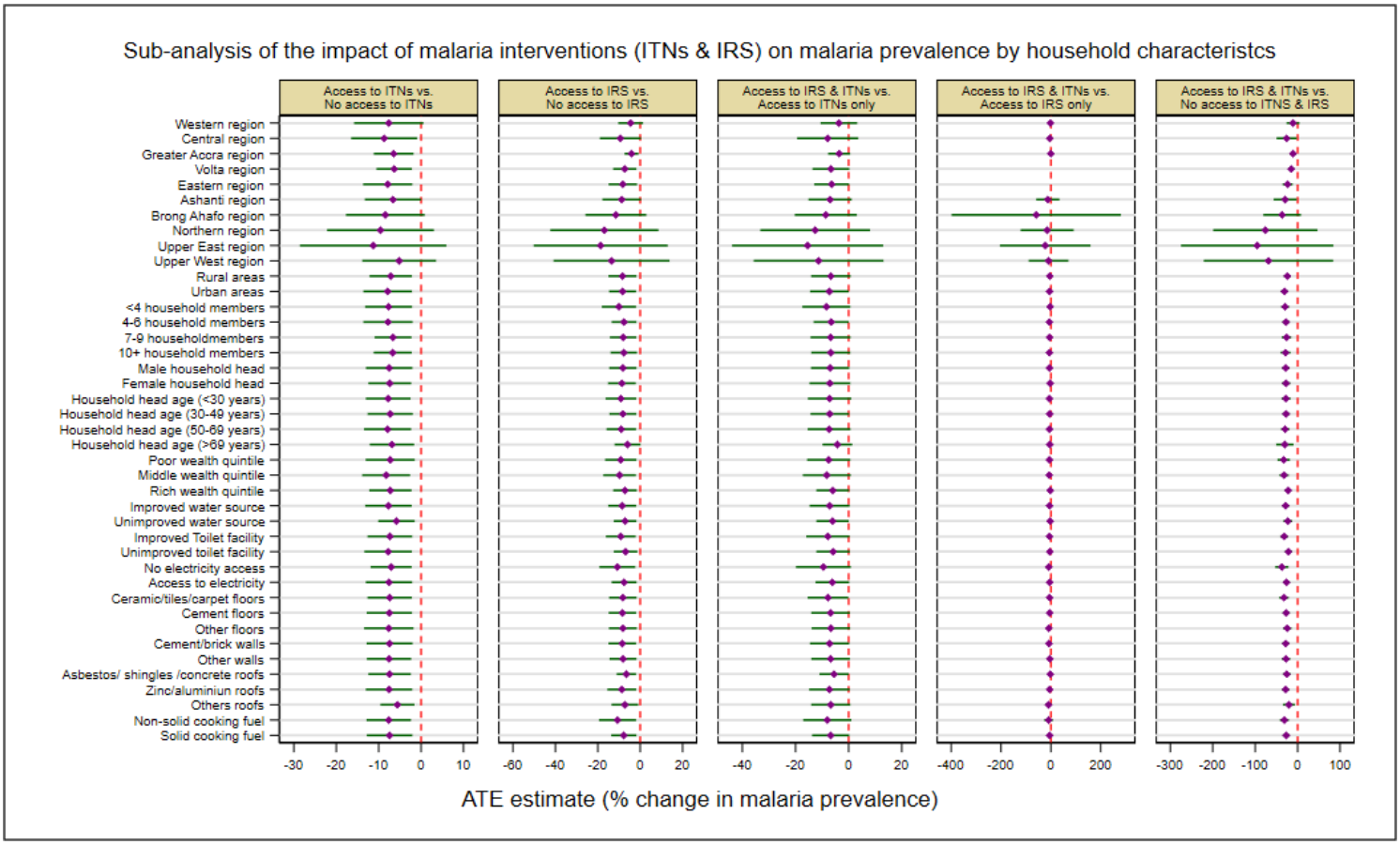

Figure 3

Sub-analysis of the impact of access to malaria intervention on malaria prevalence among women by household characteristics

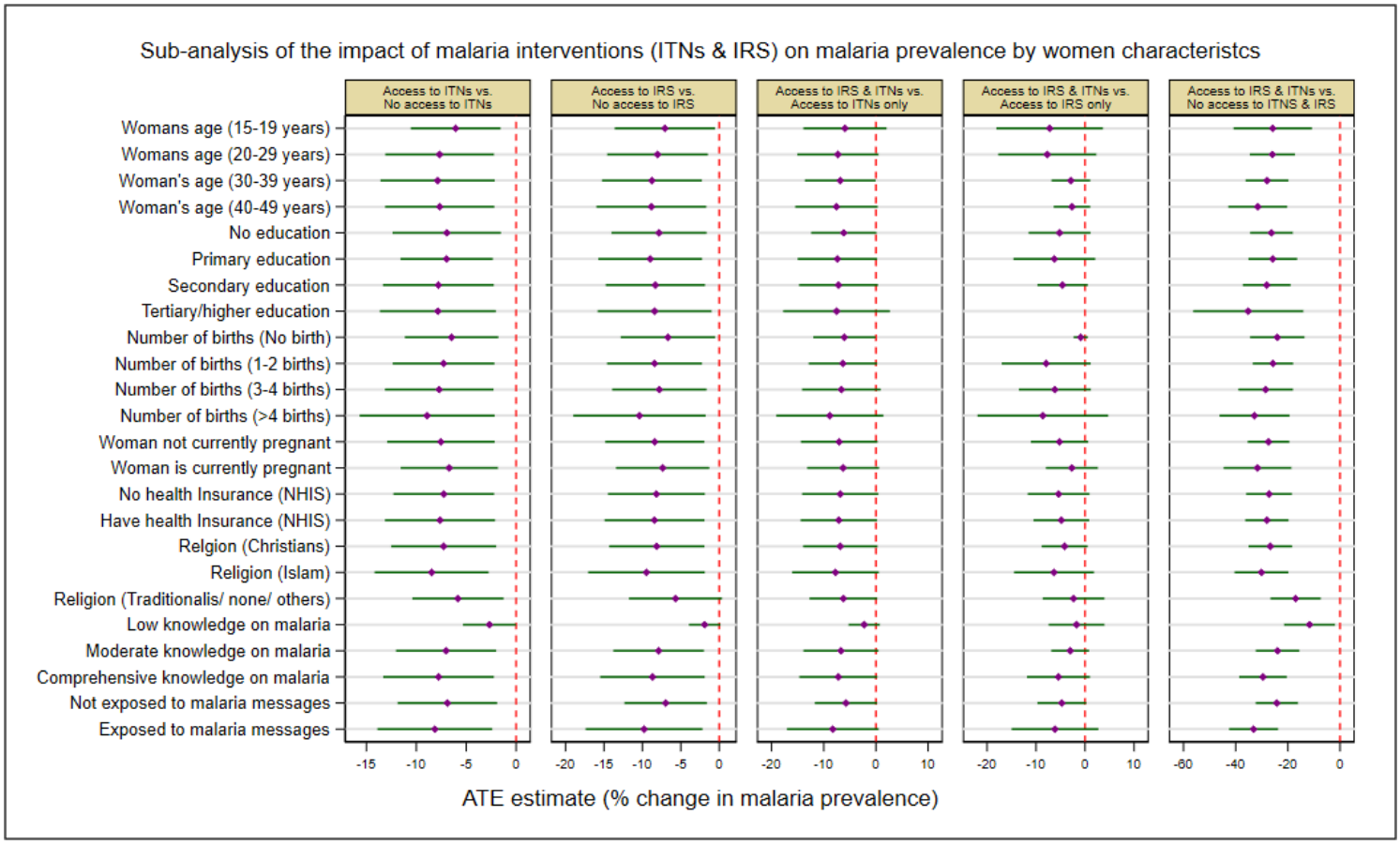

Figure 4

Sub-analysis of the impact of access to malaria intervention on malaria prevalence among women by women characteristics