vEffects of insecticide-treated net access and use on infant mortality in Malawi: a pooled analysis of demographic health surveys

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Abstract

Malaria continues to be among the top causes of death in children and Insecticide-treated nets (ITNs) are considered among the most effective malaria control methods. However, information on the association between universal ITN coverage and infant mortality is limited. A Cox proportional hazard model was applied to Malawi Demographic and Health Surveys to determine the association between ITN access and use and infant mortality between 2004 to 2015-2016. The overall infant mortality rate for the entire period was 47.9/1000 live births. Infants from the ITN-user households exhibited a lower risk of mortality [adjusted Hazard Ratio (aHR) = 0.61, 95% Confidence Interval (CI) = 0.44–0.85] than those from the ITN-nonuser households. Similarly, the infants from the high-access households exhibited a lower risk of death (aHR = 0.63, 95% CI = 0.46–0.86) than those from the no-access households. Infants from the ITN-user and high-access households exhibited a significantly lower risk of death (aHR = 0.57, 95% CI = 0.40–0.82) than those from the ITN-nonuser and no-access households. The relationship between ITN access and use and infant mortality was significant among female infants with a second or higher birth order and interval of ≥2 years. The findings of the present population-based study emphasized the importance of ITN access and use in providing optimal protection against malaria to infants in Malawi. Malaria control programs should ensure high ITN access and use in Malawi to reduce infant mortality.

Keywords: Infant mortality, insecticide-treated nets, access, use, Malawi

Abbreviations[1]

[1] ITN: insecticide-treated net; ANC: antenatal care; aHR: adjusted hazard ratio; IMR: infant mortality rate; MDHS: Malawi Demographic Health Survey; RBM: Roll Back Malaria Partnership to End Malaria; ICF: International Classification of Functioning Disability and Health; SSA: sub-Saharan Africa; HR: hazard ratio; aHR: adjusted hazard ratio; and CI: confidence interval.

Highlights

- Infants from the ITN-user and high-access households had lower risk of death
- ITN-nonuser but high-access households revealed nonsignificant protective effects
- The effect of ITN use on infant mortality was moderated by survey year

Introduction

Globally, approximately 4.6 million infant deaths occur annually, of which 99% occur in developing countries [1]. Recently, there has been a decline in infant mortality, but the decline has slowed down, or even reversed, in some countries in sub-Saharan Africa (SSA) [2]. Studies on the trends in childhood deaths in developing countries have revealed that 8.3% infants do not survive until adulthood [3]. SSA continues to face numerous challenges in the health sector with a double burden of communicable diseases, such as human immunodeficiency virus infection and malaria, and noncommunicable diseases, which undermine the efforts to reduce infant mortality.

Malaria is one of the leading causes of mortality and morbidity among infants in malaria-endemic countries [4]. Insecticide-treated nets (ITNs) are among the most effective methods to control malarial vectors [5-7] and have been associated with a 50% reduction in malaria incidence [8]. Malaria programs in malaria-endemic countries have intensified their efforts in the free distribution of ITNs to improve ITN access and use.

The World Health Organization defines universal ITN coverage as universal "access to" and "use of" ITNs by populations at a risk of malaria [9]. ITN access, according to the Roll Back Malaria (RBM) Partnership to End Malaria, is defined as the proportion of household populations that could have slept under an ITN, assuming that two people use an ITN, and ITN use refers to sleeping under an ITN and includes all individuals who spent the previous night in surveyed households [10]. As these two constructs define universal ITN coverage, they should be simultaneously considered while evaluating the effects of malarial vector control programs.

Infant mortality has reduced considerably in Malawi, and mortality rates have reduced by more than half since the 1990s [11]. This reduction was reported to coincide with a reduction in inpatient malaria-related deaths from 59 to 23 per 100,000 population [12]. The reduction in infant mortality rates (IMRs) and inpatient malaria-related deaths over the years has also occurred concurrently with an increase in the mean national ITN access and use. The overall mean national access and use increased from 19% and 12% in 2004 to 39% and 34%, respectively, in 2015 [13]. However, the ITN access and usage rates are relatively lower compared to the mean access and usage from other countries in the SSA such as Rwanda (63.8% for access and 61.4% for usage) [14]. Although increasing trends of access and usage rates have been observed, Malawi remains a malaria-endemic country, with malaria being among the top four causes of death. The burden of malaria lies specifically on children aged <5 years, especially the most vulnerable population of infants [15]. Therefore, understanding the association between ITN access and use and infant mortality is necessary to inform programs about focus areas for malaria interventions (i.e., whether to promote ITN use, access, or both) [10].

Previous studies have reported factors associated with infant mortality. Particularly, sociodemographics such as sex of an infant [16], maternal education levels [17], maternal age [17], birth order and birth interval [17], and poor sanitation [18] have been associated with infant mortality. However, few studies have examined the relationship between ITN use and access and infant mortality [19, 20]. Moreover, scant information is currently available on the moderating effects of other factors on the relationship between ITN and mortality. Among the studies that have examined the association between ITN and mortality, most have focused on household ITN ownership and not use.

Household ITN ownership is defined as the proportion of households with at least one ITN [10]. Although ITN ownership is a crucial indicator of the progress of malaria control programs, ownership does not imply use. Additionally, information on household ITN ownership alone does not describe in detail whether the ITN(s) owned are sufficient to optimally protect the household population from malaria [21]. However, information on ITN access and use provides a considerably detailed account of protection against malaria [22]. ITN use is largely influenced by ITN access [21]. Other studies have emphasized the importance of increasing ITN access because it may provide herd protection within a population [23] and within households, in particular. The relationship between ITN access, which is a newly introduced indicator for vector control, and mortality has not been investigated in the literature. Additionally, no study has explored the effects of both ITN access and use (i.e. universal ITN coverage) on infant mortality. Examining the effects of ITN access on infant mortality is crucial while considering ITN usage because although ITNs access may be high, without usage, members within the household may remain exposed to malaria infection, thus placing the entire household population at risk.

Therefore, using nationally representative datasets from the years 2004, 2010, and 2015–2016, not only the independent effects of ITN access and use on infant mortality but also the combined effects of ITN access and use in Malawi were examined. Finally, the moderating effects of other mortality covariates on the relationship between ITN access and use and infant mortality were explored.

Methodology

Study design and data source

This cross-sectional study pooled and analyzed data from the 2004, 2010, and 2015–2016 Malawi Demographic and Health Surveys (MDHSs). Methodologies used in these surveys have been previously described [13, 24, 25]. In brief, the surveys used a stratified two-stage cluster design. In the first stage, clusters were randomly selected from master sampling frames. In the second stage, a systematic sample of households was selected from the clusters.

Information on births and deaths of 9,747 infants was obtained from female respondents (aged 15–49 years) who had given birth within 1 year of the survey date. The current study selected the youngest child of each respondent and singletons who were born within 1 year prior to the survey to assess the most recent condition and avoid repetition within the same household. A total of 288 multiple births, 190 infants who were not the youngest children, and 71 infants with missing information were thus excluded, yielding a total of 9,198 infants for examination. A sensitivity analysis excluding all neonates from the analysis (n=383) was conducted and the results were fairly consistent. Therefore, the findings from the whole sample of infants were reported in this study.

Outcome variable

The outcome of infant mortality was defined as the risk of death before the age of 1 year (<12 months) in a specific year or period [1]. An event of death was coded 1 and a nonevent of survival (i.e., censored) was coded as 0.

Independent variables

Main independent variables

The main independent variables considered in this study were ITN access and use within a household.

ITN use was defined as sleeping in an ITN the night before the survey by any member of the household, and the households were categorized as “yes” or “no” for ITN use. Two key assumptions were made while operationalizing this measure. First, ITN use was assumed to be a consistent behavior that the household members practiced in the previous year [26]. Second, individuals from the same household were assumed to exhibit correlated behaviors [27, 28]; accordingly, ITN use by any member of the household may imply or influence the ITN use behavior of other members within the household [29]. Therefore, an infant was considered to belong to an ITN-user household if any member of that household had slept in an ITN the previous night.

ITN access was defined as the proportion of the household population that could have slept under an ITN, assuming that two people used an ITN [10]. ITN access was calculated using RBM Partnership to End Malaria recommendations [10] by multiplying the number of ITNs in each household by a factor of 2 to calculate the number of potential ITN users within a household. Furthermore, the number of potential ITN users was divided by the number of de facto members of each household. To adjust for households with more than one ITN for every two people, the potential ITN users were set equal to the de facto population in that household if the potential users exceeded the number of people in the household, such that ITN access ranged from 0 to 1. Households with no access were categorized as “no-access households” while households with access level being above the overall national median of 33.3% were classified as “high-access households”. Those households with access levels within and below the overall national median were classified as “low-access households” [30].

Covariates

Potential factors related to infant mortality were also considered. These included child characteristics, such as sex of the infant (male or female), a combination "birth order and birth interval (first, second/higher with <2years interval, second/higher with ≥2years interval), and type of attendant at birth (skilled or unskilled). Maternal factors were also examined, such as maternal age in years (15–24, 25–34, or ≥35), education level (no formal education, primary, secondary/higher education), employment status (yes or no), residence (urban or rural), region (northern, central, southern), and year of interview (2015–2016, 2010, or 2004). The MDHS used principal component analysis (PCA) model to calculate household wealth from a set of materials owned by a household such as bicycles, televisions, etc. Scores were then grouped into quintiles from the poorest to the richest. In this study, wealth was categorized into a three-level variable by combining two sub-categories into single categories: poorest and poor into poor and rich and richest into rich, with the middle category unchanged [31]. The health-related characteristics included the number of antenatal care (ANC) visits during the previous pregnancy defined as recommended (at least 4) and not recommended (fewer than 4) [32] and type of sanitation defined as improved (which included flush toilets, piped sewer systems, septic tanks, flush or pour flush to pit latrines, ventilated improved pit latrines, pit latrines with slabs, and composting toilets) and otherwise as unimproved [33]. Type of source of drinking water was categorized as improved or unimproved. Improved water source included piped water, boreholes or tube wells, protected dug wells, protected springs, rainwater, and packaged or delivered water [33].

Community/cluster diarrhea prevalence was constructed by aggregating individual-level diarrhea status (2 weeks before the survey) among living children under 5 years of age. The community diarrhea prevalence was further categorized as low and high using the median national communities' diarrhea prevalence. The geographical covariates data for the MDHSs were linked to the children datasets to capture the community malaria prevalence. Malaria prevalence was defined as the average parasite rate of P. falciparum in children between the ages of 2 and 10 years [34]. Community malaria prevalence was thus categorized as low and high, using the overall national communities' malaria prevalence (29.4%) as the cut-off point. Community temperature and rainfall were defined as the average annual temperature/rainfall within the 2 km (urban) or 10 km (rural) buffer surrounding the DHS survey cluster location, respectively. Community temperature and rainfall were categorized as low and high, using the overall national communities' mean temperature (22.3 degrees Celsius) or overall national communities' average rainfall (892.9 Millimeters per year) as cut-off points, respectively. The mean temperature was a modeled surface based on weather station data [34].

Statistical analyses

The distribution of study participants according to ITN access and use within the households was examined using the chi square test. Further, among the living children aged under 1 year, the distribution of selected factors according to ITN usage was investigated. The IMR was evaluated using selected characteristics, and the effects of potential factors on infant mortality were also examined.

The effects of ITN access and use on infant mortality were first assessed separately because these two variables were correlated (Cramér V = 0.69). ITN access and use within the households were also examined by combining the two variables into five-level variables (i.e., ITN-user and high-access, ITN-user and low-access, ITN-nonuser and high-access, ITN-nonuser and low-access, and ITN-nonuser and no-access households). A Cox proportional hazard regression model was fitted to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) in order to examine the effects of ITN access and use on time to infant mortality. The time to event t (in months) was defined as the duration from the date of birth to date of death or date of survey interview, whichever came first. The observation time t was truncated at the first birthday. The proportionality assumption test was conducted, and the assumption was met (i.e., survival curves for two levels of ITN use and three levels for ITN access had hazard functions that were proportional over time).

Interaction terms of ITN access and use and other potential factors associated with infant mortality were examined and subgroup analyses were conducted for the interaction terms, with $p < 0.05$ to assess potential moderation effects.

The analysis considered the complex sample design of the datasets by using the "svy" commands to account for clustering and sample weights. All analyses were performed using Stata version 15.0 (Stata Corp LP, College Station, TX, USA).

Ethical considerations

All survey protocols were reviewed and approved by the Malawi Health Sciences Research Committee. Informed consent for the surveys was obtained from each respondent at the start of each interview. Clearance to analyze the data was provided by the Demographic Health Survey program.

Results

A total of 9,198 infants were analyzed in this study. Specifically, 3198 (34.8%), 3707 (40.3%), and 2293 (24.9%), infants were selected from 2015–2016, 2010, and 2004, respectively. The IMR between 2004 and 2015–2016 was 47.9 per 1000 live births. A high proportion of children that died (73.6%) came from households that had owned an ITN for a period of over 1 year.

Distribution of participants according to ITN access and use

The distribution of child-, maternal- and health-related characteristics according to the ITN access and use status among the participants' households are presented in Table 1. Significant differences (all $p < 0.05$) were observed between the infants from the no access, low- and high-access households and between those from the ITN-user and ITN-nonuser households in terms of sex of the child, birth order and birth interval, type of attendant at birth, education level, wealth status, residence, region, survey year, ANC visits, sanitation access, drinking water source, and community temperature. Most (71.8%) infants from the ITN-user households were from the high-access households.

<insert table 1 here>

Additionally, among the living children under the age of 1 year, those who were female, from rich households, from the southern region, living in urban areas, whose mothers had adequate ANC visits, and surveyed in 2015-2016 were more likely to sleep under an ITN (results not shown).

IMR and potential factors associated with infant mortality

Table 2 summarizes the IMR and its potential associated factors. The infants who were males (54.7/1000 live births), surveyed in the year 2004 (56.3/1000 live births), from the ITN non-user households (58.4/1000 live births), and from the no-access households (62.5/1000 live births) exhibited relatively higher IMR. Additionally, infants having a first birth order or second/higher birth order with a short birth interval of <2 years (68.1/1000 and 73.2/1000 live births, respectively) had a higher IMR compared with those positioned second or higher in the birth order with a birth interval of ≥2 years. Table 2 further lists the crude hazard ratios for factors associated with IMR.

<insert table 2 here>

Infant mortality stratified by ITN access and use

The effects of ITN access and use on infant mortality are presented in Table 3. After adjusting for potential confounders, it was found that the infants from the ITN-user households were less likely to die (aHR = 0.61, 95% CI = 0.44–0.85) compared with those from the ITN-nonuser households. Similarly, the infants from the high-access households were less likely to die (aHR = 0.63, 95% CI = 0.46–0.86) compared with those from the no-access households.

The stratified analysis revealed that the infants from the ITN-user and high-access households were 43% less likely to die (aHR = 0.57, 95% CI = 0.40–0.82) compared with those from the ITN-nonuser and no-access households. Similarly, compared with infants from ITN-nonuser and no-access households, those from ITN-user and low-access households were less likely to die, albeit with a wider confidence interval, (aHR = 0.30, 95% CI = 0.10–0.94).

<insert table 3 here>

We stratified the analysis by age (i.e. 1-2 months, 3-5 months and 6 - <12 months). Neonates were excluded as their death may possibly be due to neonatal causes but not malaria related (Table 4). The results revealed significant protective effects of ITN access and usage among children aged 1-2 months and 6 - >12 months, respectively.

<insert table 4 here>

Subgroup analysis

The effect of household ITN use on infant mortality was significant among the infants surveyed in the years 2015 and 2010 (aHR = 0.56, 95% CI = 0.35–0.90 and aHR = 0.55, 95% CI = 0.34–0.88, respectively; Fig. 1). Similarly, the relationship between ITN access and infant mortality was moderated by the sex of the infant, and birth order and birth interval (Fig. 2).

<insert figure 1 here>

<insert figure 2 here>

Discussion

This is the first population-based study to assess the effects of ITN access and use within a household as well as the associated moderating effects of potential covariates on infant mortality. Specifically, the infants from the ITN-user and high-access households reported a 43% lower likelihood of death than did those from the ITN-nonuser and no-access households. The results also revealed that the effect of ITN access and use on infant mortality was significant among the infants who were positioned second or higher in the birth order and had a birth interval of ≥2 years.

The infants from the high-access households were less likely to die compared with those from the no-access households. Previous studies have demonstrated that household ITN ownership was associated with a relatively low likelihood of death in children aged <5 years [20, 35]. However, although ITN ownership is a good measure of the reach of ITN programs, ITN access portrays a better population coverage (i.e. whether there are enough ITNs getting out to meet the population need). Koenker et al. further emphasized the importance of using ITN access for assessing universal coverage [21]. Therefore, this study further demonstrated that high ITN access within a household could potentially help reduce infant deaths. The possible explanation could be that high ITN access within a household could result in increased ITN use as people may not use ITNs if they do not have access to them. Additionally, high ITN access can potentially reduce the risk of exposure of other household members, thereby reducing the risk of infection [36]. Moreover, high ITN access within a household may improve use by all household members [37], including pregnant women, thus preventing malaria in pregnancy. Malaria in pregnancy results in maternal anemia and placental parasitemia, which can cause low birth weight, a crucial contributor to infant mortality [38].

The infants from the ITN-user households were less likely to die than were those from the ITN-nonuser households. This finding is consistent with the result of a study in northern Ghana, which revealed that the under-5 mortality rate was lower among ITN users than among ITN nonusers [19]. The present study also examined the combined effect of achieving ITN use and access within a household on infant mortality. The infants from the ITN-user and high-access households exhibited a 43% lower risk of death than did those from the households with neither of the two indicators. The reduction in infant mortality in the ITN-user and high-access households reported in the present study was similar to the reduction (44%) in child mortality reported in a longitudinal study from Kenya [39]. The present study demonstrated that achieving high ITN access alone may be inadequate for controlling malaria, and malaria programs should simultaneously emphasize ITN use thus underlining the importance of achieving universal ITN coverage [23]. However, results from the current analysis should be carefully interpreted as ITN usage assessed in this study was by any household member but not specifically by infants.

The effects of ITN access and use on infant mortality were significant among infants positioned second or higher in the birth order and with a ≥2-year birth interval. Additionally, ITN use was associated with a relatively low risk of death among the infants surveyed in 2010 and 2015, possibly because Malawi initiated the first social marketing for ITNs approximately in the year 2000. Therefore, most households by the year 2004 did not have adequate ITN access; hence, these households were not able to use ITNs. The protective effects against infant mortality became significant as ITN use increased from 2004 (15.6%) to 2010 (49.7%) and 2015 (56.1%). Short birth intervals have been associated with a higher risk of infant mortality because they are associated with adverse maternal health and low maternal well-being [40]. Additionally, multiparous women have more experience in caring for their children than uniparous or nonporous women; hence, subsequent children may benefit from the experience than the first born. Together with ITN use and access, those with relatively long birth intervals may exhibit a greater reduction in mortality risk.

Strengths and limitations

Several strengths of this study merit attention. The study pooled data from 2004 to 2015–2016, which provided a sufficiently large number of samples considering the rarity of the outcome under study. The study used nationally representative data; hence, the results could be generalized to the Malawi population. A wide range of covariates were controlled for to strengthen the association observed in this study. The present study is the first to simultaneously examine the effects of ITN access and use on infant mortality.

The present study had some limitations that need to be considered when interpreting the results obtained. First, causality could not be inferred because of the cross-sectional design. Second, the surveyed households were assumed to exhibit consistency in ITN use and access within 1 year. This assumption may have resulted in misclassification because the status of these two indicators within the household may have been different before an event (death) occurred. The death of a child possibly influenced behavioral changes, which would be increased ITN use or purchase of ITNs to protect household members in this case. The strength of the association assessed in this study may then possibly be biased toward the null. Third, other factors, such as the cause of death, were not available in the MDHS and could not be examined. Therefore, in this study, malaria-related deaths among infants could not be examined. Additionally, individual-level analysis to establish the linkage between an infant's net use and risk of dying is unavailable, as net use questions are not asked of children who had died before the time of interview in the DHS surveys. This study thus attempted to address ITN usage by any household member but not by infants. Findings should be carefully interpreted. The current study was limited to examining infants because the ITN access and use status may vary over a long period. Furthermore, the DHS includes only questions on ITN use on the night before the interview. Examining the association of use on mortality for children aged <5 years (one of the most commonly used indicators) may not be feasible because behavior may possibly change over 5 years. Nevertheless, infants are the most vulnerable to malaria; hence, they constitute an important group that should be examined [11].

Conclusion

The results support the need to increase efforts for achieving universal ITN coverage. Improving ITN access and use in Malawi may be key to reducing infant deaths. Therefore, malaria programs need to be integrated with other programs working on child health with the specific aim of reducing infant mortality. Health programs working on reducing infant mortality should also consider the risk groups identified in this study in their program designs. Health education messages should emphasize the need for ITN use among households with ITN access. Future studies may examine the effects of ITN access and use on all-cause child mortality and malaria-specific mortality by using a longitudinal study design.

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Conflicts of interests

The authors declare that there are no conflicts of interest.

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Availability of Data and Materials

The study used, with permission, data from the ICF. The data are publicly available and may be requested from the ICF through https://dhsprogram.com/data/available-datasets.cfm.

Authors' Contributions

ON is a Malawian scientist, who has worked on Maternal and Child Health programs in Malawi, including a malaria program with World Vision, Malawi, in 2015–2016; he is currently enrolled in a PhD program in the School of Public Health, Taipei Medical University. ON conducted data analysis, interpreted the data, and drafted the manuscript. TWC assisted in the literature review and provided suggestions for manuscript preparation. YHC conceived and designed this study and supervised all critical data analysis and manuscript preparation. All the authors have read and approved the manuscript.

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Table 1 Distribution of participants according to the statuses of malaria indicators

Variable	ITN access				ITN use		
	No (n = 3444) n (%)	Low (n = 646) n (%)	High (n = 5108) n (%)	*p* value[a]	No (n = 5203) n (%)	Yes (n = 3995) n (%)	p value[a]
Child characteristics							
Sex of the infant				0.044			0.029
Male	1839 (36.7)	349 (7.3)	2565 (54.0)		2753 (57.9)	2000 (42.1)	
Female	1605 (36.1)	297 (6.7)	25542 (57.2)		2450 (55.1)	1995 (44.9)	
Birth order and interval				<0.001			0.014
1st	838 (37.2)	121 (5.4)	1291 (57.4)		1278 (56.8)	972 (43.2)	
2nd or higher or <2 years	316 (43.5)	65 (9.0)	346 (47.5)		457 (62.9)	270 (37.1)	
2nd or higher or ≥2 years	2290 (36.8)	460 (7.4)	3471 (55.8)		3468 (55.8)	2753 (44.2)	
Type of attendant at birth				<0.001			<0.001
Skilled	222 (31.6)	510 (7.3)	4271 (61.1)		3572 (51.1)	3421 (48.9)	
Nonskilled	1232 (55.9)	136 (6.2)	837 (37.9)		1631 (74.0)	574(26.0)	
Maternal characteristics							
Maternal age (years)				<0.001			0.154
15–24	1672 (37.8)	200 (4.5)	2554 (57.7)		2538 (57.3)	1889 (42.7)	
25–34	1278 (36.3)	255 (7.2)	1993 (56.5)		1941 (55.0)	1585 (45.0)	
≥35	494 (39.7)	191 (15.3)	561 (45.0)		724 (58.2)	521 (41.8)	
Education level				<0.001			<0.001
No formal education	748 (50.2)	152 (10.2)	590 (39.6)		1000 (67.1)	490 (32.9)	
Primary	2305 (37.8)	414 (6.8)	3387 (55.5)		3534 (57.9)	2571 (42.1)	
Secondary/higher education	392 (24.5)	80 (5.0)	1131 (70.6)		669 (41.7)	934 (58.3)	
Employment status (n = 9,191)				0.190			0.898
Yes	2246 (37.0)	452 (7.4)	3382 (55.6)		1760 (56.6)	1351 (43.4)	
No	1194 (38.4)	195 (6.3)	1722 (55.3)		3441 (56.6)	2639 (43.4)	
Wealth status				<0.001			<0.001
Poor	1852 (44.1)	279 (6.6)	2074 (49.3)		2615 (62.2)	1590 (37.8)	
Middle	715 (37.5)	140 (7.3)	1055 (55.2)		1100 (57.6)	810 (42.4)	
Rich	877 (28.4)	227 (7.4)	1979 (64.2)		1488 (48.3)	1575 (51.7)	
Residence				<0.001			<0.001
Urban	381 (29.3)	71 (5.5)	849 (65.3)		596 (45.8)	905 (54.2)	
Rural	3063 (38.8)	575 (7.3)	4259 (53.9)		4607 (58.3)	3290 (41.7)	
Region				0.009			0.002
Northern	424 (39.2)	83 (7.7)	875 (53.1)		620 (57.3)	462 (42.7)	
Central	2767 (39.7)	482 (6.9)	3713 (53.4)		4131 (59.3)	2831 (40.7)	
Southern	1445 (34.8)	289 (7.0)	2420 (58.2)		2232 (53.7)	1922 (46.3)	
Year of interview				<0.001			<0.001
2015–2016	298 (28.1)	229 (7.2)	2071 (64.8)		1405 (43.9)	1793 (56.1)	
2010	250 (25.6)	340 (9.2)	2417 (65.2)		1864 (50.3)	1843 (49.7)	
2004	1596 (69.6)	77 (3.3)	620 (27.0)		1934 (84.4)	359 (15.6	
Health-related factors							

ANC visits				0.009			0.007
Recommended	1487 (36.0)	260 (6.3)	2379 (57.7)		2256 (54.7)	1870 (45.3)	
Not recommended	1857 (38.6)	386 (7.6)	2729 (53.8)		2947 (58.1)	2125 (41.9)	
Sanitation access (9, 197)				<0.001			0.014
Improved	2082 (41.9)	275 (5.5)	2614 (52.6)		2891 (58.2)	2080 (41.8)	
Unimproved	1362 (32.2)	371 (8.8)	4293 (59.0)		2312 (54.7)	1914 (45.3)	
Water source				0.004			0.015
Improved	2780 (36.5)	535 (7.0)	4302 (56.5)		4249 (55.8)	3368 (44.2)	
Unimproved	664 (42.0)	111 (7.0)	806 51.0)		954 (60.3)	627 (39.7)	
ITN use				<0.001			-
Yes	0 (0)	328 (8.2)	3667 (91.8)		-	-	
No	3444 (66.2)	318 (6.1)	1441 (27.7)		-	-	
ITN access				-			<0.001
High	-	-	-		1441 (30.2)	3667 (71.8)	
Low	-	-	-		318 (49.2)	328 (50.8)	
No	-	-	-		3444 (100.0)	0 (0)	
Community malaria prevalence				0.096			0.288
Low	1429 (36.6)	245 (6.3)	2232 (57.1)		3171 (55.6)	1735 (44.4)	
High	2015 (38.1)	401 (7.6)	2876 (54.3)		3032 (57.3)	2260 (42.7)	
Community diarrhea prevalence				0.022			0.288
Low	3195 (39.3)	351 (7.3)	2579 (53.5)		3171 (55.6)	1735 (44.4)	
High	1549 (35.4)	295 (6.8)	2529 (57.8)		3032 (57.3)	2260 (42.7)	
Community temperature				<0.001			0.001
Low	1415 (41.5)	225 (6.6)	1772 (51.9)		2049 (60.0)	1363 (40.0)	
High	2029 (35.1)	421 (7.3)	3336 (57.6)		3154 (54.5)	2632 (45.5)	
Community rainfall				0.425			0.325
Low	2268 (37.9)	433 (7.2)	3284 (54.9)		3426 (57.2)	2559 (42.8)	
High	1176 (36.6)	213 (6.6)	1824 (56.7)		1777 (55.3)	1436 (44.7)	

[a] p-value derived using chi-square analyses

ITN: insecticide-treated net; ANC: antenatal care;

Table 2 Infant mortality rate according to background characteristics and potential factors affecting infant mortality

	Mortality			
Variable	**IMR[a]**	***p* value[b]**	**Crude HR**	**95% CI**
Child characteristics				
Sex of the infant		0.010		
Male	54.7		1.00	
Female	40.6		0.77	(0.61–0.98)
Birth order and interval		<0.001		
1st	68.1		1.00	
2nd or more/< 2 years	73.2		1.01	(0.65–1.57)
2nd or more/≥2 years	37.6		0.55	(0.42–0.73)
Type of attendant at birth		0.195		
Nonskilled	54.6		1.00	
Skilled	45.8		0.82	(0.62–1.09)
Maternal characteristics				
Maternal age (years)		0.447		
≥35	57.1		1.00	
15–24	47.2		0.89	(0.63–1.28)
25–34	45.5		0.80	(0.56–1.15)
Education level		0.867		
No formal education	51.5		1.00	
Primary	46.9		0.89	(0.63–1.26)
Secondary/higher education	48.4		0.95	(0.60–1.51)
Employment status (n =11,717)		0.435		
No	44.7		1.00	
Yes	49.6		0.94	(0.72–1.23)
Wealth status		0.401		
Poor	47.6		1.00	
Middle	41.2		0.86	(0.62–1.20)
Rich	52.4		1.09	(0.80–1.48)
Residence		0.297		
Urban	56.6		1.00	
Rural	46.5		0.81	(0.54–1.19)
Region		0.578		
Southern	50.0		1.00	
Northern	40.1		0.75	(0.51–1.09)
Central	47.8		0.92	(0.68–1.24)
Year of interview				
2004	56.3	0.027	1.00	
2015–2016	37.4		0.70	(0.50–0.97)
2010	48.8		0.84	(0.77–1.49)
Health-related factors				
ANC visits		0.091		
Not recommended	52.2		1.00	
Recommended	42.5		0.81	(0.57–0.94)
Sanitation access (11,719)		0.846		
Unimproved	48.5		1.00	
Improved	47.3		0.96	(0.73–1.24)
Water source (11,722)		0.377		
Unimproved	41.6		1.00	
Improved	49.2		1.34	(0.91–1.97)
ITN use		<0.001		
No	58.4		1.00	
Yes	34.2		0.61	(0.43–0.84)
ITN access		<0.027		
No	62.5		1.00	
Low	34.1		0.58	(0.29–1.16)
High	39.7		0.67	(0.51–0.88)
Community malaria prevalence		0.464		
Low	50.6		1.00	
High	45.9		0.94	(0.71–1.24)
Community diarrhea prevalence		<0.001		

Low	37.6		1.00	
High	59.2		1.75	(1.34–2.76)
Community temperature		0.678		
Low	49.6		1.00	
High	46.9		0.97	(0.73–1.29)
Community rainfall		0.603		
Low	49.0		1.00	
High	45.8		0.89	(0.68–1.17)

[a] Deaths per 1000 live births (weighted)
[b] p-value derived using chi-square analyses
ITN: insecticide-treated net; ANC: antenatal care; CI: confidence interval; HR: hazard ratio; IMR: infant mortality rate

Table 3 Risks of infant mortality stratified by ITN use and ITN access

ITN access [b]	ITN use HR[a] (95% CI)		**Total**
	No	Yes	

No access	1.00			-	1.00	
Low	0.73	(0.31–1.71)	0.30	(0.10–0.94)	0.52	(0.26–1.02)
High	0.75	(0.52–1.08)	0.57	(0.40–0.82)	0.63	(0.46–0.86)
Total	1.00		0.61	(0.44–0.85)		

ITN: insecticide-treated net; ANC: antenatal care; CI: confidence interval; HR hazard ratio

[a]Adjusted for sex of the infant, birth order and interval, type of attendant at birth, maternal age, employment status, wealth status, residence, region, number of ANC visits, drinking water source, household sanitation, and survey year, community malaria prevalence, community diarrhea prevalence, community temperature, community rainfall

[b] Households with access levels above the median overall national ITN access were considered "high-access households," whereas those within and below the median were considered "low-access households."

Table 4 Risks of infant mortality stratified by ITN use and ITN access at different age ranges (excluding neonates)

ITN access [b]	ITN use (1-2 mo.) HR[a] (95% CI)		**Total**	ITN use (3-5 mo.) HR[a] (95% CI)		**Total**	ITN use (6-<12 mo.) HR[a] (95% CI)		
	No	Yes		No	Yes		**No**	**Yes**	**Total**
No access	1.00	-	1.00	1.00	-	1.00	1.00	-	1.00
Low	0.97 (0.26-3.60)	0.39 (0.14-0.81)	0.45 (0.09-2.29)	0.31 (0.07-1.36)	0.71 (0.10-4.94)	0.48 (0.12-1.93)	0.71 (0.24-2.09)	0.26 (0.08-1.19)	0.48 (0.20-1.17)
High	0.74 (0.30-1.80)	0.41 (0.18-0.95)	0.51 (0.24-1.07)	0.91 (0.44-1.86)	0.59 (0.25-1.43)	0.69 (0.33-1.44)	0.60 (0.36-0.98)	0.50 (0.34-0.75)	0.53 (0.37-0.77)
Total	1.00	0.41 (0.18-0.91)		1.00	0.66 (0.32-1.36)		1.00	0.58(0.40-0.86)	

ITN: insecticide-treated net; ANC: antenatal care; CI: confidence interval; HR hazard ratio

[a]Adjusted for sex of the infant, birth order and interval, type of attendant at birth, maternal age, employment status, wealth status, residence, region, number of ANC visits, drinking water source, household sanitation, and survey year, community malaria prevalence, community diarrhea prevalence, community temperature, community rainfall

[b] Households with access levels above the median overall national ITN access were considered "high-access households," whereas those within and below the median were considered "low-access households."

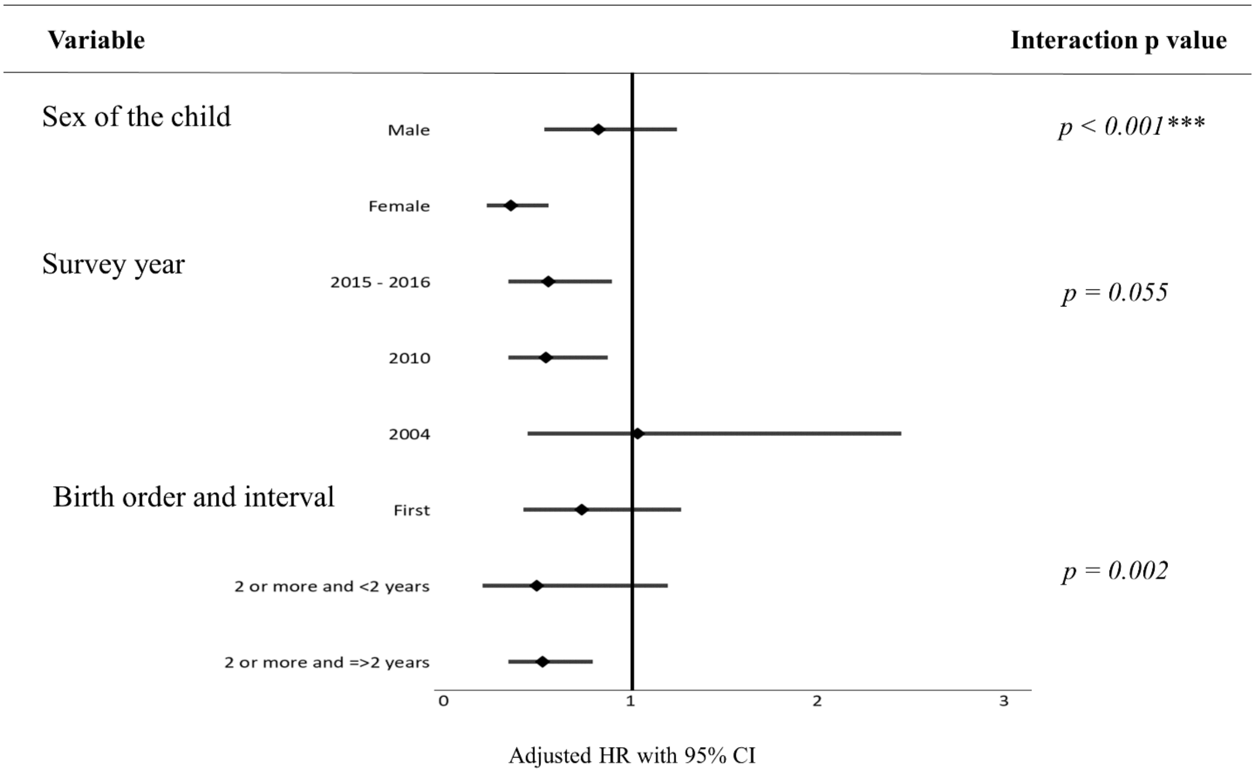

Figure 1 Subgroup analysis of effects of ITN use on infant mortality.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. ITN use: yes, or no (ref.). Results were adjusted for potential confounding factors (i.e., sex of the infant, birth order and interval, type of attendant at birth, maternal age, education level, employment, wealth status, residence, region, number of ANC visits, drinking water source, household sanitation, survey year, and ITN access. The variable that was treated as the effect modifier was excluded).

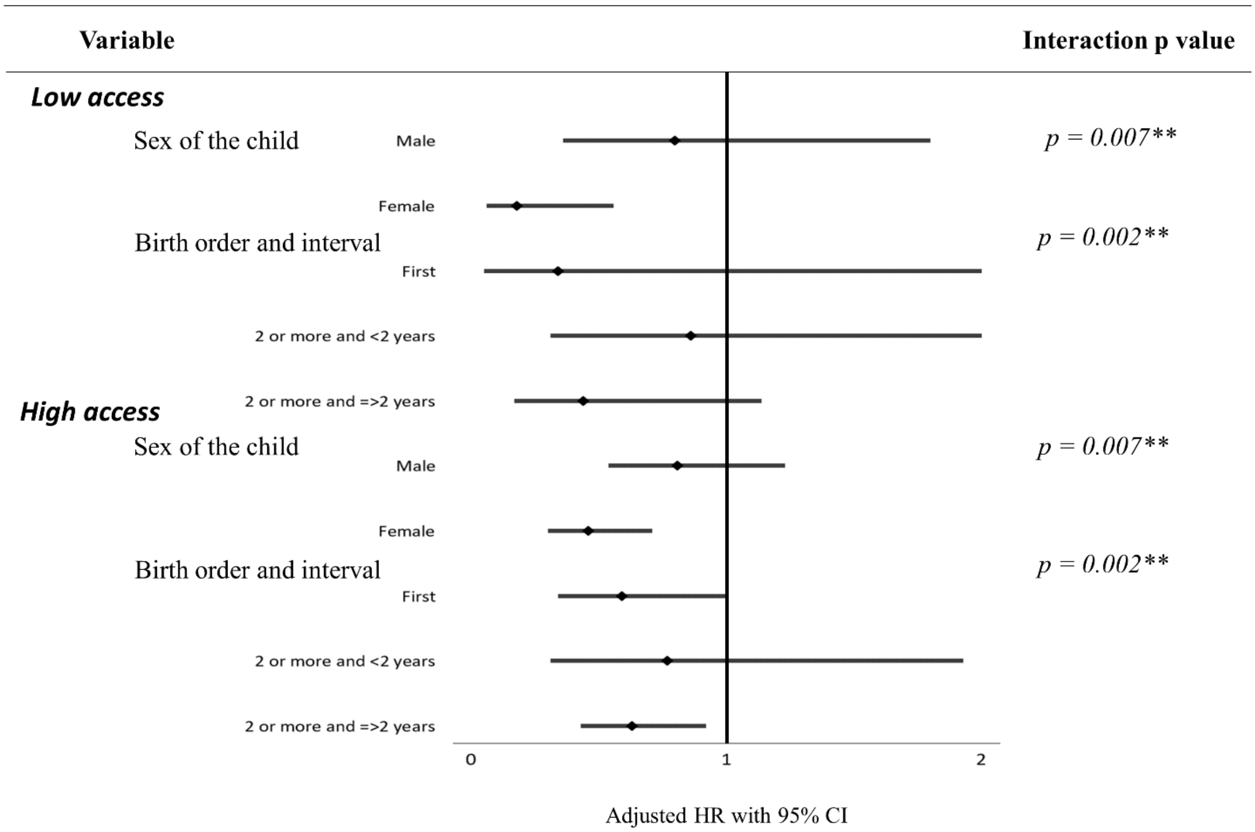

Figure 2 Subgroup analysis of effects of intra-household ITN access on infant mortality

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Intra-household ITN access: high, low or no (ref.). Results were adjusted for potential confounding factors (i.e., sex of the infant, birth order and interval, type of attendant at birth, maternal age, education level, employment status, wealth status, residence, region, number of ANC visits, drinking water source, household sanitation, survey year, and ITN use. The variable that was treated as the effect modifier was excluded.)