Integrity, Use, and Care of Treated Mosquito Nets in Kirinyaga County, Kenya

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Abstract

**Background:** Vector control is an essential component in prevention and control of malaria in malaria endemic areas. Insecticide treated nets is one of the standard tools recommended for malaria vector control. The objective of the study was to determine physical integrity and insecticidal potency of long-lasting insecticidal nets (LLINs) used in control of malaria vector in Kirinyaga County, Kenya.

**Method:** The study targeted households on an area which had received LLINs during the mass net distribution in 2016 from ministry of health. A total of 394 households were sampled using systematic sampling method with a random start, where the household heads consented to participate in the study. A semi-structured questionnaire was administered to assess physical integrity, care and use. Chemical potency was analysed in the laboratory by use of gas chromatography mass spectroscopy (GC-MS). Data analysis was done using Statistical Package for Social Sciences (SPSS) version 19.

**Results:** After eighteen months of use, 97.8% (95% CI: 96.4% – 99.3%) of the distributed nets were still available. Regarding the net utilization, 93.7% of household heads reported sleeping under an LLIN the previous night. After physical examination, 47.9% (95% CI: 43% - 52.8%) of the bed nets had at least one hole. The median number of holes of any size was 2 [interquartile range (IQR) 1-4], and most holes were located on the lower part of the nets, [median 3 (IQR 2-5)]. Only 6.4% of the nets with holes had been repaired. The median concentration for alpha-cypermethrin was 7.15mg/m² (IQR 4.25-15.31) and 0.00mg/g (IQR 0.00-1.99) for permethrin. Based on pHI Chi-square test results shows that net physical status varied significantly with the manufacturer

There was no significant difference of chemical content between nets with different number of washes.

**Conclusion:** The current study results shows that more than three-quarters of the nets supplied had survived and had insecticidal potency which was adequate in vector control. According to WHO classification 14.2% of nets supplied were too torn and required immediate replacement. In addition, studies for validated methods are needed to better understand field evaluation of surface insecticidal content available to a mosquito after landing on a bed net to rest.

Background

In Africa, malaria continues to be a major public health burden. Effective interventions have been put in place to reduce the mortality of the disease, Malaria is responsible for extensive mortality and morbidity, especially of children and it drains the workforce and diverts resources needed for development of a country [1].

Malaria vector control is an essential component in prevention and elimination of malaria. One of the interventions recommended by the World Health Organisation to reduce malaria transmission in high risk
communities is prevention of mosquito bites. Insecticide Treated Nets (ITNs) have become an effective tool and their use has been intensified. Bed nets have been shown to reduce incidence of uncomplicated malaria cases by 50%, severe malaria by 45% and malaria mortality by 55% [2].

Nearly 28 million Kenyans live in areas of high malaria burden [3]. Investment in malaria control over the last five years has had a positive impact on the overall malaria related morbidity and mortality cases. The most successful investment on malaria control has been the distribution of long lasting insecticidal nets (LLIN) by the national malaria control program (NMCP) and other partners like centre for disease control (CDC). More than 74% of households in malaria endemic areas own ITNs among them being those which have been distributed free of cost.

However, there is little information about the actual utilization of the ITNs. There have been reports of net misuse in Kwale County, Kenya [5]. Nets which are intact act as physical barriers which prevent the vector from having contact with human and thus providing personal protection [4, 5]. A bed net offers personal protection provided it is in good physical condition [6].

In order to enhance protection from mosquito bite an insecticide is added to the net fibres [9].

Protection of bed nets diminishes with increased number of holes regardless of whether the net is treated or not [8]. Hence, follow up of nets used in the field is paramount to monitor the proportion of good quality nets. Most studies that have been carried in Kenya assessed physical state and bioefficacy of LLINs after distribution but none of the studies have been done in Kirinyaga County. In this context, the current study was conducted in Kirinyaga County, Kenya, where mass net distribution had been carried out and involved the due objectives of; assessing the chemical residue on the surface of the net that is available to the vector and assessing the physical condition, retention and utilization of the bed-nets.

**Methods**

**Study Area and Population**

The study area was Mwea West and Mwea East Sub Counties in Kirinyaga County of Central region of Kenya (0.6591° S, 37.3827° E), approximately 100 km North East of Nairobi at an altitude of about 1159m above sea level. Kirinyaga County has a population density of 246 persons per km$^2$ in a total area of 581km$^2$. The County is one of the areas with highest vector populations due to rice irrigations specifically in the Mwea region. Mwea East is predominantly rice growing whereas Mwea West’s main economic activity is horticulture (Fig. 1).

**Study Design**

The study adopted a cross-sectional household survey that took place between 30$^{th}$ April and 10$^{th}$ May 2018. The study targeted all the households where LLINs were distributed by the Ministry of Health in November 2016 during mass net campaign. The study was carried out in 27 villages in two sub Counties
namely Mwea East and Mwea West of Kirinyaga County, Kenya. The Kirinyaga County Public Health Office (PHO) was the entry point where the register of households that had received the nets was availed to the coordinator of this study.

The research adopted multistage sampling procedure. Stage one involved selection of two sub-counties namely Mwea East and Mwea West from the five sub counties of Kirinyaga County based on prevailing ecological setting. After proportionally allocating the number of Villages required per sub County, selection were done using the systematic random sampling.

**Figure 1: Study Area Map**

The final stage involved systematic selection of households at equal intervals and from a random start. A total number of 420 households (15 households from each village) were selected.

The inclusion criteria for the study were those nets which were distributed during mass net campaign of November 2016. Any other net found in the homestead and not a 2016 campaign net was excluded from the study.

The field team explained the survey objectives to the household heads before administration of the questionnaire. The field team comprised of researchers and community health workers. The community health workers had been trained on the questionnaire prior to the study. Training content included seeking informed consent, technique of sampling nets for chemical analysis and classification of hole size. A total of 420 household heads consented but 394 participated in the study. Written informed consent stating the purpose of the research was sought from the household heads. The questionnaire and physical inspection of LLINs were used to collect data.

The nets were removed from their hanging place and assessed outside the house for the presence of holes. Hole sizes were categorised into four groups; holes smaller than a thumb (0.5 - 2.0 cm), holes larger than a thumb but smaller than fist (2 - 10 cm), holes larger than a fist but smaller than a head (10 - 25 cm), holes larger than a head (>25 cm) [12].

**LLINs Physical Integrity**

Integrity of the nets was quantified as per WHO guidelines [12]. The area of each 'hole size' was calculated from an assumed diameter. Size one hole diameter; 1.25cm, size two hole diameter; 6cm, size three hole diameter; 17.5cm and size four hole diameter; 30cm, [11]. Proportionate hole index (pHI) for each net was calculated by adding the areas of all hole sizes present in a net [12].

**Chemical Residue Analysis**

A random sample of 80 nets was selected for further chemical analysis. From each side of the five sides of a net 30cm x 30cm piece was cut and the pieces for each net pooled together to ensure there was no
bias, wrapped in aluminium foil, labelled and stored in separate bags for transportation to Kenya Medical Research Institute (KEMRI) laboratories for storage before chemical analysis. Five new and unused LLINs from the same batch as the nets distributed were also provided by the PHO. These new nets were used to develop baseline data for chemical testing.

**Sample Preparation**

Mechanical extraction was used since only the surface concentration of the insecticide in the netting material is available to an alighting mosquito [13]. A 10 cm x 10 cm piece was cut from the 30 cm x 30 cm sample, weighed and the total mass recorded [14]. The samples was then cut into smaller pieces and introduced in a glass vial equipped with a tight stopper containing 5ml of analytical grade methanol. The insecticide was extracted from the net by ultra-sonicating at room temperature for 30 min [13]. The extract was filtered through a 0.45µm polytetrafluoroethylene (PTFE) syringe filter and appropriate dilution was made. Methanol was evaporated from the extract before reconstituting with hexane, to bring down the permethrin and α-cypermethrin concentrations within the concentration range of the standards, of between 20ppb and 500ppb.

**Standard Preparation**

All solvents used for the analysis were high performance liquid chromatography (HPLC) grade. Pesticide standards used were of 99.9 % purity. Working standards were prepared on day of analysis and stock solutions stored at 4°C at all times. Working standards were prepared from 20ppb to 500ppb. The limit of detection and limit of quantification for the instrument were also determined as part of method development.

**GC-MS Instrumentation**

A Shimadzu QP 2010-SE GC-MS coupled to an auto sampler was used for the analysis. Ultrapure Helium was used as the carrier gas at a flow rate of 1ml / minute. A BPX5 non polar column, 30m; 0.25 mm ID; 0.25 µm film thickness, was used for separation. The GC was programmed as follows: 50 °C (1 minute); 30°C/min to 300 °C. Only 1 µL of the sample was injected. Injection was done at 200 °C in split mode, with split ratio set to 10:1. The interface temperature was set at 280 °C. The EI ion source was set at 200 °C. Mass analysis was done in Single Ion Monitoring (SIM) mode at specific retention windows. SIM group ions for permethrin were 127, 163 and 183 m/z; with 183 m/z being the quantifier ion. The retention window for these ions was between 24 – 26 minutes. SIM group ions for α-cypermethrin were 127, 163 and 181; with 163 m/z being the quantifier ion. The retention window for these ions was between 26.5 – 28.5 minutes. To test the method suitability, extraction efficiency, repeatability, accuracy and limit of detection were determined before sample injection. All samples were analysed at the Jomo Kenyatta University of Agriculture and Technology (JKUAT) analytical chemistry laboratory. Limit of detection for the standards was determined.

**Data Analysis**
Data collected using questionnaire was entered into a Microsoft excel sheet before being exported to SPSS version 19. For continuous data, distribution characteristics were confirmed using Kolmogorov-Smirnov test and Exploratory Data Analysis (EDA). For continuous variables means, medians and standard deviations were calculated and for categorical data, proportions and 95% Confidence Intervals. Testing for difference between grouping variable categories was performed using Chi-square (for categorical data), Student T test or One-way analysis of variance (ANOVA) (for continuous normally distributed data) and Mann-Whitney U test or Kruskal Wallis test (for continuous skewed data) depending on number of grouping variable categories.

The number of holes in a net were used to calculate the proportionate hole index (pHI). Each hole was weighted by its size and summing them up for each net. WHO formula for pHI was used; 

\[
pHI = \left( \frac{\text{area}}{1.23} \times \text{no. of size-1 holes} \right) + \left( \frac{\text{area}}{1.23} \times \text{no. of size-2 holes} \right) + \left( \frac{\text{area}}{1.23} \times \text{no. of size-3 holes} \right) + \left( \frac{\text{area}}{1.23} \times \text{no. of size-4 holes} \right)
\]

The area for each sample was calculated on the assumption that the holes are circular and the diameter is equal to the midpoint in each hole size category. A net with pHI of 0 - 64 is a good net, a net with pHI of between 65 and 642 is a damaged net and a net with a pHI ≥ 643 is a net which is too torn [12].

The pooled pieces of net samples were used for chemical analysis to determine the amount of insecticide available on the surface.

**Ethical Approval**

Approval for this study was sought from the Kenya Medical Research Institute (KEMRI) Scientific and Ethics Review Unit (SERU), approval reference number KEMRI/SERU/CTMDR/037/3374.

**Results**

**Household Demographic**

Table 1 shows the characteristics of households in Mwea East and Mwea West of Kirinyaga County. Of all the 420 household heads who consented to participate in the study, 298 (71%) were females and 122 (29%) were male (Table 1). The median age of respondents was 40 years (IQR 30 - 51) years and ranged from 17 to 90 years. Nearly 36% of them had no formal education or educated up to primary school level.

**Table 1: Household Demography**
| Characteristics         | Number | Percent |
|------------------------|--------|---------|
| Total number of households | 420    | 100     |
| Gender of respondent   |        |         |
| Male                   | 122    | 29.0    |
| Female                 | 298    | 71.0    |
| Level of Education     |        |         |
| No education           | 23     | 5.5     |
| Below class 8          | 128    | 30.5    |
| Above class 8          | 109    | 26      |
| Secondary education    | 107    | 25      |
| College                | 24     | 5.7     |

**Bed Net Utilisation**

Of the sampled households, 97.6% (CI: 96.4% – 99.3%) of the nets distributed in November 2016 were still present (Table 2). The proportion of nets that were in use the night prior to survey day was 91.2%, and on visual observations all the nets were hanged over the bed during the survey. Of the nets present, 8.0% (n = 34) had not been used the night prior to the survey. Out of those nets that were not in use, 3.1% (13) were new and still in their original package. 2.1% (9) of the nets had been given out to family members, 1.2% (4) of the nets owners had forgotten to hang, 1% (4) had been used for other purposes (misused), while another 1% was reported to have been too torn for use.

**Table 2: Physical Presence of the Net**
| Characteristics                  | Frequency | Percent |
|----------------------------------|-----------|---------|
| Is the net still present?        |           |         |
| Yes                              | 410       | 97.6    |
| No                               | 10        | 2.3     |
| Was the net in use last night?   |           |         |
| Yes                              | 373       | 91.2    |
| No                               | 34        | 8.0     |
| Manufacturer's name              |           |         |
| Manufacturer A                   | 294       | 70.0    |
| Manufacturer B                   | 94        | 22.4    |
| Manufacturer C                   | 26        | 6.2     |
| Is the net intact?               |           |         |
| Yes                              | 206       | 49.0    |
| No                               | 191       | 45.5    |

**Physical Integrity**

Almost half of the nets in the study area 47.9% (95% CI: 43% - 52.8%) had at least one hole. More than 85% (n = 704 out of 820) of the holes in nets were located on the lower parts [median 3 (IQR 2-5)]. The four sizes of holes (1, 2, 3 and 4) were present in the nets, of which size two were the most common, at 29%. The median number of holes of any size was 2 [inter-quartile range (IQR) 1-4] (Table 3). Only 6.4% of the nets with holes had been repaired.

A minimum of one hole and a maximum of 18 holes were counted in a net. Reasons for net damage varied from continuous use (91.3%), open wood fire (4.1%), candle burn (0.5%), cigarette burn (0.5%), hanging challenges (2.1%) to rodent damage at 1.5% (Fig. 2).

**Figure 2: Reasons given as to why the net was damaged**

**Table 3: LLIN Characteristics Median and Inter-quartile Range (IQR 25-75)**
| Bed Net Parameters | Total | Median | IQR\(^1\) | Total hole area (cm\(^2\)) | Total hole area quartiles |
|--------------------|-------|--------|-----------|----------------------------|-------------------------|
| No. of size one holes | 239   | 2.00   | 1.00 – 3.00 | 282                        | 0.00 – 1.23             |
| No. of size two holes | 259   | 2.00   | 1.00 – 4.00 | 88                         | 28.28 – 1132.12         |
| No. of size three holes | 168   | 2.00   | 1.00 – 4.00 | 61                         | 240.56 – 962.24         |
| No. of size four holes | 154   | 2.00   | 1.00 – 4.00 | 60                         | 706.95 – 2827.80        |
| Location of hole |        |        |           |                            |                         |
| upper part of net | 115    | 3.00   | 2.00 – 5.00 |                            |                         |
| lower part of net | 704    | 3.00   | 1.00 – 5.00 |                            |                         |

\(^1\) inter-quartile range

Of the total nets present, 276 were from manufacturer A, 84 and 26 nets from manufacturers B and C respectively. Six of the nets had their label washed off and thus the manufacturer could not have been identified.

Of the total nets with holes, when grouped by the manufacturer, 42% were from manufacturer A, 56% from manufacturer B, and 81% from manufacturer C.

“Good” and “damaged” nets were further categorised as serviceable nets. Manufacturer A had the highest proportion of serviceable nets at 88.7% (n = 246 out of 294), manufacturer B 80% (n = 71 out of 94), manufacturer C had the highest proportion of nets with holes recorded and also the lowest proportion of serviceable nets at 61% (n = 17 out of 26) (Fig. 3). From the three manufacturers 85.8% (95% CI: 82.3% - 89.2%) of the nets was the proportion of “serviceable” nets after eighteen months of continuous use in the study area. pHI ranged from 0 to 6480. When nets were categorised according to pHI Chi-square test results shows that the pHI varied significantly with the manufacturer.

**Figure 3: Net Category by pHI**

Up to 85% of the nets under routine use, and had holes, had not been repaired. For those repaired the mode of repair was; tying a knot (3.3%), and hand sewing (3.1%).

When the baseline concentration of the pyrethroid in the nets was compared, the median surface concentration for α-cypermethrin treated nets was 39.4mg/m\(^2\) (IQR 39.15 – 42.10) and 6.98 mg/g (IQR
0.10 – 17.02) for permethrin treated nets. For the used nets the median for α-cypermethrin and permethrin treated nets was 7.1 mg/m² (IQR 4.25–15.13) and 0.00 mg/g (IQR 0.00–1.99) respectively (Table 4). Pyrethroid content differed significantly from one net (washed) to the other with some of the nets having undetectable insecticidal content.

When pyrethroid content in a net for both permethrin and α-cypermethrin was compared to the number of washes a net had undergone, the difference was not significant for α-cypermethrin treated nets and for permethrin treated nets.

Table 4: Median and Inter-quartile Range (IQR 25-75) of Active Ingredients in Baseline and Washed Nets

| Active ingredients | N¹ | Median | IQR² |
|--------------------|----|--------|------|
| Baseline nets      |    |        |      |
| permethrin         | 20 | 6.98   | 0.10 – 17.02 |
| α-cypermethrin     | 5  | 39.400 | 39.15 – 42.10 |
| Washed nets        |    |        |      |
| permethrin         | 40 | 0.00   | 0.00 – 1.99 |
| α-cypermethrin     | 40 | 7.15   | 4.25 – 15.31 |

¹Number of nets, ²Interquartile range

Discussion

This study assessed the physical integrity and insecticidal residue of bed nets distributed in two sub Counties of Kirinyaga County, Kenya eighteen months after mass distribution campaign of 2016. Additionally, the use and care for bed nets was evaluated. This study is novel because no other study has assessed care, use and chemical residue of nets in Kirinyaga County which is one of the endemic areas in Kenya mostly due to rice farming.

Net usage was high in the two sub counties of Kirinyaga County at 97.9% of the respondent reporting to have used the net the previous night. This is in line with earlier report of high net utilisation [31, 16]. This high rate of net usage has been found to decrease as the nets get older and the number of holes increases [5, 20]. The high net utilization in the study area has led to speedy drop of malaria incidences in Kirinyaga County, where health facilities have reported a zero positive malaria case for a period of one year, according to unpublished report by department of health Kirinyaga County. This high net utilization is an indicator that people have accepted use of free nets [18, 19] in compliance to the guidelines issued during distribution. This high net usage could be due to round the year larva development, facilitated by rice irrigation farms.

The percentage of nets with at least one hole in this study was 47.9% after 18 months of use, and 1% of those with holes were too torn to offer personal protection. This small proportion of nets unable to offer
personal protection changed when the nets surveyed were classified according to WHO criteria of serviceable and too torn nets. The results showed that 14.2 % of the nets were too torn. This is unlike what it had been shown in Uganda where considerable physical net damage (48-78% of nets) had occurred within one year of bed net use [21, 22]. This low percentage of torn nets in the current study could be accredited to the sensitization campaign carried out by the National Malaria Control Program (NMCP) through the Ministry of Health, on use, care and maintenance of bed nets, carried prior to net distribution [20, 10]. Education information campaign on net maintenance was seen to improve on net care and proper use as reported by Spencer et al. after a pre-distribution education campaign in South West Uganda [22].

Majority of the holes were found on the lower part of the net, with all the sides having almost the same proportions of holes. The main cause of holes on the lower side as reported was due to continuous tucking under the mattress and often, the net getting caught by rough edges. House environment (type of building material), and general handling contribute to bed net deterioration [20]. The uniform rate of deterioration on all the sides of bed nets in this study shows that the social economic status of the population is relatively the same. Deterioration of bed nets have been shown to be higher in poorer communities [4].

More than half of nets (85%), with at least one hole had not been repaired, as was the case in an Ethiopian study where very few households had repaired their nets [21]. When participants were asked why they had not repaired their nets, they reported not to know that a net needed repair. A net becomes less protective with increased number of holes even when treated with an insecticide [5].

The current study results shows that 81.7% of the nets supplied had survived, and serviceable according to WHO criteria which is encouraging after eighteen months of use. The only cause of net loss in the study area was due to net being given away to family members living far away [12]. The combination of insecticidal potency and the good physical condition demonstrates nets effectiveness in providing personal protection.

Nets were further categorised as “serviceable” and “too torn” nets (bed nets which requires immediate replacement) [12]. Classification of nets as serviceable (good and damaged nets) was arrived at using the pHl, shows that nets can inhibit mosquito bite even when they are in “damaged” status. This could be attributed partly to the repellent effect of the pyrethroid incorporated or coated in the nets [20].

The statistical difference between net deterioration and the manufacturer points underlying factors associated with defects during manufacturing.

In the current study, 3.1% of the nets were found in their original package. When owners were asked what they had been using, they reported to have been using nets given during the previous mass net distribution of 2011. This excess ownership of bed nets was also found by Githinji et al. in a study conducted in Western Kenya where more than half (63%) of the nets in their original package were provided during free mass net campaign [15]. Free mass net distribution campaign of 2006 made Kenya
the country with highest number of net distributed at that time in Africa [23]. Sambe and others [4] reported that net owners keep excess nets in order to replace, once the existing nets in use become old.

1% of the nets in the current had been used for other purposes (mis-used) rather than protection. Higher rates of net mis-use had been reported by Mutuku et. al. in Kwale County, Kenya, where up to 21% of distributed nets had been mis-used [5, 23 and 24].

Social economic status of the community was not assessed, but majority of the houses visited were constructed either by wood or earth walled with planks. House material is a major contributor to the rate of net deterioration. This could possibly explain the cause of holes found on the upper part of the nets, explained as challenges faced during hanging. The net ability to offer protection from mosquito bite could have been compromised if the number of holes on the upper part of the net was big; since it has been shown that mosquitoes are more likely to enter bed nets from the upper part of bed net [32].

A safety measure considered during bed net manufacture is ensuring that if a spark lands on a net the burn should not exceed a few centimetres [6]. This could possibly explain why the holes caused by fire burn, were all size one holes.

Baseline concentration of the insecticide in the nets had a median surface concentration of; for α-cypermethrin treated nets 39.40 mg/m² (IQR 39.15 – 42.10) and 6.98 mg/g (IQR 0.97 – 17.02) for permethrin treated nets (Table 4).

Different sides of a baseline nets had different amount of the pyrethroid. There was non-uniformity with any of the sides’ in different baseline nets. This could be attributed to a problem in the manufacturing process. During manufacture cooling and stretching of the polymer segregates permethrin to the fibre surface [25]. This could be responsible of low initial surface concentration in some parts of the net. This low surface concentration on the surface fibres of a net has also been reported [25, 30].

Insecticide content had decreased to 81.85% of the baseline concentration in α-cypermethrin treated nets. Some of the factors associated with insecticide decrease in a net are washing (and before complete regeneration occurs) and abrasion. The study did not assess the last time the nets were washed, but some of the nets were found drying after a wash on the survey date. This could have been a cause of low surface concentration in some of the nets; and in any event that the sampled net was less than two weeks since it was last washed. A complete regeneration of insecticide in a treated net from the sub surface of the fibres to the surface fibres requires approximately two weeks at 30 after washing [28].

Abrasion also lowers insecticidal concentration on the surface of a net [13]. This is likely to happen when tacking the net or when the net is being rolled up in the morning [7]. The findings on the net chemical residue are in line with most programmes where a net insecticidal activity last for at least three years. In a phase III evaluation study of LLINs, it was found that concentration as low as 1.3 mg/m² of α-cypermethrin remaining in a net (from an initial concentration of 40mg/m²) is effective in killing mosquitoes [26].
Analysis of variance showed that a net chemical content is relatively the same for nets with different number of washes. A washed net would protect an individual just like an unwashed net. Every time a net is washed it loses some of its insecticidal content on the surface fibres, but a replacement of the washed insecticide from the sub-surface to the surface fibres occurs which makes a bed net to be effective throughout its life span of 3 years [27].

The study did not capture the “last time” the net was washed which is a potential limiting factor because we could not ascertain whether complete regeneration had occurred prior to analysis. Secondly due to lack of a validated data on the expected initial surface concentration of a baseline net we were not able to quantify the rate of loss after a net has been washed.

**Conclusion**

This study is the first to report on the performance of nets under operational conditions in Kirinyaga County, Kenya by checking the physical integrity, use and the insecticidal efficacy of nets post distribution. The current study results shows that more than three-quarters of the nets supplied had survived and had insecticidal potency. 14.2% of nets supplied were too torn and required immediate replacement. In addition studies for validated methods are needed to better understand field evaluation of surface insecticidal content available to a mosquito after landing on a bed net to rest.

**Abbreviations**

ANOVA: analysis of variance; **CDC**: Centre for Disease Control; **CI**: Confidence Interval; **CTMDR**: Centre for Traditional Medicine and Drug research; **EDA**: Exploratory Data Analysis; **EI**: Electron Ionisation; **GC**: Gas Chromatography; **GC-MS**: Gas Chromatography Mass Spectrometer; **HPLC**: High-Performance Liquid Chromatography; **ID**: Internal Diameter; **IQR**: Inter-Quartile Range; **ITNs**: Insecticides Treated Nets; **JKUAT**: Jomo Kenyatta University of Agriculture and Technology; **KEMRI**: Kenya Medical Research Institute; **LLINs**: Long Lasting Insecticides Nets; **NMCP**: National Malaria Control Program; **pHI**: Proportionate Hole Index; **PHO**: Public Health Office; **PTFE**: Polytetrafluoroethylene; **SIM**: Single Ion Monitoring; **SPSS**: Statistical Package for Social Sciences; **WHO**: World Health Organization.

**Declarations**

**Ethical Approval**

Approval for this study was sought from the Kenya Medical Research Institute (KEMRI) Scientific and Ethics Review Unit (SERU), approval reference number KEMRI/SERU/CTMDR/037/3374.

**Ethics Approval and Consent to Participate**
Approval and consent to participate in the study was granted by the Kenya Medical Research Institute (KEMRI) Scientific and Ethics Review Unit (SERU). The SERU committee approval reference number is KEMRI/SERU/CTMDR/037/3374.

Consent for Publication:

Not applicable.

Availability of Data and Materials:

Not applicable.

Competing Interest:

The authors declare that they have no competing interests.

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Authors’ Contribution

JG, EM, BI designed the study. JG led the project team in the field. EM, RN, MN contributed to the design and implementation in the field and assured data quality. MN, AG and MM were responsible for the chemical analysis results. MN, EM, BI and LK contributed to the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Study Area Map
Figure 2

Reasons given as to why the net was damaged
Figure 3

Net Category by pH

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