Monitoring of attrition, physical Integrity, and insecticidal activity of long-lasting insecticidal net in Ethiopia: A longitudinal multi-site study

Final Report after 36 Months Follow-up
2019

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Acronyms

ACIPH	Addis Continental Institute of Public Health
CI	Confidence Interval
CSA	Central Statistical Agency
EA	Enumeration Area
FMoH	Federal Ministry of Health
GC	Gas Chromatography
GPS	Global Positioning System
HPLC	High-Performance Liquid Chromatography
IRB	Institutional Review Board
LLIN	Long Lasting Insecticide Nets
MIS	Malaria Indicator Survey
pHI	proportionate Hole Index
PMI	Presidents Malaria Initiative
SNNPR	Southern Nations, Nationalities, and Peoples' Region
WHO	World Health Organization
WHOPES	World Health Organization Pesticide Evaluation Scheme

Executive Summary

Long Lasting Insecticide Nets (LLINs) provide protection against malaria infection serving as physical barrier between human and mosquito, and by killing mosquitos due to the chemical included in the nets. This dual protection remains intact if the net has both physical and chemical integrity. According to the World Health Organization Pesticide Evaluation Scheme (WHOPES), LLINs are expected to serve for 3 years in a field setting.

National Malaria Prevention and Control Program of Ethiopia has been using Long Lasting Insecticide Nets (LLINs) as one of the main vector control intervention since 2005. The most recent 2015 malaria indicator survey reported 64% coverage of the intervention. Even though the coverage is very well documented, the question remains how long the nets can last in actual settings of the county. This study aims to monitor the survivorship, physical integrity and insecticidal activity of LLINs in sampled study sites in the four big regions of Ethiopia.

We conducted a 3-year longitudinal study between 2015 and 2018 in four regions: Tigray, Amhara, Oromia and Southern Nations, Nationalities, and Peoples' Region (SNNPR). At baseline, a total of 3403 LLINs from 1837 households were tagged for follow up. The status of these LLINs were assessed in three rounds of follow-up surveys conducted in 2016, 2017, and 2018. In all surveys, the availability and physical integrity of the nets were assessed following World Health Organization Pesticide Evaluation Scheme procedures. Attrition was measured as the number of nets not found in households divided by number of nets tagged for follow up. The cause of attrition was further divided into three types – physical damage, removal, and repurposing. Physical integrity was assessed by counting the number and size of holes and categorizing nets as torn, serviceable and good using proportionate hole index (pHI) criteria. Survivorship refers to the number of functional LLINs observed divided by the number of LLINs that were not given away. In addition, insecticidal activity of nets was assessed using WHO cone bioassay method and residual concentration of chemical were measured using the High-Performance Liquid Chromatography and Gas Chromatography methods.

We were able to follow 1665 (90.6%) of the households all the way up to the end of the study. These number varies by study site from 88% in Tigray to 95% in SNNPR. The common reasons that might negatively affect LLIN durability in this study include storing food in sleeping places (57.0%) cooking in sleeping rooms always (23.5%) and rodent infestation (81.4%). Overall, exposure about health education messages about LLIN use and care was very low, only 24.6% and 18.5% of respondents had exposure about LLIN use and care 6 months prior to the baseline and third-year survey. In all regional study sites and survey periods health extension workers are the main sources of information. Out of the respondents exposed, more than half (54.4%) of the respondents reported the content of the message as repair your nets in the third-year survey.

All cause attrition three years after campaign distribution was 71.8% [95% CI: 70.3, 73.3]. This rate varies by study site. It is calculated to be 49.9% [95%CI: 46.6, 53.3] in Tigray, 90.7% [95% CI: 88.4, 92.7] in Amahara, 73.4% [95% CI: 70.6, 76.1] in Oromia and 77.0% [95% CI: 73.8, 80.0] in SNNPR.

Out of the 555 nets that found in the 36 months, 42.3% didn't have any holes, 12.8% were in good condition, 17.3% were serviceable condition and 27.4% were torn. By the 3rd year following the distribution campaign, only 15.6% survived. Relatively speaking, survivorship is high in Tigray (28.3%) followed by Oromia (13.8%), and SNNPR (11.8%). Amahara demonstrated the lowest survivorship (6.9%).
Median survival time showed variation across study sites. The longest (27 months) was observed in Tigray, while the shortest (11 months) was in Amahara. Oromia and SNNPR study sites showed 22 and 20 months median survival time respectively.

The WHO cone bioassay test result indicated that 92.4% of the LLINs remain meeting the WHO pesticide evaluation scheme criteria of effectiveness for the first and second year. But in the third year, only 20% of the sampled bed nets fulfil this criterion.

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1 Background

Long-lasting insecticide nets (LLIN) were introduced in 2005 and have been rapidly scaled-up in Ethiopia(1). In the 2007 Ethiopia malaria indicator survey (MIS), the LLIN coverage was 68% in malaria endemic areas of the country (2). Results from the 2011 MIS showed that the LLIN coverage decreased to 55%, with some variations across the country (3). And the most recent MIS in 2015 reported coverage with LLINs to be at 64% (4).

LLINs protect people sleeping under them from mosquitoes that transmit malaria through a combination of a physical barrier offered by the net and the insecticide on the net, which reduces mosquito numbers and life expectancy. According to the World Health Organization Pesticide Evaluation Scheme (WHOPES), LLINs are expected to be effective for about 3 years under field conditions and survive at least 20 washes. However durability of LLINs is affected by many factors, including attrition, survivorship, fabric integrity, and insecticidal activity, influence this expectation (5).

1.1 Attrition or survivorship

Attrition is defined as the rate of loss of LLINs from study households due to wear and tear or other causes. It is measured by observing the physical presence of the LLIN in the household. It can farther be categorized as attrition due to physical damage, removal and repurposing. Survivorship, on the other hand, refers to the amount of LLINs that are available for sleeping under in surveyed households. (5).

Attrition can be due to discarding of nets because of excessive loss of fabric integrity (true attrition); movement of nets by selling them, giving them away or using them in another location (migration); or use for other than the intended purpose, although still owned by the household (misuse). Nets that are worn out but stored in the house and no longer used for their original purpose should be considered to have undergone true attrition. Attrition due to migration or misuse is likely to occur with any type of net, whereas true attrition is usually associated with the physical characteristics of the net. The cause of true attrition can be further disaggregated according to the type of damage, such as wear and tear from regular use or damage due to animals or fire (5).

Survivorship refers to the total number of each LLINs that are available for sleeping under out of the total number of LLINs distributed to surveyed households in the study cohort at the beginning of the study. It can be measured as proportion or median survival time (5).

Several studies have estimated attrition rates of LLINs in different field setting using wide range of methods, including cohort studies. Generally, the rate of attrition is more rapid than the previously thought three year of serviceable life. Bayesian model using data from 102 countries estimated attrition rate of 50% by 23 months (6). Attrition rate of 34% was reported after 3 years in Nigeria(7). In Benin, attrition due to discarding and re-purposing was overall 17% after 18 months

with a range between sites between 10 and 32% after 18 months of follow up time. A prospective evaluation of LLINs in Mozambique reported LLIN attrition of 25% after 3 years of follow-up time (8).

Couple of studies done in Ethiopia also reported attrition rats faster than the expectation. Two year follow up cohort study done in South-central Ethiopia reported overall attrition rate of 96% withen two years of follow up. In this study majority (64.2%) of the attrition was due to disposal (9). Cross sectional study also reported that 31% of the LLINs were discarded in 3 years (10). Another cross sectional study done two years after campaign distribution reported retention rate of 72%, which might be equivalent to attrition rate of 28% (11).

1.2 Fabric integrity

Fabric integrity is assessed by counting the number of holes (including tears and split seams) by their location on the net and their size. Holes can be classified into: size 1: smaller than a thumb (0.5–2 cm), size 2: larger than a thumb but smaller than a fist (2–10 cm), size 3: larger than a fist but smaller than a head (10–25cm) and size 4: larger than a head (> 25 cm). The proportionate hole index (pHI) is calculated by weighting each hole by size and summing for each net. Using pHI, nets are categorized as good (pHI<64 or total hole surface area <0.01m^2), serviceable (pHI 64 – 642 or total hole surface area <=0.1 m^2) and torn (pHI > 642 or total hole surface area>0.1m^2) (5).

Overall in Ethiopia, LLINs damage began quickly. This coupled with very low repair practice LLINs deteriorate very rapidly (9,10,12). For example; 35.8% of the LLINs have developed holes after 6 months of distribution(9). The proportion of nets in 'poor' condition (hole index >300) increased from 0% at three to six months to 30% at 26 to 32 months. Farther more 68% had holes and 28% were classed as 'mediocre' or 'poor' by hole index at 14 to 20 months of use. (13). Batisso et al. found out that only 3.7% of nets repaired, the stated the finding as *"nets are frequently washed, but rarely repaired"* (10). Farther more several factors affect the physical integrity of LLINs. Low-denier nets are likely to be less durable(5). Presence of rats in in the household, distance of the house from mosquito breeding site are other factors (9)

1.3 Functional survival time

LLINs are expected to serve 3 years of recommended use under field conditions, as defined in WHO guidelines(5). However, the literature seems to agree with the survival time is shorter than the expected 3 years. Survival time of LLINs have showed a wide range of variation ranging from 12 months in Ethiopia (9), 23 months in multi country study in Africa(6) and more than 3 years (14).

1.4 Insecticidal activity

The insecticidal activity (biological efficacy) of the nets should be determined in WHO cone tests and, when necessary, in tunnel tests at baseline and subsequent follow-ups. When knockdown is < 95% and mortality is < 80% on a given LN, it should be subjected to a tunnel test. For each net that

fails to meet the criteria of the WHO cone test, the tunnel test should be conducted on the piece of netting that results in the mean mortality closest to that in the WHO cone assay. A candidate LN is considered to meet the criteria for efficacy for testing in phase III studies if, after 3 years, at least 80% of sampled nets are effective in WHO cone tests (≥ 95% knockdown or ≥ 80% mortality) or tunnel tests (≥ 80% mortality or ≥ 90% inhibition of blood-feeding) (5).

WHOPES supervised study of PermaNet 2.0 was done in six African countries between 2007 and 2008. The findings indicated that after one year, 98% of the nets met the WHO requirements based on the cone bioassay, decreasing to 85% and 57% in years 2 and 3 respectively. Among the 26 three-year old net samples (43%) that failed WHO cone bioassays, 61% were effective in tunnel tests based on mortality (>80%) and/or blood-feeding inhibition (>90%). Overall, 80% of three-year-old nets met the WHO requirements for either the WHO cone test or the tunnel test. Large differences were observed among countries: nets collected in Ghana and Madagascar failed to meet the WHO criteria of an LN, whereas in Angola all nets fulfilled the requirements (15).

In Ethiopia studies have reported that PermaNet 2.0 met the criteria of effective bio-efficacy up to 24 months after distribution (9), 32 months (12). Tomass et al. assessed six nets after 24 months of use and reported 100% 24 hour mortality in all the samples (16).

Few studies have assessed the bio-efficacy of MAGNet. Wash resistance study done India reported that 25 times washed MAGNet LN produced 100% mortality in cone bioassays before and after hut evaluation (17) . WHOPES supervisored study also reported that the KD of MAGNet net after 20 washes was 100% and therefore met the WHO threshold. Over the course of 25 washes, KD was never less than 99% (18).

Chemical analysis

According to the WHO manual, chemical analysis of nets should be done in phase III field trials of LLINs. The chemical content and density (mass of net per unit area) should be analyzed in each of the nets to estimate between-net variation. If it is necessary to analyses these parameters in each of the five net samples from a net, such as to correlate chemical content with bio-efficacy, density and within- and between-net variation should be estimated. The chemical analysis should be conducted with the methods published by CIPAC for each LN or, if unavailable, tests developed by the manufacturer and validated. Results should be expressed in both grams of active ingredient per kilogram of netting and milligrams of active ingredient per square meter of netting (5).

There seems no agreement on the amount of chemical concentration needed to achieve WHO efficacy criteria of cone bioassays (≥ 80% mortality or ≥ 95% knock-down). Manufacturers report the concentration of active ingredient in their product batch specification, they also claim their brand continues enough chemical content to meet WHO efficacy criteria even after 3 years of use. Researchers have used different chemical concentration levels to identify the minimum level needed to meet WHO bio-efficacy level. There is also variation based on the brand and the

chemical in which the net is treated. For example there is variation between PermaNet 2.0 and MagNet.

PermaNet 2.0® is a deltamethrin-coated LLIN. The net is made of knitted poly-filament polyester fibers and is coated with deltamethrin to a target concentration of 55 mg/m2 (= 1.4 g/kg for a 100-denier net; 1.8 g/kg for a 75-denier net). The insecticide is bound in a resin coating that reduces the amount of insecticide lost during routine washing. It has granted WHOs full recommendation in 2009 (15). Different studies have assessed the chemical concentration of this net.

According to the twelfth WHOPES working group report, a wide range (0.208 g/kg to 0.818 g/kg) of deltamethrin content met the WHO criteria measured by cone and tunnel combined. The mean deltamethrin content of nets causing <80% mortality was 0.274 g/kg (95% CI, 0.235–0.314) and causing <95% knock-down was 0.241 g/kg (95% CI, 0.193–0.289). The report also stated that all nets that failed (cone tests and tunnel tests combined; had a deltamethrin content <0.2 g/kg, which is the quantification limit of the analytical method used in this study (15).

Anshebo et al. used two concentrations levels of deltamethrin detected by X-ray fluorescence (XRF): 10 mg/m2 as a conservative estimate of minimum effective concentration, and 25 mg/m2 as a measure of optimum concentration. Using this cut of points they reported that 75% of the nets have insecticide concentrations above the optimum concentration of 25 mg/m2 in all groups, including the longest time period of 26- 32 months (12).

Content of active ingredient is expected to degrade over time with usage and repeated wash. WHOPS analyzed a total of 420 PermaNet 2.0 LNs from six African countries, overall (all countries combined), the deltamethrin content decreased from a mean value of 0.821 g/kg (95% CI, 0.723–0.920) in year 1, 0.558 g/kg (95% CI, 0.491–0.626) in year 2 to 0.431 g/kg (95% CI, 0.367–0.495) in year 3 (15). Anshebo et al. reported mean concentration of deltamethrin 66.2 mg/m2 (SD 14.6, N = 189) at 3-6 months, 44.1 mg/m2 (SD 21.2, N= 220) at 14- 20 months and 41.1 mg/m2 (SD 18.9, N= 200) at 26-32 months (12). In Uganda the PermaNet maintained 42% of the baseline dose after 36 months (19)

MAGNet® is a bed net made of High-Density Polyethylene Monofilament. The specification state that the active ingredient, Alpha-cypermethrin, is incorporated into the polyethylene filaments with a targeted does of 5.8 g/kg ± 25% (20). Few studies have measured the chemical content of this brand in lab settings.

The fourteen WHOPES working group meeting reported the wash resistance and efficacy findings of MAGNet. Accordingly the alpha-cypermethrin content (6.08 g AI/kg and 6.07 g AI/kg) in the reserved and the unwashed MAGNet complied with the target dose ± 25% of 5.8 g AI/kg [4.35 g AI/kg – 7.25 g AI/kg] (18).

Another study in India reported the MAGNet retained 5.3 ± 0.07 g/kg and 5.1 ± 0.05 g/kg of alpha-cypermethrin content after 20 and 25 washes which is equivalent to 95% and 90% of the baseline

content respectively. Same study reported that *"after the hut trial, alpha-cypermethrin content did not decrease a lot, as it was 5.2 ± 0.09, 5.0 ± 0.05 and 4.9 ± 0.04 g/kg in the MAGNet unwashed and washed 20 times or 25 times, respectively"* (17).

To get the most out of the LLINs in the fight against malaria, it is essential to monitor the durability of nets distributed. Farther more, monitoring of the use, care, and repair of nets, the physical integrity, and the insecticidal effects of nets is essential to make evidence based programmatic decisions. However, there is shortage of comprehensive evidence in this area.

Pervious study assessed only part of the three components of durability in a limited study site. Most of them were cross sectional study designs done in relatively smaller sample sizes. To bridge this gap, we conducted a longitudinal multi-site large-scale field trial (phase III) to monitor the attrition, physical integrity, and insecticidal activity of long-lasting insecticidal nets in Ethiopia.

2 OBJECTIVES

The objectives of this assessment are,

1. To monitor LLIN survivorship or attrition and reasons for net attrition over three years
2. To evaluate physical integrity of LLINs over three years and
3. To determine the residual chemical concentration and insecticidal activity of LLINs in 4 regions (Amhara, Oromia, Tigray and SNNP) of Ethiopia over three years

3 Methods

3.1 Sites

The study was conducted in 4 study sites that are administrative regions representative of the different eco-environmental conditions in Ethiopia (Figure 1). Each region was considered as an independent sampling domain. The four regions constitute about 86% of the total population of the country (CSA, 2007 census).

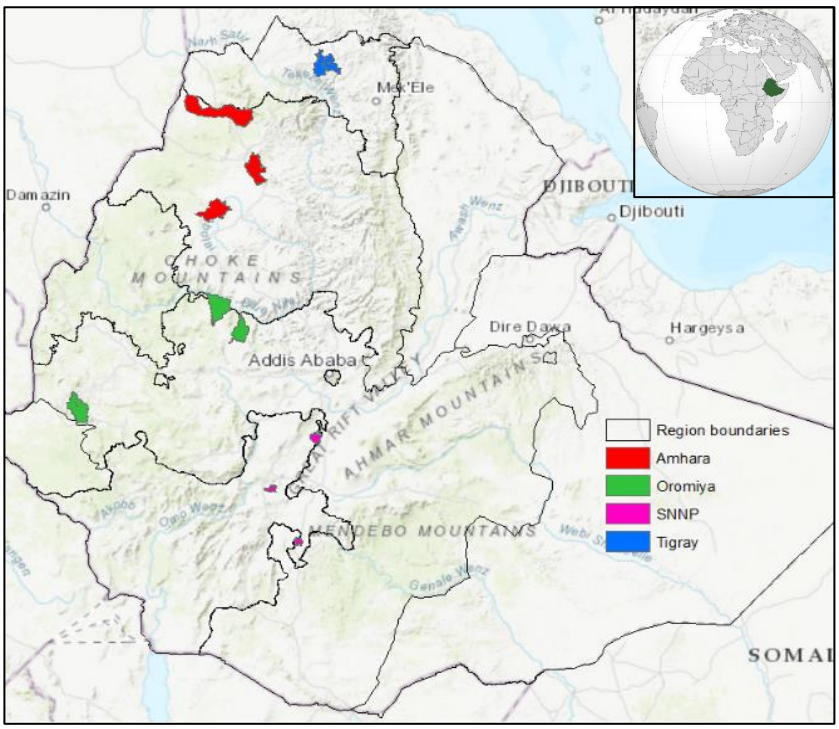

Figure 1: LLIN durability monitoring study sites in Ethiopia.

3.2 Study Design

Longitudinal multi-site study was conducted to monitor a cohort of nets in four regions of Ethiopia over three years. The study started following the mass distribution of two brands of nets, MAGNet® and PermaNet® by the NMCEP. The study also employed repeated cross-sectional data collection to assess the physical integrity and insecticidal activities of the nets. The nets were selected at the household level after the households were selected following a multi-stage cluster sampling procedure. The households were selected based on their malaria transmission status of the district and whether the regions were part of the recent LLIN distribution campaign.

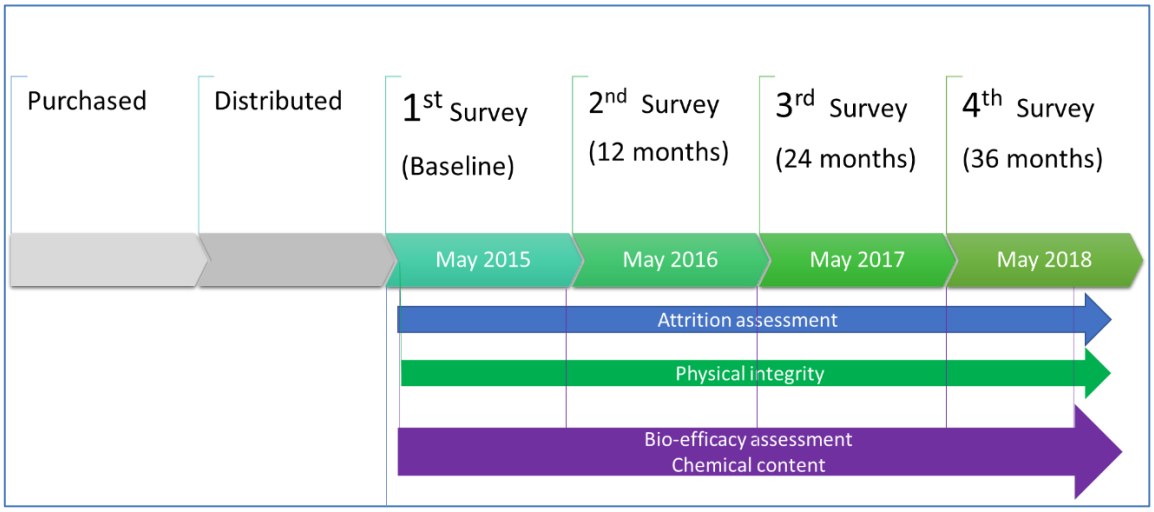

Figure 3: Study design and yearly followed parameters

3.3 Sample size

The sample size calculation follows the WHO standard for phase III filed trial of nets. It was calculated for physical durability and insecticidal activity separately (5).

Physical Durability: as per the guidelines, a sample size of 250 nets per region were taken based on conservative attrition rate of 20% per year and 50% over three years. In addition, 95% confidence intervals (alpha-error) and 80% power (beta-error) were considered. Attrition and fabric integrity were measured at 12, 24 and 36 months on all the sampled nets(5).

Insecticidal activity assessment: We collected 10 LLINs from each of the woredas for chemical and bioassay testing. This makes a sample of 30 LLINs per study site, with a total of 120 nets. The nets were taken from randomly selected households located in the same enumeration area, but not sampled for the physical durability monitoring(5).

3.4 Sampling Procedure

The sample size and sampling procedures were carried-out separately for each region. A multi-stage sampling procedure was used to select the households in the selected regions:

Selection of Districts: for each the four regions (survey domains), a list of districts was prepared based on their malaria transmission status and whether there was net distribution in the last one month or there is a plan for net distribution in the near future. Accordingly, a total of 12 districts were selected. Three, two and seven of the selected districts were from high, moderate and low transmission settings respectively.

Selection of clusters: in this study clusters refers to standard enumeration area (EA) developed by central statistical agency of Ethiopia. Selection of the EAs was done proportional to the size of the district's population. A list of eligible EAs and their estimated population size was prepared, then . Twenty-three clusters were selected randomly from the each of districts within each region.

Selection of Households: First, complete listing of all the households within the selected EAs was done to generate fresh sampling frame. Twenty households were selected from each of EAs using systematic random sampling.

Consent was requested for the selected households and those agreed to participate in the study were followed over the course of the study. Household GPS location and the names of two next door houses were used to identify houses in subsequent follow-up visits. .

3.5 Data collection and management

The data were collected at 4 time points (baseline and follow-up at 1, 2, and 3 years post distribution). We used four methods of data collection; interview with heads of households, observation of LLINs, bioassay and chemical concentration measurement.

3.5.1 Interview Questionnaires

The first visit to the households selected randomly was made on average approximately one month after the distribution of the nets and consisted of an assessment of acceptability and the administration of the questionnaire (baseline). No nets were assessed for physical integrity at this point since an insignificant amount of damage was anticipated at this point in time. As the data to be collected differs between baseline and the subsequent time points, the baseline questionnaire was slightly different from the subsequent questionnaires. The questioner collects information about household characteristics and net ownership, attitude and practices towards net care and repair, information about lost nets, knowledge and attitude towards malaria and bed nets.

3.5.1.1 Coding of nets

During the initial visit when the baseline questionnaires were administered (one-month post distribution), the nets were also tagged with plastic "coins" that had a numeric identification to uniquely identify individual net. Additionally, the number was written on the label of the LLIN using waterproof marker. This was used to ensure that nets present during the initial study were the ones being monitored over the study period. Up to four nets were tagged for follow up per household.

3.5.1.2 Follow-up visits

At each subsequent time point (months 12, 24, and 36), the data collectors used GPS coordinates and GPS trackers to return to the selected households and administer a questionnaire to all houses visited on the first survey. The head of the household or any adult resident was asked if they still had the net and, if the net was not present, what was the reason for the absence.

3.5.2 Assessment of physical integrity

Physical integrity of nets was assessed following WHOPES guidelines (see annex). The nets were taken outdoors, where they could be examined more accurately for holes and other types of damage. The holes were measured using tape measure and their size and location was recorded.

3.5.3 Assessment of insecticidal effects

The insecticidal effectiveness of the nets was measured in two ways. The first, through bioassays and the second through residual chemical concentration measurements. Because these activities require destruction of the nets they were removed, after replacement with new nets, from the households and taken to the laboratory. Nets for insecticide measurement were collected at baseline (before distribution) and then at 12, 24, and 36 months.

3.5.3.1 Bio-efficacy assessment

Bio-efficacy of net samples was assessed using the WHO cone test. The cone test involves placing susceptible mosquitoes in contact with net samples for a specific period of time (3 minutes) to see if contact is sufficient to result in the >95% knockdown and 80% mortality rate of the mosquitos in one and 24 hours after exposure respectively. The bioassays were conducted with a pyrethroid-susceptible strain of mosquitoes, *Anopheles arabiensis*, primary malaria vector in Ethiopia.

3.5.3.2 Residual chemical content measurement

Chemical analysis was done at baseline and in all the three follow up surveys. At baseline, five pieces of netting measuring 30 cm x 30 cm where cut from adjacent positions, following the WHOPES sampling scheme. In subsequent surveys, the piece from position 1 was excluded, as it is considered to be tucked under the bed and exposed to excessive abrasion. Net samples were measured to estimate their density (mass of net per unit area), and then samples from the same net were combined for chemical analysis.

Chemical content of deltamethrin and alpha-cypermethrin was measured using high-performance liquid chromatography (HPLC), and gas chromatography (GC) respectively.

3.6 Analysis

The analysis was done using STATA version 15 (Stata Corporation, College Station, Texas) using the "surveyset" command to account for complex survey data, population weights were also applied to account for unequal probability of selection across the districts. The main outcome variables were calculated following standard formulas showed in box 1.

Box 1: durability monitoring indicators calculation.

All cause attrition rate at time T_i	=	$\frac{\text{Total LLINs under follow up reported as missing from households at } T_i}{\text{Total LLINs enrolled for follow up at time } T_0}$	X100
Attrition rate-1 (Physical damage) at time T_i	=	$\frac{\text{Total LLINs under follow up reported as thrown out due to wear and tear at time } T_i}{\text{Total LLINs enrolled for follow up at time } T_0}$	X100
Attrition rate-2 (Removal) at time T_i	=	$\frac{\text{Total LLINs under follow up reported as given away, stolen, sold or used in another location at time } T_i}{\text{Total LLINs enrolled for follow up at time } T_0}$	X100
Attrition rate-3 (Re-purposed) at time T_i	=	$\frac{\text{Total LLINs under follow up reported as being used for another purpose at time } T_i}{\text{Total LLINs enrolled for follow up at } T_0}$	X100
pHI	=	*# size 1 holes + (# size 2 holes x 23) + (# size 3 holes x 196) + (# size 4 holes x 576)*	
Good	=	total hole surface area <0.01m² or pHI <64	
Serviceable	=	total hole surface area <=0.1 m² or pHI 64 – 642	
Torn	=	total hole surface area>0.1m² or pHI > 642	
Survivorship	=	$\frac{\text{LLINs found in households with no hole + in good + serviceable condition – unknown status}}{\text{Total LLINs enrolled for follow up at } T_0 \text{ – Given away – unknown status}}$	X100
Median Survival time	=	$t_1 + \frac{(t_2-t_1)-(P_1-50)}{(P_1-P_2)}$ *t_1: first time point, t_2: Second time point, P_1: functional survival at t_1, P_2: functional survival at t_2*	
Bio-efficacy	=	A candidate LLIN is considered to meet the criteria for efficacy for testing in phase III studies if, after 3 years, at least 80% of sampled nets are effective in WHO cone tests (≥ 95% knockdown or ≥ 80% mortality)	

3.7 Ethical Clearance

The study protocol was submitted and approved by the Institutional Review Board (IRB) at Addis Continental Institute of Public Health (ACIPH). Upon approval, permission letters were obtained from each region where the study was conducted. Districts and kebeles were also notified of the study before the start of the assessment. At the household level, prior to implementation of any study activities such net marking and questionnaire administration, the study was fully explained to respondents and their consent was obtained.

Personal identifiers in the survey questionnaire were only used for follow-up purposes and locating the nets over the three-year period. All data were collected on tablets and transferred to computers that only investigators had access to.

Before interviewing and retrieving LLINs, the data collectors asked for consent from local leaders in the area as well as the head of the sampled households. A verbal consent text was read in the local language to the member of the household who received the interviewer.

There were no any risks to participants in this study. Those household heads whose net were taken for durability/insecticide evaluation were provided with a replacement with WHO licensed LLIN.

4 Results

Initially, there were 459 households enrolled in Tigray, Amhara, and Oromia and 460 in SNNPR study sites. Percentage of households who completed follow up ranged from 88% in Tigray to 95% in SNNPR at 36 months. Twelve months follow-up percentages were all above 93% and at the conclusion of the study (year 3) all rates were over 88%.

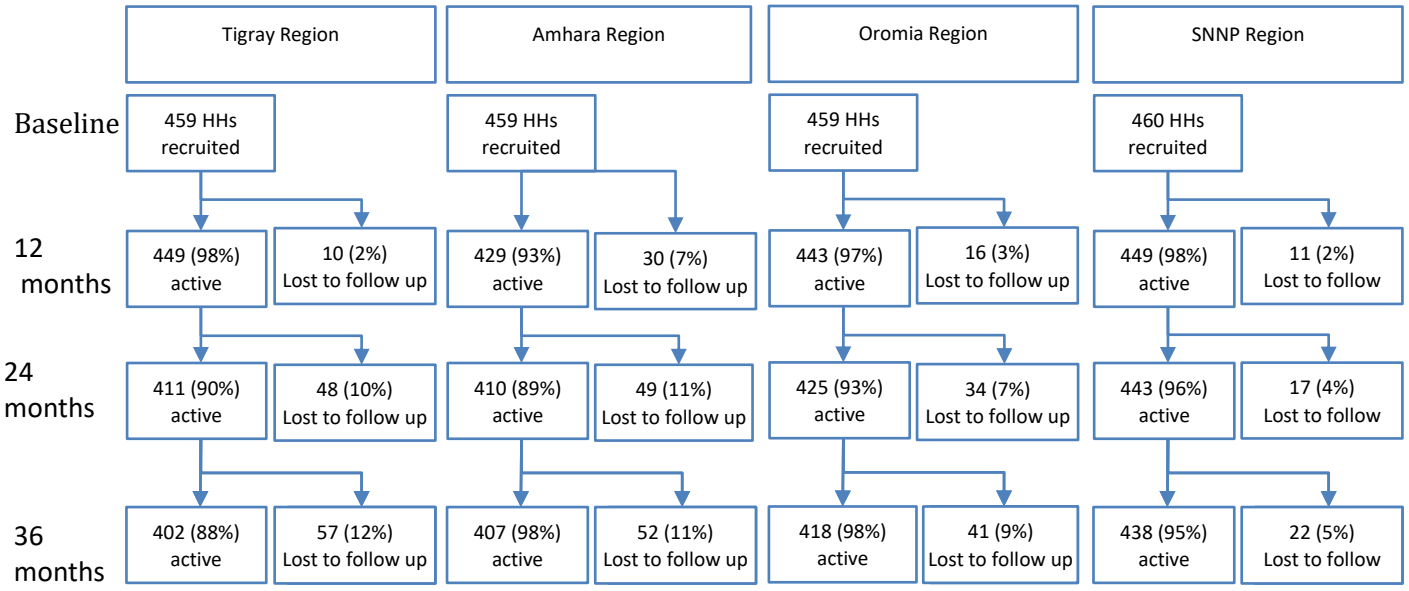

Figure 4: Follow up status of cohort households in four study sits in Ethiopia, 2015- 2018

4.1 Determinants of Durability

Storage and cooking of food in room where members of the household sleep and observation of rats within the last six months were assessed as reasons at each visit. Storing food and cooking in sleeping room, and rodent infestation looks very common in all study sites. Cooking of food in sleeping rooms was consistently most common in SNNPR with 58.9% and 50.6% reporting always preparing food in sleeping rooms at baseline and year 3 respectively. People residing in Oromia were the least likely to use rooms where family members sleep to prepare food – in the final 36 months follow up, 91.1% of the households has never cooked in their sleeping rooms. All districts consistently report the presence of rodents in the last six months throughout the study. The lowest levels are in Tigray, and Oromia reported the highest.

Table 1: Household reasons for LLIN durability in four study sites in Ethiopia, 2015-18

Variable and site	Baseline	12 months	24 months	36 months
Total	n=1837	n=1770	n=1689	n=1665
Ever store food in sleeping room	72.6%	62.9%	66.1%	57.0%
Cook in sleeping room				
Always	31.0%	24.6%	24.5%	23.5%
Most of the time	8.8%	7.2%	7.1%	4.7%
Sometimes	14.7%	15.4%	13.4%	14.7%

Never	44.7%	51.9%	55.0%	57.0%
Don't Know	0.7%	0.9%	0.0%	0.1%
Rodents observed (last 6 months)	80.7%	81.9%	79.3%	81.4%
Tigray	n=459	n=449	n=411	n=402
Ever store food in sleeping room	79.9%	69.7 %	82.6%	67.6%
Cook in sleeping room				
Always	27.2%	21.3%	22.3%	19.6%
Most of the time	17.6%	16.5%	19.0%	10.9%
Sometimes	22.9%	26.9%	26.9%	29.3%
Never	31.8%	34.9%	31.8%	39.8%
Don't Know	0.4%	0.4%	0.0%	0.3%
Rodents observed (last 6 months)	64.4 %	71.4%	65.3%	64.9%
Amhara	n=459	n=429	n=410	n=407
Ever store food in sleeping room	89.8%	71.7 %	81.2%	61.3%
Cook in sleeping room				
Always	31.7%	19.1%	22.3%	23.3%
Most of the time	14.8%	9.9%	8.5%	3.3%
Sometimes	25.2%	24.7%	18.7%	20.6%
Never	28.4%	45.7%	50.5%	52.8%
Don't Know	0 %	0.6%	0.0%	0.0%
Rodents observed (last 6 months)	85.5 %	84.8%	79.0%	77.6%
Oromia	n=459	n=443	n=425	n=418
Ever store food in sleeping room	53.3%	46.5%	38.6%	38.1%
Cook in sleeping room				
Always	12.0%	8.4%	3.7%	4.4%
Most of the time	0.5%	0.9%	0.5%	0.8%
Sometimes	2.9%	6.4%	4.5%	3.7%
Never	84.7%	83.3%	91.4%	91.1%
Don't Know	0%	1.0%	0.0%	0.0%
Rodents observed (last 6 months)	87.7 %	88.6%	85.8%	94.7%
SNNPR	n=460	n=449	n=443	n=438
Ever store food in sleeping room	68.0 %	63.2%	61.9%	63.8%
Cook in sleeping room				
Always	58.9 %	55.0%	54.7%	50.6%
Most of the time	2.5 %	2.2%	1.7%	4.6%
Sometimes	7.9 %	3.8%	4.5%	6.2%
Never	27.9 %	37.4%	39.1%	38.6%
Don't Know	2.7 %	1.5%	0.0%	0.0%
Rodents observed (last 6 months)	84.2 %	81.2%	85.5%	86.5%

Exposure to messages about LLIN use and care in the six months prior to each survey was low, less than 50% in all areas and years. Study participants living in Tigray reported the highest levels of exposure ranging from 41.9% at baseline to 49.4% at the 12-month survey. In Oromia, only 6% reported hearing messages regarding LLIN use and care at baseline. Although the percentage increased to 20.7% one year after net distribution, it fell again to 6.5% and 8.2% in years two and three. Amhara remained relatively consistent and low throughout the study, and SNNPR saw a decline from 38% at baseline to 6.7% at year three.

In all study sites, Health Extension Workers were the primary source of LLIN messaging. Health Development Armies and Health Facility workers were also reported to be a source of information. Other mechanisms such as mass media and religious leaders were either non-existent or extremely low.

Table 2: Exposure to messages on nets in the last six months in four study sites in Ethiopia, 2015-18

Variable and site	Baseline	12 months	24 months	36 months
Total	n=1837	n=1770	n=1689	n=1665
Any exposure about LLIN use and care 6 months prior to survey	24.6%	32.7%	18.5%	18.57%
Source of information	(n=470)	(n=582)	(n=346)	(n=311)
Health Extension Worker	75.5%	89.5%	79.9%	89.1%
Health Development Army	19.5%	17.8%	31.6%	14.6%
Radio Message	2.9%	5.9%	5.3%	7.6%
Radio Song	0.5%	0.6%	1.1%	0.3%
Drama performance	0.7%	0.0%	0.0%	0.0%
Health facility worker	21.1%	25.0%	22.6%	24.0%
Community leader	4.2%	3.8%	6.2%	3.8%
Town announcer	1.5%	1.0%	3.6%	0.8%
Pharmacy	0.0%	0.3%	1.0%	0.0%
Family or friends	4.5%	3.7%	10.1%	1.3%
Mosque or church	0.2%	0.1%	1.5%	0.2%
Newspaper or TV	1.0%	5.0%	7.2%	1.6%
Other	0.3%	0.1%	0.3%	0.3%
Tigray	n=459	n=449	n=411	n=402
Any exposure about LLIN use and care 6 months proper to survey	41.9%	49.4%	42.1%	47.2%
Source of information	(n=182)	(n=200)	(n=162)	(n=187)
Health Extension Worker	56.7%	77.1%	70.3%	85.9%
Health Development Army	32.5%	28.4%	48.6%	15.6%
Radio Message	5.0%	8.5%	7.3%	11.4%
Radio Song	0.5%	0.0%	1.4%	0.4%
Drama performance	1.1%	0.0%	0.0%	0.0%
Health facility worker	34.4%	49.2%	34.5%	29.6%
Community leader	1.9%	3.2%	6.9%	4.3%
Town announcer	3.7%	1.0%	3.6%	1.0%
Pharmacy	0.0%	0.8%	1.8%	0.0%
Family or friends	5.8%	6.9%	17.5%	2.2%
Mosque or church	0.0%	0..3%	2.9%	0.4%
Newspaper or TV	2.4%	13.4%	12.7%	2.7%
Other	0.0%	0.0%	0.6%	0.6%
Amhara	n=459	n=429	n=410	n=407
Any exposure about LLIN use and care 6 months proper to survey	17.6%	23.3%	14.1%	13.8%
Source of information	(n=69)	(n=96)	(n=66)	(n=55)
Health Extension Worker	91.8%	97.2%	84.2%	94.1%

Health Development Army	10.7%	17.3%	22.2%	17.0%
Radio Message	0.0%	0.9%	5.3%	3.7%
Radio Song	0.0%	0.0%	1.9%	0.0%
Drama performance	0.0%	0.0%	0.0%	0.0%
Health facility worker	16.0%	4.4%	15.8%	17.6%
Community leader	1.4%	1.9%	10.2%	0.7%
Town announcer	0.0%	2.4%	8.4%	1.0%
Pharmacy	0.0%	0.0%	0.0%	0.0%
Family or friends	10.3%	0.0%	2.3%	0.0%
Mosque or church	2.9%	0.0%	0.0%	0.0%
Newspaper or TV	0.0%	0.0%	0.0%	0.0%
Other	1.7%	0.0%	0.0%	0.0%
Oromia	n=459	n=443	n=425	n=418
Any exposure about LLIN use and care 6 months proper to survey	6.0%	20.7	6.5%	8.2%
Source of information	(n=32)	(n=97)	(n=27)	(n=34)
Health Extension Worker	86.4%	95.0%	94.0%	92.5%
Health Development Army	6.4%	8.1%	0.0%	12.4%
Radio Message	0.0%	3.8%	0.0%	0.0%
Radio Song	0.0%	0.0%	0.0%	0.0%
Drama performance	0.0%	0.0%	0.0%	0.0%
Health facility worker	16.2%	6.3%	9.6%	11.8%
Community leader	0.0%	7.2%	0.0%	4.4%
Town announcer	0.0%	1.1%	0.0%	0.0%
Pharmacy	0.0%	0.0%	0.0%	0.0%
Family or friends	0.0%	6.8%	0.0%	0.0%
Mosque or church	0.0%	0.0%	0.0%	0.0%
Newspaper or TV	0.0%	0.0%	5.9%	0.0%
Other	0.0%	0.0%	%	0.0%
SNNPR	n=460	n=449	n=443	n=438
Any exposure about LLIN use and care 6 months proper to survey	38%	40.4%	14.6%	6.7%
Source of information	(n=187)	(n=189)	(n=91)	(n=35)
Health Extension Worker	87.3%	97.2%	95.3%	94.9%
Health Development Army	11.0%	10.4%	10.2%	5.1%
Radio Message	2.3%	7.3%	2.3%	0.0%
Radio Song	0.8%	2.2%	0.0%	0.0%
Drama performance	0.8%	0.0%	0.0%	0.0%
Health facility worker	8.3%	1.9%	2.9%	16.7%
Community leader	9.6%	3.3%	2.9%	6.4%
Town announcer	0.0%	0.0%	0.0%	0.0%
Pharmacy	0.0%	0.0%	0.0%	0.0%
Family or friends	0.02%	0.0%	2.9%	0.0%
Mosque or church	0.0%	0.0%	0.0%	0.0%
Newspaper or TV	0.0%	0.7%	0.0%	0.0%
Other	0.0%	0.5%	0.0%	0.0%

All sample sizes “n” are unweighted.

In terms of the focus of messaging, promotion of the use of nets was reported most often in all regions. In all years a little more than half of the respondents have favorable attitude towards net care and repair.

Table 3: Recall of messages about net use, care and repair and attitude towards net care & repair in four study sites in Ethiopia, 2015-18

Variable and site	Baseline	12 months	24 months	36 months
Total	(n=470)	(n=582)	(n=346)	(n=311)
Recalled messages				
Use your nets	78.4%	86.7%	79.5%	86.9%
Care for your nets	56.6%	59.8%	56.5%	61.8%
Hang up your nets	72.8%	63.5%	62.0%	58.2%
Nets prevent malaria	41.6%	36.2%	19.9%	28.1%
Repair your nets	64.4%	53.8%	50%	54.4%
others	3.3%	12.3%	5.7%	13.1%
Ever discussed care and repair	19.1%	41.5%	34.4%	30.3%
Attitude towards net care and repair				
Mean	25.6	24.2	25.5	24.5
Unfavorable (% with score <mean)	46.4%	48.6%	39.3%	34.7%
Favorable (% with score >mean)	53.6%	51.4%	60.7%	65.3%
Tigray	n=459	n=449	n=411	n=402
Recalled messages				
Use your nets	90.6 %	85.2 %	74.4 %	93.8 %
Care for your nets	56.7 %	59.3 %	43.2 %	64.6%
Hang up your nets	75.9 %	61.4 %	62.4 %	61.4 %
Nets prevent malaria	43.6 %	26.9 %	10.4 %	24.8 %
Repair your nets	62.1 %	55.6 %	60.4%	65.7 %
others	0.6%	2.2 %	7.0 %	13.7 %
Ever discussed care and repair	25.2%	64.2%	52.2%	40.9%
Attitude towards net care and repair				
Mean	27.2	24.8	25.5	25.5
Unfavorable (% with score <mean)	30.8 %	47.5%	42.1%	37.3%
Favorable (% with score >mean)	69.2 %	52.4%	57.9%	62.7 %
Amhara	n=459	n=429	n=410	n=407
Recalled messages				
Use your nets	74.7 %	88.6 %	87.2 %	81.5 %
Care for your nets	76.3%	52.4 %	78.0 %	69.8 %
Hang up your nets	71.8 %	65.6 %	72.6 %	52.7 %
Nets prevent malaria	49.5 %	41.3 %	33.7 %	36.9 %
Repair your nets	70.2 %	56.2%	58.9 %	42.2 %
others	11.7 %	31.9 %	4.3 %	6.2 %
Ever discussed care and repair	18.3%	32.1%	31.7%	28.7%
Attitude towards net care and repair				

Mean	25.1	24.7	25.3	24.9
Unfavorable (% with score <mean)	49.4%	34.1%	37.1 %	39.7 %
Favorable (% with score >mean)	50.5%	65.9%	62.9 %	60.3 %
Oromia	n=459	n=443	n=425	n=418
Recalled messages				
Use your nets	46.5%	80.8 %	71.8 %	71.6 %
Care for your nets	62.0%	53.8 %	56.9 %	56.7 %
Hang up your nets	44.9%	60.2 %	67.4%	74.9 %
Nets prevent malaria	31.2 %	49.7 %	26.2 %	39.4 %
Repair your nets	37.2 %	38.9 %	19.0 %	37.9 %
others	0.0%	8.2 %	5.9 %	23.9%
Ever discussed care and repair	92.3%	26.9%	13.8%	24.9%
Attitude towards net care and repair				
Mean	24.6	23.1	25.7	22.9
Unfavorable (% with score <mean)	57.6 %	63.3%	44.5 %	43.6 %
Favorable (% with score >mean)	42.4 %	36.6%	55.5%	56.4 %
SNNPR	n=460	n=449	n=443	n=438
Recalled messages				
Use your nets	72.0%	91.0 %	89.6 %	72.5 %
Care for your nets	44.2%	69.4 %	70.7 %	30.4 %
Hang up your nets	75.2%	67.2 %	46.3 %	24.6 %
Nets prevent malaria	36.7 %	36.2%	22.8 %	14.4 %
Repair your nets	69.4 %	59.6%	30.5 %	26.3 %
others	2.5% %	14.8 %	3.3 %	9.4 %
Ever discussed care and repair	72.5%	47.2%	34.3%	27.8%
Attitude towards net care and repair				
Mean	25.8	24.6	25.6	23.8
Unfavorable (% with score <mean)	45.7%	48.1%	32.5%	15.6 %
Favorable (% with score >mean)	54.3%	51.8%	67.4 %	84.4 %

In all study sites, a considerable portion of the nets were stored and still in package at baseline but, as expected, the portion dropped considerably during the one-year follow-up. In Tigray, most nets were either not hanging but not stored or stored away unpacked, and in year three only 12.5% were hanging loose over the sleeping place. In Amhara, nets hanging over the sleeping place ranged from 51.6% at year one to 53.3% in year three, but nets that were not hanging and stored were also relatively high peaking at year two follow up (38.9%). Oromia had a similar pattern of around 50% of nets hanging over the bed. In SNNPR 49.6% and 51.4% of the nets were not hanging but not stored, respectively.

Detergent was the most common type of cleaning agent used for washing the nets in Tigray and Amhara, while in Oromia and SNNPR bar soap was used more commonly. Locations where nets were dried varied widely from region to region. In all, however, drying the net in direct sunshine was common.

Table 4**:** Handling of campaign nets in four study sites in Ethiopia, 2015-18

Variable and site	**Baseline**	**12 months**	**24 months**	**36 months**

Total (n)	(n=3397)	(n=2454)	(n=1557)	(n=555)
Place Net was found				
Hanging loose over sleeping place	27.6%	44.6%	36.6%	34.2%
Hanging and folded up or tied	1.8%	6.7%	4.9%	6.8%
Not hanging but not stored	8.1%	20.5%	41.8%	31.2%
Stored away unpacked	15.8%	20.4%	11.6%	23.7%
Stored away still in package	46.6%	7.9%	5.1%	4.0%
Net EVER washed	1.1%	50.6%	64.2%	72.4%
Median washed last 6 months	1	2	2	1
Type of detergent/soap used for wash				
Soap bar	52.1%	57.1%	53.2%	44.6%
Detergent	40.3%	41.3%	44.3%	52.1%
No detergent/soap used	7.6%	1.6%	2.1%	2.8%
Place net was dried				
Direct sunshine, outside on the ground	10.5%	8.0%	2.8%	4.2%
Under the shade, outside on the ground	34.0%	17.5%	5.8%	8.2%
Direct sunshine, outside on cloths line	51.1%	19.3%	32.8%	33.7%
Under the shade, outside on cloths line	4.3%	27.8%	20.7%	32.1%
Direct sunshine, outside on a bush or fence	0.0%	11.9%	19.3%	9.4%
Under the shade, outside on a bush or fence	0.0%	13.6%	15.2%	11.0%
Inside house	0.0%	1.9%	3.3%	1.3%
Tigray (n)	(n=886)	(n=724)	(n=508)	(n=257)
Place Net was found				
Hanging loose over sleeping place	15.9 %	27.6%	23.1%	12.5%
Hanging and folded up or tied	3.0 %	7.4%	4.2%	8.8%
Not hanging but not stored	2.7 %	12.8%	36.4%	26.5%
Stored away unpacked	25.7 %	39.7%	26.3%	45.3%
Stored away still in package	53.6 %	12.4%	10.0%	6.9%
Net EVER washed	0.7 %	31.4%	46.6%	64.4%
Median washed last 6 months	1	2	1	1
Type of detergent/soap used for wash				
Soap bar	0.0%	4.5%	8.3%	16.1%
Detergent	55.6%	92.5%	87.4%	76.1%
No detergent/soap used	44.4%	3.0%	4.3%	6.6%
Place net was dried				
Direct sunshine, outside on the ground	0.0%	8.8%	0.4%	7.3%
Under the shade, outside on the ground	64.6%	22.9%	4.4%	7.5%
Direct sunshine, outside on cloths line	35.4%	40.2%	46.9%	41.0%
Under the shade, outside on cloths line	0.0%	23.6%	23.7%	39.9%
Direct sunshine, outside bush or fence	0.0%	1.9%	11.3%	0.8%
Under the shade, outside bush or fence	0.0%	0.5%	6.1%	1.3%
Inside house	0.0%	2.2%	7.1%	2.0%
Amhara	(n=721)	(n=359)	(n=279)	(n=63)
Place Net was found				
Hanging loose over sleeping place	28.0 %	51.6%	46.2%	53.3%
Hanging and folded up or tied	0.4 %	5.9%	5.4%	1.7%
Not hanging but not stored	8.9 %	19.1%	38.9%	37.8%
Stored away unpacked	26.9%	15.6%	6.3%	3.5%
Stored away still in package	35.7%	7.6%	3.2%	3.5%

Net EVER washed	1.7%	58.2%	77.5%	88.3%
Median washed last 6 months	1	2	2	1
Type of detergent/soap used for wash				
Soap bar	18.2%	5.8%	18.2%	28.1%
Detergent	77.3%	92.9%	79.1%	71.9%
No detergent/soap used	4.5%	1.2%	2.7%	0.0%
Place net was dried				
Direct sunshine, outside on them ground	67.2%	7.3%	0.0%	0.0%
Under the shade, outside on the ground	32.3%	10.9%	0.7%	12.4%
Direct sunshine, outside on cloths line	48.7%	33.7%	50.4%	36.6%
Under the shade, outside on cloths line	12.3%	12.9%	8.3%	23.9%
Direct sunshine, outside bush or fence	0.0%	31.4%	24.1%	18.9%
Under the shade, outside bush or fence	0.0%	2.4%	9.9%	6.0%
Inside house	0.0%	1.4%	6.5%	2.2%
Oromia	(n=1046)	(n=798)	(n=527)	(n=142)
Place Net was found				
Hanging loose over sleeping place	22.8%	49.0%	41.8 %	56.6 %
Hanging and folded up or tied	0.1%	5.7%	43.2 %	6.3 %
Not hanging but not stored	1.8%	22.7%	44.9 %	25.9 %
Stored away unpacked	6.3%	14.9%	5.4 %	9.6 %
Stored away still in package	68.9%	7.7%	3.6 %	1.6 %
Net EVER washed	0.07%	46.5%	64.4%	68.6%
Median washed last 6 months	1	1	1	1
Type of detergent/soap used for wash				
Soap bar	100%	90.6%	88.4%	70.9%
Detergent	0.0%	7.4%	9.8%	29.1%
No detergent/soap used	0.0%	2.0%	10.9%	%
Place net was dried				
Direct sunshine, outside on them ground	0.0%	10.5%	2.7%	0.5%
Under the shade, outside on the ground	100%	26.6%	1.7%	76.4%
Direct sunshine, outside on cloths line	0.0%	5.3%	22.2%	30.6%
Under the shade, outside on cloths line	0.0%	28.0%	28.2%	34.6%
Direct sunshine, outside bush or fence	0.0%	8.2%	21.7%	11.8%
Under the shade, outside bush or fence	0.0%	18.5%	22.7%	14.9%
Inside house	0.0%	2.9%	0.7%	0.0%
SNNPR	(n=744)	(n=573)	(n=243)	(n=93)
Place Net was found				
Hanging loose over sleeping place	50.4%	54.9%	40.5%	38.6%
Hanging and folded up or tied	4.8%	7.8%	7.3%	5.7%
Not hanging but not stored	24.9%	28.2%	49.6%	51.4%
Stored away unpacked	8.3%	6.9%	2.4%	3.6%
Stored away still in package	11.5%	2.2%	0.4%	0.7%
Net EVER washed	2.7%	78.6%	85.9%	92%%
Median washed last 6 months	1	2	2	2
Type of detergent/soap used for wash				
Soap bar	84.9%	78.2%	82.4%	75.1%
Detergent	4.2%	21.2%	16.1%	23.7%
No detergent/soap used	10.7%	0.5%	1.5%	1.2%
Place net was dried				
Direct sunshine, outside on the ground	18.0%	5.3%	9.5%	6.8%
Under the shade, outside on the ground	20.1%	8.6%	22.2%	7.4%
Direct sunshine, outside on cloths line	61.8%	14.4%	15.4%	21.3%

Under the shade, outside on cloths line	0.0%	38.0%	16.6%	17.9%
Direct sunshine, outside bush or fence	0.0%	10.9%	18.7%	16.9%
Under the shade, outside bush or fence	0.0%	21.9%	17.5%	28.6%
Inside house	0.0%	0.9%	0.0%	1.1%

4.2 LLIN Utilization of

In all study sites, use of bed nets every night of the week prior to the administration of the survey questionnaire peaked one year after the nets were distributed. In Tigray, net use every night before the survey never reached 50%, with just 45.1% reported usage during the 12-month follow up visit. Use of bed nets the night before the survey was low at baseline, but this is not surprising since study participants had only recently received the nets and most of the nets were still in their packages. In SNNPR, the percentage of participants using nets the night before the survey dropped dramatically to 8.0%, which is the lowest rate reported for all regions if baseline is excluded. With that said, 72.3% of the SNNPR participants reported using nets every night of the same year so there is some inconsistency from respondents in the reported data from this region.

Table 5: Utilization of LLINs in four study sites in Ethiopia, 2015-18

Variable	Baseline	12 months	24 months	36 months
Total	(n=3403)	(n=2454)	(n=1557)	(n=555)
Number of nights net was used last week				
Every night (7 nights)	29.9%	51.2%	40.6%	36.6%
Most nights (5-6nights)	2.3%	4.5%	6.1%	5.2%
Some nights (1-4 nights)	7.3%	5.1%	5.7%	5.5%
Not used last week	4.1%	21.8%	37.7%	41.7%
Net never used at all	56.0%	17.1%	9.9%	10.8%
Unknown	0.4%	0.3%	40.6%	0.1%
Tigray	(n=886)	(n=724)	(n=508)	(n=257)
Number of nights net was used last week				
Every night (7 nights)	22.1%	30.5%	26.7%	26.7%
Most nights (5-6nights)	2.8%	2.3%	2.6%	2.6%
Some nights (1-4 nights)	1.5%	7.0%	3.0%	3.0%
Not used last week	9.5%	37.8%	50.4%	50.4%
Net never used at all	64.1%	22.3%	17.4%	17.4%
Unknown	0.3%	0.2%	0.0 %	0.0 %
Amhara	(n=721)	(n=359)	(n=279)	(n=63)
Number of nights net was used last week				
Every night (7 nights)	21.6%	53.3%	48.6%	48.6%
Most nights (5-6nights)	3.5%	9.6%	9.6%	9.6%
Some nights (1-4 nights)	9.2%	5.5%	5.9%	5.9%
Not used last week	6.5%	14.2%	30.6%	30.6%
Net never used at all	58.9%	17.4%	5.4%	5.4%
Unknown	0.07%	0.0%	0.0%	0.0 %
Oromia	(n=1046)	(n=798)	(n=527)	(n=142)
Number of nights net was used last week				
Every night (7 nights)	12.2%	51.5%	41.6%	41.6%
Most nights (5-6nights)	0.0%	4.3%	4.8%	4.8%
Some nights (1-4 nights)	9.9%	3.9%	6.7%	6.7%
Not used last week	1.6	20.6%	38.8%	38.8%

Net never used at all	76.4%	19.1%	8.2%	8.2%
Unknown	0.0%	0.6%	0.0 %	0.0 %
SNNPR	(n=744)	(n=573)	(n=243)	(n=93)
Number of nights net was used last week				
Every night (7 nights)	77.7%	77.7%	59.1%	72.3%
Most nights (5-6nights)	3.4%	4.6%	12.9%	59.1%
Some nights (1-4 nights)	4.3%	4.1%	9.4%	12.9%
Not used last week	0.5%	7.4%	14.9%	9.4%
Net never used at all	13.9%	6.1%	3.6%	14.9%
Unknown	0.0%	0.2%	0.0%%	0.0%

Tabel 6 presents the types of sleeping place in which nets were being used. In Tigray participants reported using nets with a finished bedframe while in all other regions a bedframe made of sticks were used commonly. In Tigray, 25.1% and 31.3% in years one and three respectively, individuals reported using the nets on the floor with no mattress, which is their sleeping place. Use of nets while sleeping on the floor and on grass were higher in SNNPR – at baseline, 47.0% used the nets while sleeping on grass.

Table 6: Types of sleeping place[1] for campaign nets used (Sleeping space categories among utilized bed nets N=every net – never used), in four study sites in Ethiopia, 2015-18

	Baseline	**12 months**	**24 months**	**36 months**
Total	(n=1510)	(n=1996)	(n=309)	(n=481)
Bed frame (finished)	15.9%	18.8%	21.5%	24.7%
Bed frame (sticks)	42.2%	40.3%	40.6%	41.6%
Foam mattress	2.8%	6.3%	3.6%	6.0%
Reed mattress	1.7%	5.4%	6.1%	4.2%
Grass mattress	22.6%	15.7%	8.0%	5.0%
Floor with no mattress	14.8%	13.5%	21.5%	18.5%
Tigray	(n=267)	(n=562)	(n=371)	(n=216)
Bed frame (finished)	31.5%	24.6%	31.8%	31.5%
Bed frame (sticks)	21.8%	23.5%	19.1%	21.8%
Foam mattress	7.4%	11.0%	4.3%	7.4%
Reed mat	3.7%	2.0%	0.3%	3.7%
Grass	3.2%	1.4%	1.1%	3.2%
Floor with no mattress	32.4%	37.5%	43.4%	32.4%
Amhara	(n=313)	(n=301)	(n=261)	(n=56)
Bed frame (finished)	14.3%	19.3%	18.0%	14.3%
Bed frame (sticks)	71.4%	68.8%	75.9%	71.4%
Foam mattress	5.4%	4.0%	0.0%	5.4%
Reed mat	0.0%	0.7%	0.0%	0.0%
Grass	3.6%	5.3%	1.5%	3.6%
Floor with no mattress	5.4%	2.0%	4.6%	5.4%
Oromia	(n=285)	(n=607)	(n=451)	(n=121)

Bed frame (finished)	22.3%	19.3%	16.4%	22.3%
Bed frame (sticks)	61.2%	46.0%	38.8%	61.2%
Foam mattress	5.0%	3.0%	4.9%	5.0%
Reed mat	2.5%	6.1%	13.7%	2.5%
Grass	2.5%	20.1%	11.8%	2.5%
Floor with no mattress	6.6%	5.6%	14.4%	6.6%
SNNPR	(n=645)	(n=526)	(n=226)	(n=88)
Bed frame (finished)	18.2%	12.0%	19.0%	18.2%
Bed frame (sticks)	44.3%	35.4%	38.5%	44.3%
Foam mattress	4.5%	6.3%	4.0%	4.5%
Reed mat	10.2%	11.0%	7.5%	10.2%
Grass	13.6%	31.7%	19.5%	13.6%
Floor with no mattress	9.1%	3.6%	11.5%	9.1%

[1]Sleeping space categories among utilized bed nets N=every net – never used

4.3 Durability of campaign nets

Durability of LLINs was measured using three parameters: attrition, physically integrity, and insecticidal activity.

4.3.1 Attrition rates

Overall attrition was 22.2% [95% CI: 20.8, 23.7], 39.1% [95: CI:37.4,40.7]and 71.8% [95% CI:70.3, 73.3] in the 12, 24 and 36 months of follow up, respectively (see *Figure 5* and Table 7).

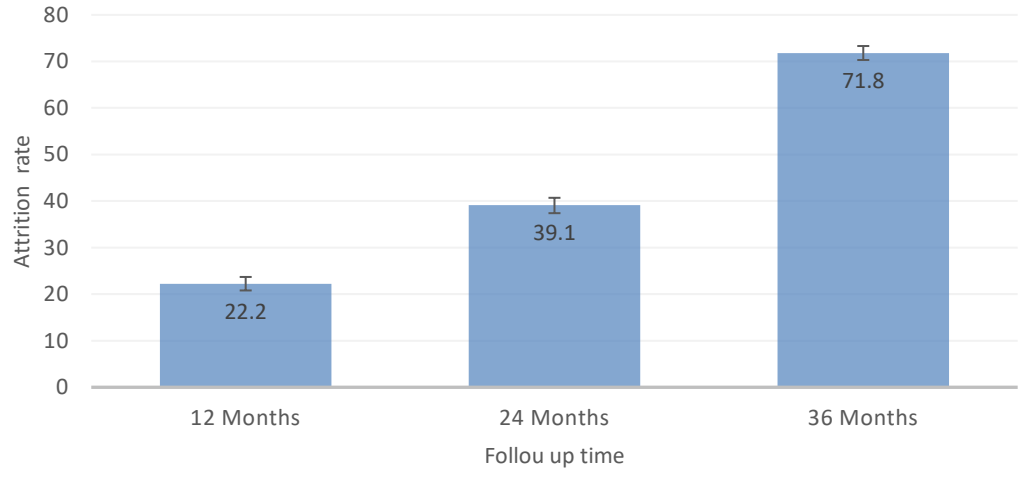

Figure 5: Attrition rates of campaign nets in four study sites in Ethiopia, 2015-18

The main cause of attrition, as reported by households, in general is physical damage in all follow up visits. There is variation between different study sites in the overall attrition rate and their causes. At baseline 889 LLINs were tagged for follow up in Tigray, out of which 108 (12.1%), 210 (23.6%) and 444 (49.9%) were missing by the 12, 24, and 36 months of follow up, respectively. In Amhara region

723 LLINs were tagged at baseline, of which 289 (40.0%), 387 (53.5%), 656 (90.7%) were missing by the 12, 24 and 36 months, respectively. In Oromia, of the 1,046 LLINs distributed at baseline, 215 (20.6%), 328 (31.4%), 768 (73.4%) were missing by 12, 24, and 36 months, respectively. In SNNPR, 745 LLINs were distributed at bassline and 144 (19.3%), 403 (54.1%) and 574 (77.0%) were missing by the 12, 24 and 36 months respectively.

The causes of attrition vary across time and study site. In Tigray the major type of attrition in the first year was removal (giving away the nets to another person), in the second and third years the major causes were physical damage of the LLINs. The same is true for Amhara, except the first year in which the main cause was repurposing. However, in Oromia and SNNPR the main type of attrition is physical damage at all follow up times. The overall contribution of repurposing by the end of the follow up period (36 months) is relatively small in all regions. It accounted for 13.3%, 17.2%, 3.3%, 10.2% attrition rate in Tigray, Amhara, Oromia and SNNPR regions, respectively.

Table 7: Attrition rates of campaign nets in four study sites in Ethiopia, 2015-18

Variable	**12 months f (%) [95% CI]**	**24 months f (%) [95% CI]**	**36 months f (%) [95% CI]**
Total (n=3403)			
All cause attrition rate	756 (22.2) [20.8, 23.7]	1328 (39.1) [37.4,40.7]	2444 (71.8) [70.3, 73.3]
Attrition rate-1 (Physical damage)	303 (8.9) [7.9, 9.9]	942 (27.7) [26.2, 29.2]	1910 (56.1) [54.4, 57.8]
Attrition rate-2 (removal)	237 (6.9%) [6.1, 7.9]	252 (7.4%) [6.5, 8.3]	162 (4.7%) [4.0, 5.5]
Attrition rate-3 (Re-purposed)	191 (5.6) [4.8, 6.4]	115 (3.4) [2.8, 4.0]	352 (10.3) [9.3, 11.4]
Unknown	25 (0.7) [0.5, 1.1]	19 (0.6) [0.3, 0.9]	20 (0.6) [0.1, 0.9]
Tigray (n=889)			
All cause attrition rate	108 (12.1) [10.1,14.5]	210 (23.6) [20.9, 26.6]	444 (49.9) [46.6, 53.3]
Attrition rate-1 (Physical damage)	31 (3.5) [2.4, 4.9]	119 (13.4) [11.2, 15.8]	260 (29.3) [26.3, 32.4]
Attrition rate-2 (removal)			
Removal responses	56 (6.3)	71 (8.0)	52 (5.7)
[95% CI]	[4.8, 8.1]	[6.3, 10.1]	[4.3, 7.5]
Attrition rate-3 (Re-purposed)	9 (1.0) [0.5, 1.9]	9 (1.0) [0.4, 1.9]	118 (13.3) [11.1, 15.7]
Unknown	12 (1.3) [0.7, 2.3]	11 (1.2) [0.6, 2.2]	15 (1.7) [0.9, 2.8]
Amhara (n=723)			
All cause attrition	289 (40.0)	387 (53.5)	656 (90.7)

	[36.4, 43.6]	[49.8, 57.2]	[88.4, 92.7]
Attrition rate-1 (Physical damage)	97 (13.4%) [11.0, 16.1]	274 (37.9) [34.3 41.5]	514 (71.1) [67.6, 74.4]
Attrition rate-2 (removal)	51 (7.1) [5.3, 9.2]	49 (6.8) [5.1, 8.9]	20 (2.8) [1.7, 4.2]
Attrition rate-3 (Re-purposed)	138 (19.1) [16.3, 22.1]	62 (8.6) [6.6, 10.9]	124 (17.2) [14.5, 20.1]
Unknown	3 (0.4) [0.1, 1.2]	2 (0.3) [0.03, 1.0]	0 (0) NA
Oromia (n=1046)			
All cause attrition rate	215 (20.6) [18.1, 23.1]	328 (31.4) [28.6, 34.3]	768 (73.4) [70.6, 76.1]
Attrition rate-1 (Physical damage)	115 (11.0) [9.2, 13.1]	212 (20.3) [17.9, 22.8]	681 (65.1) [62.1, 68.1]
Attrition rate-2 (removal)	83 (7.9) [6.4, 9.7]	75 (7.2) [5.7, 8.9]	50 (4.8) [3.6, 6.3]
Attrition rate-3 (Re-purposed)	13 (1.2) [0.7, 2.1]	36 (3.4) [2.4, 4.7]	34 (3.3) [2.3, 4.5]
Unknown	4 (0.2) [0.1, 1.0]	5 (0.5) [0.2, 1.1]	3 (0.3) [0.06, 0.8]
SNNPR (n=745)			
All cause attrition rate	144 (19.3) [16.6, 22.4]	403 (54.1) [50.4, 57.7]	574 (77.0) [73.8, 80.0]
Attrition rate-1 (Physical damage)	60 (8.1) [6.2, 10.3]	337 (45.2) [41.6, 48.9]	455 (61.1) [57.5, 64.6]
Attrition rate-2 (removal)	47 (6.3) [4.7, 8.3]	57 (7.6) [5.8, 9.8]	41 (5.5) [4.0, 7.4]
Attrition rate-3 (Re-purposed)	31 (4.2) [2.8, 5.9]	8 (1.1) [0.5, 2.1]	76 (10.2) [8.1, 12.6]
Unknown	6 (0.8) [0.3, 1.7]	1 (0.1) [0.003, 0.7]	2 (0.3) [0.03, 1.0]

Figure 6 below shows all cause attrition rates in the four study sites. By the end of the third year 49.9%, 73.4%, 76.9% and 90.7% LLINs in Tigray, Oromia, SNNPR and Amhara regions, respectively, were not in their original households due to different reasons.

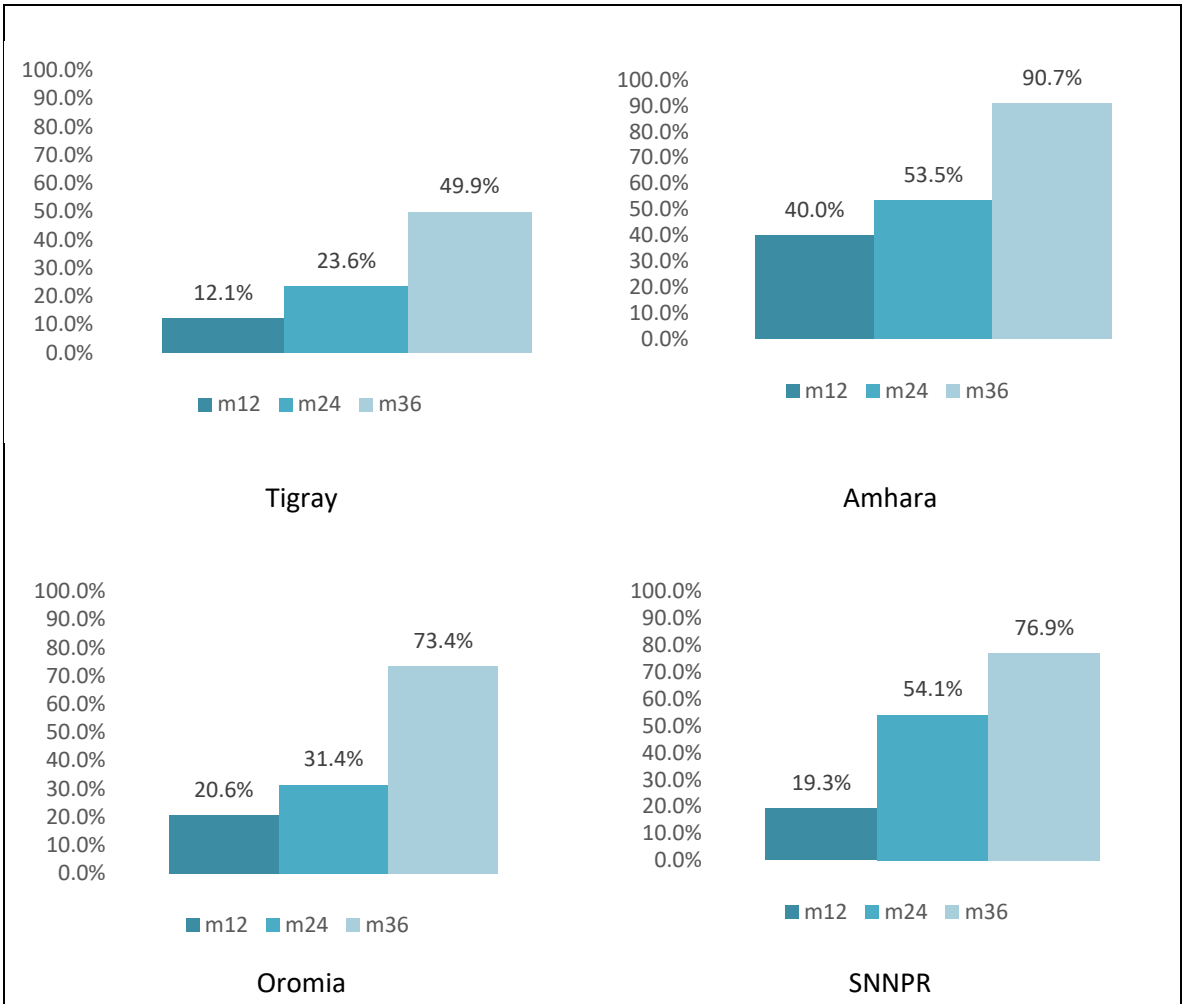

Figure 6: Trends in all cause attrition as a function of time since distribution in four study sites in Ethiopia, 2015-18

4.3.2 Physical integrity of surviving cohort nets

Physical integrity is the other component of LLIN durability measured. It refers to the physical intactness of the nets that survived at a given time. The physical integrity was not studied at baseline or year 0 with the assumption that all nets distributed have intact fabric. As expected, the percentage of LLINs that were torn increased year after year. And by the end of the 36 months 27. 4% [23.8, 31.2] of the available nets were torn. In Tigray the percentage of torn LLINs escalated from 1.5% to 25% between month 12 and 36, while in Amhara 9.2% and 34.9% of the available nets were torn in the first and third year after the distribution campaign. On the other hand, the percentage of LLINs with no holes deteriorated over time. By the 36 month this percentage was 58.8%, 25.4%, 35.2%, 19.4% in Tigray, Amhara, Oromia and SNNPR regions, respectively.

Table 8: Physical condition (integrity) of surviving cohort nets using pHI in the four study regions in Ethiopia, 2015-18

Variable	12 months	24 months	36 months
Total			
LLINs observed	2454	1557	555
Torn LLINs (pHI>642)			

Frequency	216	417	152
%	8.8%	26.8%	27.4%
[95% CI]	[7.7, 10.0]	[24.6, 29.0]	[23.8, 31.2]
LLINs with holes and serviceable condition (pHI: 64-642)			
Frequency	227	229	96
%	9.2%	14.7%	17.3%
[95% CI]	[8.2, 10.5]	[13.0, 16.6]	[14.4, 20.7]
LLINs with holes but in good condition (pHI<64)			
Frequency	244	183	71
%	9.9%	11.8%	12.8%
[95% CI]	[8.8, 11.2]	[10.2, 13.5]	[10.3, 15.8]
LLINs with no holes			
Frequency	1763	724	235
%	71.8%	46.5%	42.3%
[95% CI]	[70.0, 73.6]	[44.0, 50.0]	[38.2, 46.5]
Unknown Status[1]			
Frequency	4	4	1
%	0.2%	0.3%	0.2%
[95% CI]	[0.06, 0.4]	[0.1, 0.7]	[0.02, 1.3]
Tigray			
LLINs observed	742	508	257
Torn LLINs (pHI>642)			
Frequency	11	47	66
%	1.5%	9.3%	25.8%
[95% CI]	[0.8, 2.7]	[7.0, 12.1]	[20.7, 31.4]
LLINs with holes and serviceable condition (pHI: 64-642)			
Frequency	17	28	25
%	2.3%	5.5%	9.7%
[95% CI]	[1.5, 3.7]	[3.8, 7.9]	[6.6, 14.0]
LLINs with Holes and good condition (pHI<64)			
Frequency	23	30	14
%	3.2%	5.9%	5.4%
[95% CI]	[2.1, 4.7]	[4.2, 8.3]	[3.2, 9.0]
LLINs with no holes			
Frequency	672	402	151
%	92.8%	79.1%	58.8%
[95% CI]	[90.7, 94.5]	[75.4, 82.5]	[52.6, 64.6]
Unknown Status			
Frequency	1	1	1
%	0.1%	0.2%	0.4%
[95% CI]	[0.01, 1.0]	[0.03, 1.4]	[0.1, 2.7]
Amhara			
LLINs observed	359	279	63

Torn LLINs (pHI>642)			
Frequency	33	109	22
%	9.2%	39.1%	34.9%
[95% CI]	[6.6, 12.7]	[33.5, 44.9]	[24.0, 47.6]
LLINs with holes and serviceable condition (pHI: 64-642)			
Frequency	36	50	16
%	10.0%	17.9%	25.4%
[95% CI]	[7.3, 13.6]	[13.8, 22.9]	[16.0, 37.8]
LLINs with Holes and good condition (pHI<64)			
Frequency	39	35	9
%	10.8%	12.5%	14.3%
[95% CI]	[8.0, 14.5]	[9.1, 17.0]	[7.5, 25.5]
LLINs with no holes			
Frequency	251	83	16
%	69.9%	29.7%	25.4%
[95% CI]	[65.0, 74.5]	[24.7, 35.4]	[16.0, 37.8]
Unknown Status			
Frequency	0	2	0
%	0%	0.7%	0%
[95% CI]	NA	[0.2, 2.8]	NA
Oromia			
LLINs observed	798	527	142
Torn LLINs (pHI>642)			
Frequency	86	181	32
%	10.8%	34.3%	22.5%
[95% CI]	[8.8, 13.1]	[30.4, 38.5]	[16.4, 30.2]
LLINs with holes and serviceable condition (pHI: 64-642)			
Frequency	87	99	28
%	10.9%	18.8%	19.7%
[95% CI]	[8.9, 13.3]	[15.7, 22.4]	[13.9, 27.2]
LLINs with Holes and good condition (pHI<64)			
Frequency	129	88	32
%	16.2%	16.7%	22.5%
[95% CI]	[13.8, 18.9]	[13.7, 20.1]	[16.4, 30.2]
LLINs with no holes			
Frequency	493	158	50
%	61.8%	29.9%	35.2%
[95% CI]	[58.4, 65.1]	[26.2, 34.0]	[27.7, 43.5]
Unknown Status			
Frequency	3	1	0
%	0.4%	0.2%	0%
[95% CI]	[0.1, 1.1]	[0.03, 1.3]	NA
SNNPR			

LLINs observed	573	243	93
Torn LLINs (pHI>642)			
Frequency	86	80	32
%	15.0%	32.9%	34.4%
[95% CI]	[12.3, 18.2]	[27.3, 39.1]	[25.4, 44.7]
LLINs with holes and serviceable condition (pHI: 64-642)			
Frequency	87	52	27
%	15.2%	32.9%	29.0%
[95% CI]	[12.5, 18.4]	[27.3, 39.1]	[20.6, 39.2]
LLINs with Holes and good condition (pHI<64)			
Frequency	53	30	16
%	9.2%	21.4%	17.2%
[95% CI]	[7.1, 11.9]	[16.7, 27.0]	[10.7, 26.4]
LLINs with no holes			
Frequency	347	81	18
%	60.6%	12.3%	19.4%
[95% CI]	[56.5, 64.5]	[33.3, 27.7]	[12.5, 28.8]
Unknown Status			
Frequency	0	0	0
%	0%	0%	0%
[95% CI]	NA	NA	NA

LLIN was not neither reported as lost nor available for observation at the time of data collection.

4.3.2.1 Survivorship

Survivorship refers to the amount of nets available at a given time that are fit for use. In this study the numerator for survivorship considers the cohort of LLINs tagged for follow up and that were found at consecutive follow up times either with no holes, in good condition, or in serviceable condition. The denominator includes LLINs that were tagged at baseline and not given away to some other person. We excluded LLINs with unknown status both from the numerator and denominator of the calculation. Below is the formula we used to calculate survivorship.

$$\frac{(LLINs\ a\ viable\ with\ no\ hole\ +\ in\ good\ +\ in\ serviceable\ conduction) - unknown\ status}{(LLINs\ tagged\ for\ follow\ up - Given\ away) - unkown\ status}$$

Table 9 shows survivorship in four of the study sites across three years of follow up time. Overall, by the end of 36 months only 15.6% [14.2, 17.0] survived. This number ranged from 28.5% in Tigray to 13.8% in Oromia, 11.8% in SNNPR and 6.9% in Amhara.

Table 9: Nets surviving in serviceable condition in four study sites in Ethiopia, 2015-18

Variable	12 months	24 months	36 months
Total			
Survivorship in serviceable condition	1525	1136	402
%	48.6%	39.6%	15.6%
95% CI	[46.8, 50.3]	[37.8, 41.4]	[14.2, 17.0]
Tigray			

Survivorship in serviceable condition	712	460	190
%	86.7%	62.2%	28.3%
95% CI	[84.2, 89.0]	[58.6, 65.8]	[24.9, 31.8]
Amhara			
Survivorship in serviceable condition	326	168	41
%	48.7%	27.2%	6.9%
95% CI	[44.9, 52.6]	[23.7, 30.9]	[5.0, 9.2]
Oromia			
Survivorship in serviceable condition	709	345	110
%	73.9%	39.2%	13.8%
95% CI	[71.0, 76.7]	[36.0, 42.6]	[11.5, 16.4]
SNNPR			
Survivorship in serviceable condition	487	163	61
%	70.4%	25.7%	11.8%
95% CI	[66.8, 73.8]	[22.3, 29.3]	[9.1, 14.9]

Median survival time showed variation between study sites, the highest being in Tigray and the lowest in Amahara. The median survival time varies between 11 months in Amhara to 27 months in Tigray region. (it is 22 months in Oromia and 20 months in SNNPR).

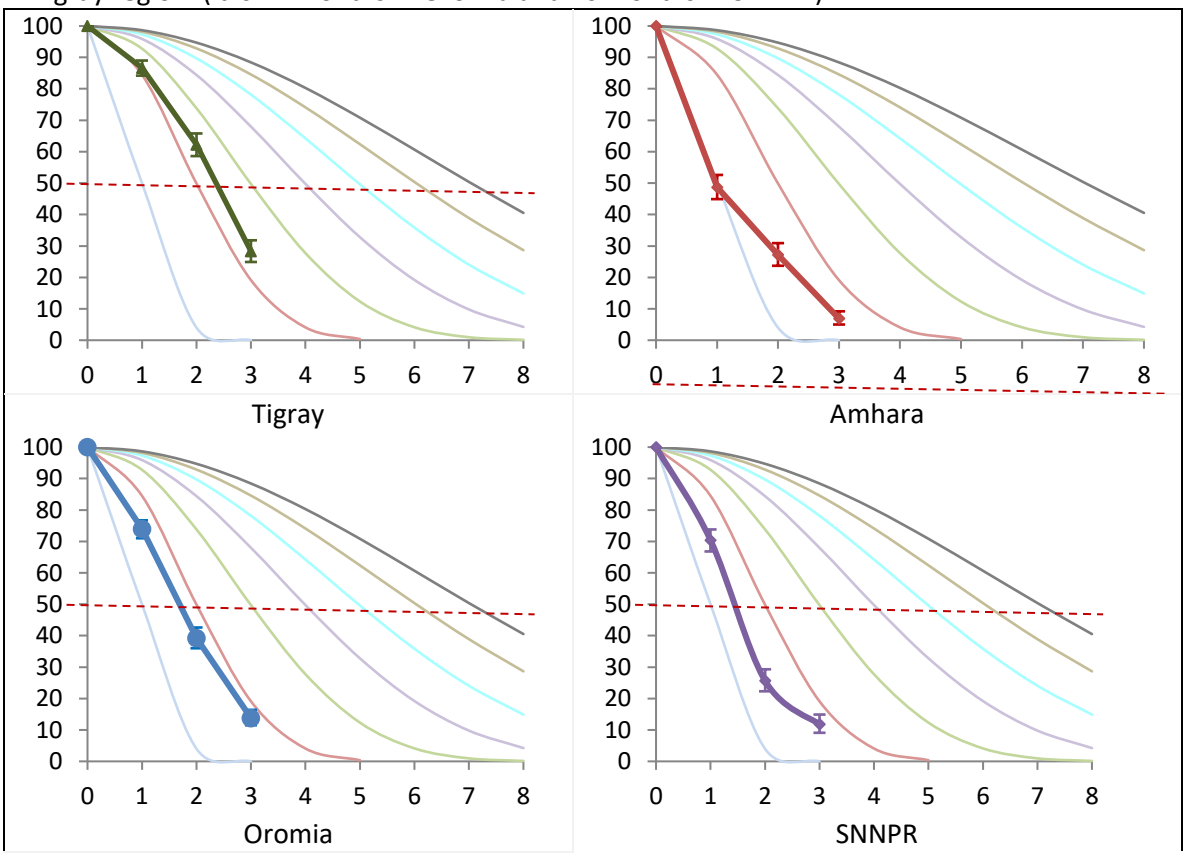

Figure 7: Estimated net survival in serviceable condition with 95% confidence intervals (error bars) plotted against hypothetical survival curves in fours study sites in Ethiopia, 2015-18

Table 10: Median survival time of LLINs in four study sites in Ethiopia, 2015-18

Regions	Median survival in months (95% CI)	
Tigray	27	(25.8, 28.4)
Oromia	22	(20.5, 22.6)
SNNPR	20	(19.0, 21.7)
Amhara	11	(8.9, 13.4)

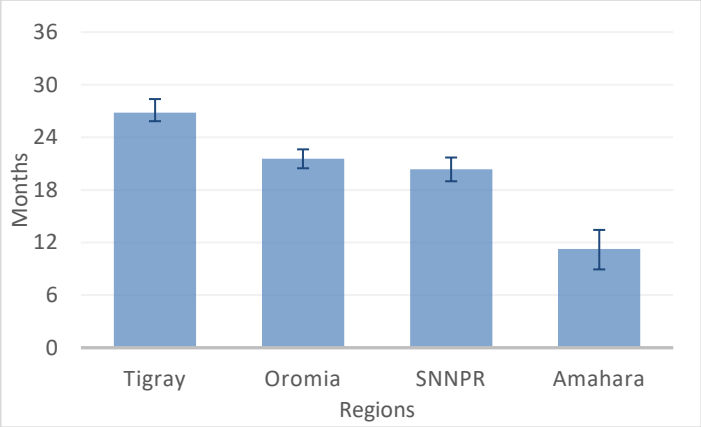

Figure 5: Median survival time of LLINs in four study sites in Ethiopia.

4.3.3 Bio efficacy of campaign nets

As per the WHOPES criteria LLINs were considered effective, if they result in >95% knockdown of the mosquitoes 1 hour after the test, or in >80% mortality 24 hours after the exposure. Accordingly, 92.4% of the LLINs meet the criteria of effectiveness 12 months after distribution however it was only 20.0% of the nets that fulfil the criteria by the 36 months. This reduction was observed across all study sites. The largest reduction was observed in Amhara study site where it deteriorates from 93.3% to 6.8% between 12 and 36 months after distribution.

Table 11: Proportion of long-lasting insecticidal nets meeting WHO pesticide evaluation scheme criteria effective (1-h knockdown ≥ 95% or 24-h mortality ≥ 80%) in Ethiopia, 2015-18

Variable	12 months	24 months	36 months
Total	n=97	n=64	n=105
Proportion and 95% CI of LLINs meeting WHO pesticide evaluation scheme criteria effective (1-h knockdown ≥ 95% or 24-h mortality ≥ 80%)	100% (na)	95.3% (86.4, 98.5)	19.0% (12.6, 27.7)

Tigray	n=26	n=25	n=25
Proportion of LLINs meeting WHO pesticide evaluation scheme criteria effective (1-h knockdown ≥ 95% or 24-h mortality ≥ 80%)	100% (na)	96.3% (75.9, 99.5)	32.0% (16.7, 52.5)
Amhara	n=28	N=11	n=29
Proportion of LLINs meeting WHO pesticide evaluation scheme criteria effective (1-h knockdown ≥ 95% or 24-h mortality ≥ 80%)	100% (na)	100% (na)	6.8% (1.7, 24.2)
Oromia	n=18	n=16	n=26
Proportion of LLINs meeting WHO pesticide evaluation scheme criteria effective (1-h knockdown ≥ 95% or 24-h mortality ≥ 80%)	100% (na)	87.5% (60.7, 96.9)	19.2% (8.1, 39.2)
SNNPR	n=25	n=12	n=25
Proportion of LLINs meeting WHO pesticide evaluation scheme criteria effective (1-h knockdown ≥ 95% or 24-h mortality ≥ 80%)	100% (na)	100% (na)	20% (8.4, 40.4)

4.3.4 Insecticidal chemical content of campaign nets

Table 12 presents the mean, standard deviation, 95% confidence interval and percentage of residual concentration of alpha cypermethrin content of MAGNet bed nets at baseline, and follow-up survey. At baseline we sampled 22 nets. The average concentration of Alpha-cypermethrin in these samples was 4.64g/kg with standard deviation of 0.58 which is within the WHO specification of 5.8 g/kg ± 25% (4.35 – 7.25) (20). In the survey we did 12 months after distribution the average concentration was 5.55g/kg, which is equivalent to 76.64% of the baseline concentration. The 47 nets we sampled and analyzed 24 months after distribution resulted average concertation of 3.84g/kg which is 82.87% of the baseline chemical content. Unexpectedly this concentration contains is higher than the samples collected in 12 months after distribution. Possible explanations are given in the discussion section. By the 36-month analysis of 36 nets resulted average content of 3.39g/kg, which is equivalent to 73.33% of the baseline. The average chemical content of the 12, 24, and 36 months is below the WHO specification.

Table 12: Insecticide (Alpha-cypermethrin) content of MAGNet® LLIN after 12, 24 and 36 months of campaign distribution in Ethiopia, 2019

	Baseline n=22	12 months n=62	24 months n=47	36 months n=58

Mean concentration of A.I.* in g/kg (Std. Dev.) (95% CI)	4.64 (0.58) (4.40, 4.88)	3.55 (1.12) (3.27, 3.83)	3.84 (0.95) (3.57, 4.11)	3.39 (1.43) (3.03, 3.77)
Percentage of residual A.I. from baseline	NA	76.64%	82.87%	73.33%
* Active ingredient				

The chemical (Deltamethrin) concentration of PermaNet 2.0® at baseline, and follow-up surveys is presented in table 13 below. At baseline we analyses 8 bed nets and found average chemical concentration of 1.91 g/kg (95%CI: 1.73, 2.06). This concentration is within the WHO specification for PermaNet 2.0® (21). The average chemical concentration of the 24 bed nets we sampled after twelve months of distribution resulted 0.78g/kg which is 41.07% of the baseline concentration. After 24 and 36 months of distribution we found average chemical concentration of 0.45g/kg and 0.47g/kg respectively. Unexpectedly the last year chemical concentration is slightly higher than the second year.

Table 13: Chemical (Deltamethrin) content of PermaNet 2.0® LLIN after 12, 24 and 36 months of campaign distribution in Ethiopia, 2019				
	Baseline n=8	12 months n=24	24 months n=14	36 months n=27
Mean concentration of A.I.* in g/kg (Std. Dev.) (95% CI)	1.91 (0.24) (1.73, 2.06)	0.78 (0.36) (0.63, 0.92)	0.45 (0.38) (0.25, 0.65)	0.47 (0.47) (0.31, 0.62)
Percentage of residual A.I. from baseline	NA	41.07%	23.86%	24.64%
* Active ingredient *Deltamethrin 55 mg/m2 (1.8 g/kg for netting in 75D; 1.4 g/kg for netting in 100D)				

5 Discussion

In this study we monitored attrition, physical integrity, survivorship, and insecticidal activity of LLINs in four study sites (Amhara, Oromia, Tigray and SNNP regions) of Ethiopia over three years. Our findings indicated that attrition of LLINs is more rapid than expected. The amount of missing LLINs accumulated from 22.2% [95% CI: 20.8, 23.7], to 39.1% [95% CI: 37.4,40.7] and 71.8% [95% CI: 70.3, 73.3] by the first, second and third years. The main (56.1% [95%CI: 54.4, 57.8]) cause of attrition is physical damage. The high level of attrition is worsened by physical damage of the remaining nets - 27.4%[95% CI: 23.8, 31.2] of the available nets were too torn (none functional) by the end third year. Due to this (rapid attrition rate and physical damage) only 15.6% [95% CI: 14.2,

17.0] of the LLINs survived in serviceable condition to the third year. This limited the median functional survival time to 11, 20, 22, and 27months in Amhara, SNNPR, Oromia and Tigray study sites as opposed to the expected third year. Farther more only 19.0% of the sampled LLINs meet WHO pesticide evaluation scheme criteria effective (1-h knockdown ≥ 95% or 24-h mortality ≥ 80%). The average chemical concentration of Alpha-cypermethrin content of MAGNet® bed nets was within WHO specification only at baseline.

We reported attrition rate of 71.8% by the end of the third year, majority (51.6%) of which was due to physical damage. Cross sectional study done in SNNPR estimated 31% of all nets owned in the previous three years had been discarded by owners, the majority of whom considered the nets too torn, old or dirty(10). Our estimation is higher than a study done in Zambia reported attrition rate of 40.3%. However, this study has shorter (30 months) of follow up time(22).

Our finding indicated that more than a quarter (27.4%) of the surviving nets were too torn by the end of the third year. This finding is comparable with another estimation of 23.1% after two years of follow up (9). It should also be noted that bed nets that are too torn still provide some level of protection by inhibiting blood feeding (23).

By the end of the third year only 15.6% of the LLINs were found in in serviceable condition. This number is bigger than the 4% estimation by Solomon et al that follows LLINs only for 24 months (9). The difference could be since our study was done in four study sites as opposed to the other study which was done in one study site. Ours might have included a wider range of cultural and behavioral factors that might positively affect LLIN durability. In addition, Solomon et al. monitored only one type of bed nets while in ours we monitored two types of nets.

In this study median survival time was found to be shorter than the expected three years in all study sites. Several other studies have reported shorter survival time of less than three years in Ethiopia(9), and other African countries (6,24–26). We also identified variation across study sites. Other studies have also reported variation across study sites(14,27). For example Kilian et al observed difference in durability of the same type of long-lasting insecticidal net between regions in Nigeria due to differences in household behavior and living conditions (14). We also conducted farther regression analysis of data using the second-year survey (data not presented), our finding indicated that LLINs owned by rural households are more likely to be damaged compared to those owned by urban households. In line with this most (68.34%) of the randomly selected EAs in Tigray were in urban settings while the percentage of urban EAs in Amahara was only 5.93%. This might be one of the possible explanations for the variation across study sites. Farther more there might be behavioral and living condition variation across study sites that might affect LLIN durability.

The average chemical concentration of Alpha-cypermethrin in MAGNet® nets was within the range of the WHO specification at baseline only. And the chemical content at the second year was bigger than the first year. It should be noted that all LLINs sampled for insecticidal activity assessment (bioassay testing and chemical analysis) were collected from households inside the enumeration areas selected for the study but not included in the durability monitoring cohort. The samples were

taken if the households obtain the LLIN from the 2015 campaign distribution. However, this doesn't affirm the utilization of the sample since they were obtained. Despite the effort of our data collectors to obtain LLINs that were being used, households might tend to give the "best" net they own to be sampled. On the other hand, some of the nets that were sampled were too torn and it was not possible to get enough sample for the chemical analysis. Hence the trend in residual chemical concentration over time might be affected by these factors. Farther more, detail information, such as housing condition and the factor affecting bioassay effectiveness was not collected from these households from which LLINs were sampled for bioassay testing. Hence it was not possible to assess the determinants of insecticidal activity.

There are important limitations that should be considered in interpreting the findings of this study. The aim of the study was to assess durability of LLINs in four study sites. Each of the regions were considered as separate sampling domain. And sample size was calculated with the objective of measuring attrition over time. Hence estimated durability indicators are neither national nor reginal level estimations. Similarly, sample size was not powered to make comparisons across studies sites or between the two brands of nets assessed. Hence comparison of indicators across regions and brands be interpreted carefully.

We assess bio-efficacy of LLINs using WHO bio cone assay only. However, as per the WHOPES manual, tunnel tests should have been done for those net that didn't meet WHO biological efficacy level. Hence in this study not fulfilling the WHO pesticide evaluation scheme criteria does not necessary interpret in to frailer to prevent mosquito bite in actual field settings.

There might be respondent bias due to the follow up nature of the study. Households might have given extra care for nets that are tagged for follow up. This might have resulted in over estimation of the true durability of LLINs.

6 Conclusion

We managed to trace back 96.4%, 91.9% and 90.0% of the households in the first, second and third years follow up surveys. The common identified reason for lower bed net physical durability includes storing food and cooking in sleeping rooms and rodent infestation. The magnitude of the risk varies across regional study sites. Exposure to messages about LLIN use and care is overall low with regional variations. Health extension workers are the main sources of information in all study sites. More than half of the respondents have favorable attitude towards net care and repair.

By the third-year survey, one third of the LLINs were found hanging loose over sleeping places, while four percent of the nets were found still in their packages. LLINs are mostly washed using, either bar-soap or detergent and they are dried in different locations including direct sunshine. Utilization of campaign nets is low. Less than half of the LLINs were used 7 nights in a week. Keeping some of the received LLINs while using the others is also common practice. Two out of five Bed nets are used in bad frame made of sticks.

All cause attrition rate is high (71.8%), with variation across regions. The largest (90.7%) attrition rate was observed in Amhara, while the lowest (49.9%) was in Tigray. Despite small regional and time variations physical damage is the main cause of attrition while the contribution of repurposing is relatively small across study sites and time. On top of high attrition rate, the physical integrity of the remaining nets was found to be poor. Out of the nets that made it all the way up to the 36 months, 27% of the nets were torn. After considering the effect of attrition and physical integrity, survivorship in serviceable condition is very low. Only 15.6% of the LLINs survived 36 months post distribution campaign. The highest survivorship (28.3%) was observed in Tigray region, while the lowest was in Amhara (6.9%).

In general, the median survival time is shorter than the expected 36 months, the longest being 27 months in Tigray and shortest 11 months in Amhara regions. Only 19.0% of the sampled LLINs meet WHO pesticide evaluation scheme criteria of effectiveness after 36 months of usage using.

8. Recommendation

Based on the findings of the study, the following recommendations are provided for the NMCP, community health workers, and researchers.

National Malaria Control Program

- The median survival time of the LLINs assessed was found to be shorter than the expected 36 months. Hence, our study suggests NMCEP consider shortening the period for distribution of campaign nets from 3 to 2 years.
- The contribution of physical damage for shorter survival time can be mitigated by teaching community about net care and repair, providing LLINs that have stronger fabric integrity.

Community health workers

- Improve coverage of standard LLIN behavioral change communication messages.
- Behavioral Change Communications should focus on net care and repair messaging in addition to the traditional utilization focused communication campaigns.

Researchers

- Further investigation of the factors for shorter duration using higher sample is highly recommended.
- Investigation of factor affecting insecticidal activity of nets is recommended.

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