

# Use of Standard and Next-Generation Insecticide-Treated Nets by Populations in Southern Benin

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## Abstract

Malaria remains a major public health concern in Benin, where long-lasting insecticidal nets (LLINs) constitute the primary vector control strategy. However, the effectiveness of LLINs depends not only on coverage but also on their actual use, which is often overestimated by self-reported measures. This study aimed to generate more accurate estimates of LLIN utilization and to compare usage patterns between standard and next-generation LLINs distributed during the 2023 nationwide campaign. A total of 200 households per commune were randomly selected across seven communes. ITN utilization was assessed through (i) a strict definition, considering only LLINs observed hanging above a sleeping space, and (ii) an extended definition, including LLINs that were hanging, placed on the bed, or positioned immediately beside the bed, whose use was confirmed by the household head. Data were collected using Open Data Kit (ODK). For 5% absolute precision and 95% confidence, at least 246 nets per commune were evaluated. Overall, 1,762 nets were observed, including Interceptor G2 (44.83%), PermaNet 3.0 (13.62%), Yorkool (40.63%), Yahe

(0.68%), and Olyset Plus (0.22%). Four months after distribution, 96.39% of 2023 campaign nets remained present in households. Coverage reached 38.69% for 2023-distributed nets and 51.24% overall, corresponding approximately to one net for two people. Five of the seven communes met the target of one net per two persons. An observed minimum utilization rate of 80% was recorded, meeting WHO recommendations. Declared individual use was very high (95.72%) but overestimated actual use compared to field observations. Observational assessment (nets hung, on or beside beds) provided more realistic estimates than self-reported declarations. Utilization of next-generation nets (72.40%) was substantially higher than that of standard nets (50.98%). In conclusion, four months post-distribution, net retention and coverage were high, and WHO-recommended utilization thresholds were achieved. Direct observation remains a more reliable method for estimating actual LLIN use. Next-generation nets demonstrated significantly higher community utilization than standard LLINs.

## Keywords

Malaria, *Anopheles gambiae* s.l. Pyrethroids, Chlorfenapyr, Mosquito Nets

## 1. Introduction

Malaria remains a major public health problem in Africa [1], and particularly in Benin, with a prevalence of infection in the general population ranging from 11% to 51% depending on the region, and a particularly heavy burden among children under 5 years of age [2]. According to [3]–[5], malaria control interventions contributed to a 40% reduction in malaria incidence in Africa between 2000 and 2015, with insecticide-treated nets (ITNs) being the factor that contributed most to this reduction (68% of cases averted) [6] [7]. This explains why nationally distributed ITNs every three years form the main pillar on which Benin's National Malaria Control Program (PNLP) relies to protect the population against malaria vectors [8].

During the most recent nationwide campaign conducted in 2023, multiple types of LLINs were distributed, including standard pyrethroid-only nets (e.g., PermaNet® 2.0, Yorkool®, Yahe®), piperonyl butoxide (PBO)-treated nets (e.g., Olyset Plus®, PermaNet® 3.0), and dual-active ingredient nets such as Interceptor® G2. These next-generation LLINs have been specifically developed to address the widespread and increasing resistance of malaria vectors, particularly *Anopheles gambiae* sensu lato and *Anopheles funestus* sensu lato, to pyrethroid insecticides.

According to the World Health Organization, the public health impact of LLINs depends critically not only on population access but also on their consistent and correct use. A minimum threshold of 80% utilization is generally considered necessary to achieve meaningful reductions in malaria transmission. Sustained nightly use of LLINs reduces human-vector contact, lowers malaria incidence, and con-

tributes to decreased mortality [9] [10]. However, evidence from several settings suggests that reported LLIN use may overestimate actual utilization due to reporting bias.

In this context, improving the accuracy of LLIN utilization measurement has become an important methodological challenge. Traditional approaches relying on self-reported use—typically based on whether individuals declare having slept under a net the previous night—are widely used in large-scale surveys but are prone to social desirability and recall biases. Alternative approaches based on direct household observations may provide more objective estimates but remain underutilized and insufficiently validated at scale.

A preliminary study conducted by the Centre de Recherche Entomologique de Cotonou (CREC) in southern Benin highlighted substantial discrepancies between these two measurement approaches. While 95.7% of household heads reported having slept under a net the previous night, only 65.5% of nets were observed hanging above sleeping spaces, suggesting potential overestimation of LLIN use when relying solely on self-reported data. However, this initial study was limited in scale and did not account for variability across ecological settings or LLIN types.

At the same time, the evaluation of novel LLINs incorporating new insecticide combinations is progressing through phased experimental studies. While early-phase (Phase I and II) evaluations conducted under controlled conditions have demonstrated promising efficacy of candidate LLINs against pyrethroid-resistant vectors, their real-world effectiveness ultimately depends on community-level acceptance and utilization. This highlights the need to generate robust field-based evidence on LLIN use patterns, particularly for next-generation nets deployed in routine control programs.

In this study, we therefore aimed to address two critical gaps. First, we sought to provide a more accurate and scalable estimate of LLIN utilization by combining self-reported data with standardized direct household observations. Second, we compared utilization patterns between standard LLINs and next-generation LLINs distributed during the 2023 campaign. By expanding the scope of previous investigations across multiple communes and ecological contexts, this study provides novel insights into both the measurement and determinants of LLIN use in a real-world operational setting.

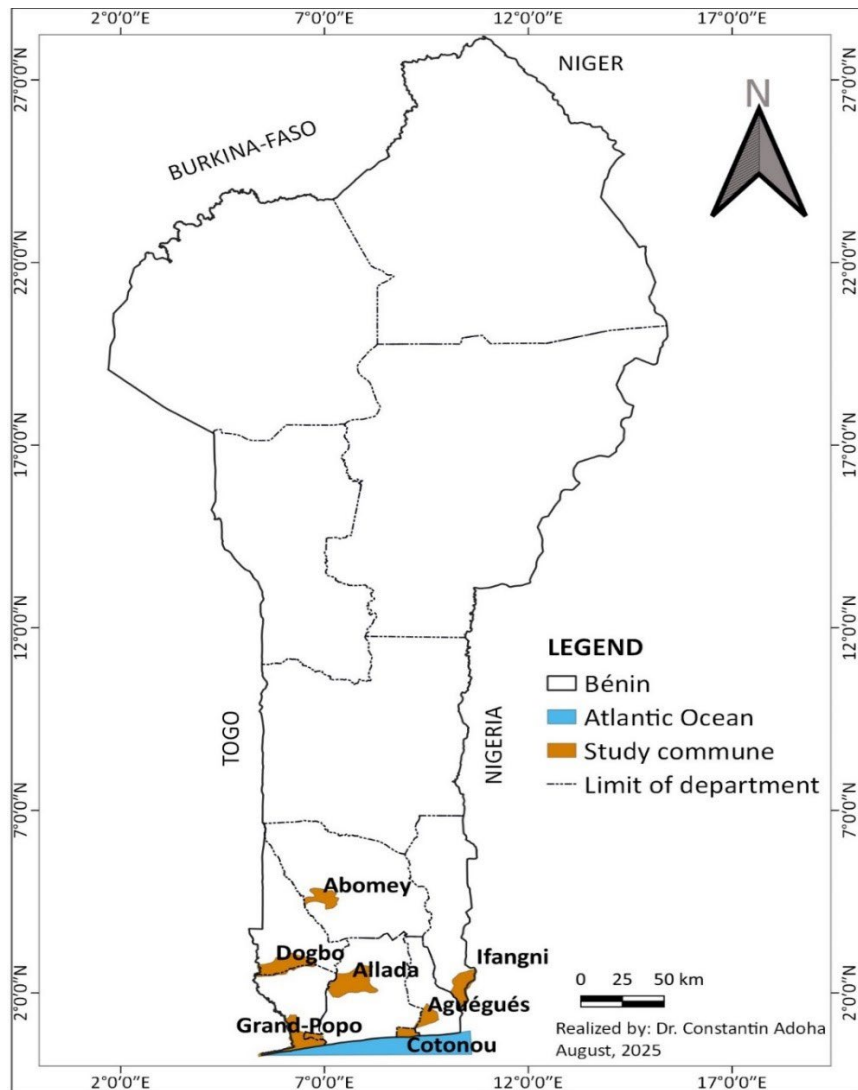
## 2. Materials and Methods

### 2.1. Study Area

To reflect the cultural and socio-economic diversity of Benin, households were monitored in 14 randomly selected villages across 7 communes in southern Benin (Figure 1).

Self-reported LLIN use was collected through structured interviews with the household head or, in their absence, an adult household member. Respondents were asked to report whether each household member slept under an LLIN the night preceding the survey. Therefore, responses were proxy-reported at the household level

rather than individually verified. The key question was formulated as: “Did each household member sleep under an insecticide-treated net last night?” All survey data were recorded using Open Data Kit (ODK) software installed on tablets.



**Figure 1.** Map of Benin showing the study areas.

## 2.2. Household Sampling

Sampling was conducted based on the premise that an insecticide-treated net (ITN) utilization rate below 80% would not justify attributing impact to these interventions. Therefore, for an absolute precision of 5% and a 95% confidence level, a minimum of 246 ITNs per commune was required to assess the impact of ITN utilization in the respective commune [11]. Given that the average household size in Benin is 5 persons, corresponding to at least 2 nets per household, the minimum number of households needed to achieve 246 nets is 123 per commune. A sample of 200 households per commune was therefore more than sufficient for evaluating the impact of ITN utilization. In total, 1400 households were visited

across the 7 selected communes. The survey was conducted in a single phase (over four months; rainy season) after the mass distribution campaign of mosquito nets.

To address potential confounding due to uneven distribution of LLIN types across communes, analyses were stratified by commune and season. Additionally, multivariate logistic regression models were fitted including LLIN type, commune, and survey period as covariates. In addition, generalized linear models (GLMs) with a binomial distribution and logit link function were fitted to assess factors associated with LLIN use, incorporating robust variance estimators clustered at the village level. All collected data were recorded on Samsung Galaxy Tab A 10.1 tablets using ODK Collect.

### 2.3. Parameters Recorded

At the end of each evaluation day, data were directly uploaded to a cloud server and retrieved at the end of the study for analysis. The following parameters were systematically recorded:

- Number of persons in the household (children and adults).
- Number of insecticide-treated nets received during the 2023 mass distribution campaign.
- Total number of insecticide-treated nets observed in the household.
- Number of insecticide-treated nets from the 2023 campaign observed in the household.
- Number of insecticide-treated nets classified as used (nets found hung, placed on the bed, or positioned immediately beside/near the bed).
- Number of persons who declared having slept under a net the previous night.
- Number of torn or holed nets.
- Coverage rate by department.
- Utilization rate based on nets found hung.
- Utilization rate based on nets found hung plus nets placed on or near the bed.
- Utilization rate based on self-reported declarations of having slept under a net the previous night.

### 2.4. Ethical Considerations

The study protocol was reviewed and approved by the National Health Research Ethics Committee (Comité National d'Éthique de la Recherche en Santé, CNER; approval No. 024, September 30, 2020). All participants provided free and informed consent after being clearly informed about the objectives of the study, the minimal risks involved, the expected benefits, and their voluntary right to participate.

### 2.5. Statistics Analyses

Data were entered and analyzed using Microsoft Excel® and R software (version 4.4.1). All analyses were performed at a 5% significance level ( $p < 0.05$ ).

As a sensitivity analysis, mixed-effects logistic regression models including commune as a random effect were also considered to evaluate the consistency of

the results. LLIN coverage rate was calculated as the ratio of the number of observed LLINs to the total population enumerated in the surveyed households. Compliance with the one-net-per-two-people threshold was assessed at both commune and arrondissement levels.

LLIN use was estimated using two complementary approaches:

(i) a strict definition, considering only LLINs observed hanging above a sleeping space, and

(ii) an extended definition, including LLINs that were hanging, placed on the bed, or positioned immediately beside the bed, whose use was confirmed by the household head. A sensitivity analysis was performed to compare LLIN utilization estimates under both definitions.

Agreement between self-reported and observed LLIN use was assessed by comparing proportions and their 95% confidence intervals across communes.

### 3. Results

#### 3.1. Insecticide-Treated Nets Encountered in the 7 Communes

The study was conducted 4 months after the distribution of long-lasting insecticidal nets (LLINs) from the 2023 mass campaign, corresponding respectively to the rainy season and the dry/cool season (harmattan period). The majority of LLINs encountered were those distributed during the 2023 campaign.

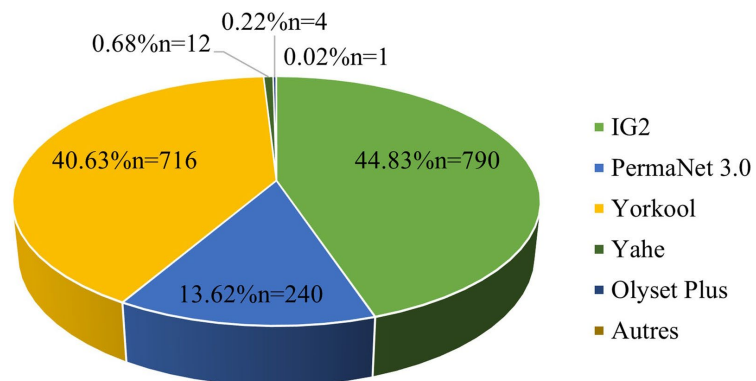
In total, 1762 insecticide-treated nets were observed across the surveyed households. The breakdown by type was as follows: Interceptor G2 ( $n = 790$ ), PermaNet 3.0 ( $n = 240$ ), Yorkool ( $n = 716$ ), Yahe ( $n = 12$ ), and Olyset Plus ( $n = 4$ ) (**Table 1**). Their respective proportions were:

- Interceptor G2: 44.83%
- PermaNet 3.0: 13.62%
- Yorkool: 40.63%
- Yahe: 0.68%
- Olyset Plus: 0.22%

**Table 1.** Distribution of long-lasting insecticidal nets (LLINs) and types of LLINs distributed in the 2023 campaign, by municipality.

| Municipality | Type of MILD   |             |              |      |         |
|--------------|----------------|-------------|--------------|------|---------|
|              | Interceptor G2 | Olyset Plus | PermaNet 3.0 | Yahe | Yorkool |
| Abomey       | 260            | 0           | 0            | 0    | 1       |
| Aguégoué     | 2              | 1           | 0            | 6    | 256     |
| Allada       | 1              | 0           | 240          | 0    | 1       |
| Cotonou      | 264            | 1           | 0            | 6    | 3       |
| Dogbo        | 0              | 0           | 0            | 0    | 228     |
| Grand Popo   | 2              | 0           | 0            | 0    | 224     |
| Ifangni      | 261            | 2           | 0            | 0    | 3       |
| Zone d'étude | 790            | 4           | 240          | 12   | 716     |

Other LLIN brands/types were also observed but in very low proportions (0.02%) (Figure 2).



**Figure 2.** Distribution of long-lasting insecticidal nets (LLINs) from the 2023 mass distribution campaign, by brand across the 7 study municipality.

The recorded data indicate that in Dogbo, only one type of long-lasting insecticidal net (LLIN) was encountered: Yorkool.

During the 2023 mass distribution campaign, Interceptor G2 (44.83%,  $n = 790$ ) and Yorkool (40.63%,  $n = 716$ ) were the most commonly observed LLINs across the visited communes (Table 1).

### 3.2. Insecticide-Treated Net (ITN) Coverage Rates

During the single visit, conducted 4 months after the mass distribution of long-lasting insecticidal nets (LLINs), we surveyed 911 households comprising 4553 individuals (2328 children and 2225 adults), with an average household size of 5 persons (Table 2).

Based on the number of nets physically observed in households 4 months post-distribution, the average ITN coverage rate was 38.69% (1762/4553; 95% CI: 0.37 - 0.40) for nets distributed during the 2023 campaign and 51.24% (2333/4553; 95% CI: 0.49 - 0.52) when considering all ITNs present in households, equivalent to approximately 1 net per 2 persons (Table 3).

The initial hypothesis that the average household size in Benin is 5 persons was overall verified in the study area and in nearly all of the surveyed communes (Table 2).

**Table 2.** Average coverage rates of long-lasting insecticidal nets (LLINs) by district and the proportion of households achieving the threshold of one (1) net per 2 persons.

| Department | Municipality | District     | Proportion of households meeting the one bed net for two persons threshold | Average coverage rate per village | IC 95%      |
|------------|--------------|--------------|----------------------------------------------------------------------------|-----------------------------------|-------------|
| Atlantique | Allada       | Ahouannouzou | 42.19                                                                      | 0.46                              | 0.40 - 0.52 |
|            |              | Sékou        | 27.69                                                                      | 0.35                              | 0.30 - 0.41 |

## Continued

|              |            |                     |       |      |             |
|--------------|------------|---------------------|-------|------|-------------|
| Couffo       | Dogbo      | Honto               | 44.62 | 0.46 | 0.40 - 0.52 |
|              |            | Tota                | 75.76 | 0.55 | 0.49 - 0.60 |
| Littoral     | Cotonou    | 12th arrondissement | 44.62 | 0.41 | 0.34 - 0.48 |
|              |            | 1st arrondissement  | 29.08 | 0.33 | 0.29 - 0.37 |
| Mono         | Grand Popo | Grand Popo          | 56.06 | 0.47 | 0.40 - 0.54 |
|              |            | Sazue               | 67.69 | 0.56 | 0.50 - 0.62 |
| Ouémé        | Aguegue    | Avagbodji           | 49.29 | 0.49 | 0.44 - 0.53 |
|              |            | Houedome            | 35.38 | 0.42 | 0.34 - 0.81 |
| Plateau      | Ifangni    | Banigbe             | 50.77 | 0.58 | 0.34 - 0.31 |
|              |            | Ifangni             | 37.88 | 0.47 | 0.40 - 0.54 |
| Zou          | Abomey     | Détouhou            | 51.56 | 0.63 | 0.30 - 0.96 |
|              |            | Dègbé               | 46.03 | 0.44 | 0.37 - 0.50 |
| Zone d'étude |            |                     | 47.04 | 0.47 | 0.38 - 0.55 |

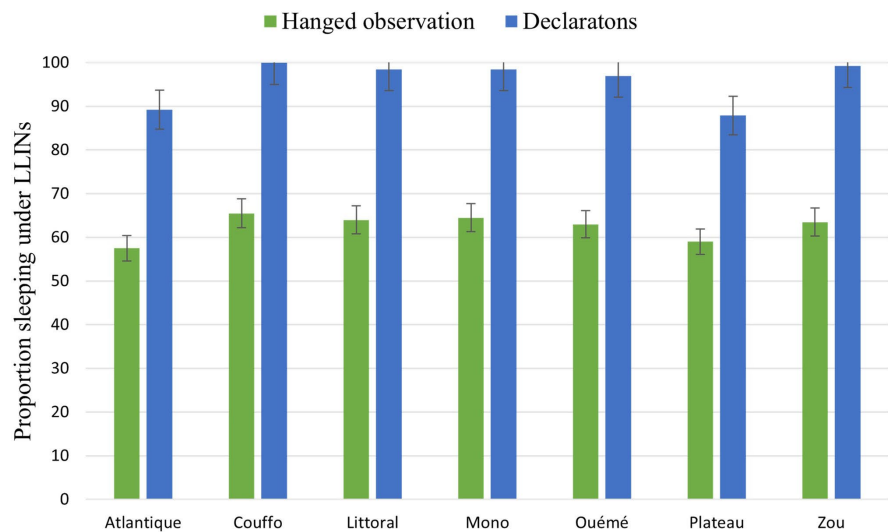
**Table 3.** Household population density and population by municipality.

| Department   | Municipality | District            | Number of households visited | Number of children | Number of adults | Household density |
|--------------|--------------|---------------------|------------------------------|--------------------|------------------|-------------------|
| Atlantique   | Allada       | Ahounnouzou         | 64                           | 152                | 148              | 4.69              |
|              |              | Sékou               | 65                           | 217                | 155              | 5.72              |
| Couffo       | Dogbo        | Honto               | 65                           | 116                | 145              | 4.02              |
|              |              | Tota                | 66                           | 130                | 124              | 3.85              |
| Littoral     | Cotonou      | 12th arrondissement | 65                           | 129                | 285              | 6.37              |
|              |              | 1st arrondissement  | 65                           | 215                | 133              | 5.35              |
| Mono         | Grand Popo   | Grand Popo          | 66                           | 129                | 147              | 4.18              |
|              |              | Sazue               | 65                           | 120                | 118              | 3.66              |
| Ouémé        | Aguegue      | Avagbodji           | 65                           | 173                | 138              | 4.78              |
|              |              | Houedome            | 65                           | 184                | 210              | 6.06              |
| Plateau      | Ifangni      | Banigbe             | 66                           | 162                | 220              | 5.79              |
|              |              | Ifangni             | 66                           | 215                | 131              | 5.24              |
| Zou          | Abomey       | Détouhou            | 65                           | 181                | 149              | 5.08              |
|              |              | Dègbé               | 63                           | 205                | 122              | 5.31              |
| Zone d'étude |              |                     | 911                          | 2328               | 2225             | 5                 |

## LLIN Utilization

The minimum utilization rate of 80% was achieved in the study area when LLINs found hung, as well as those placed beside or on the bed, were considered in use (**Figure 3**). However, in some villages, rates below 80% were observed, with

the lowest utilization rates recorded in Honto village, Dogbo commune, at 62.5% for the LLINs distributed during the 2023 campaign. Overall, LLIN utilization varied significantly across villages and communes ( $P < 0.0001$ ).



**Figure 3.** Percentage of LLINs reported as used by households versus those observed hung above the bed, plus those observed placed near the bed or on the bed.

Furthermore, of the 1,428 LLINs from the 2023 campaign considered in realistic (effective) use, 1,174 were consistently hung above a sleeping space, representing a proportion of 82.21% (95% CI: 0.80 - 0.84) of frequently used LLINs in the study area (**Table 4**).

Using the strict definition (hung LLINs only), utilization was 63.78%, whereas the extended definition yielded a higher estimate of 78.56%. (**Table 4**).

In comparison, the utilization rate of standard (pyrethroid-only) LLINs from the 2023 campaign was 50.98% (728/1,428; 95% CI: 0.48 - 0.53), which was substantially lower than that of next-generation LLINs at 72.40% (1,034/1,428; 95% CI: 0.69 - 0.74) (**Table 4**).

**Table 4.** Utilization rates of long-lasting insecticidal nets (LLINs) based on nets observed hung, and nets observed placed beside or on the bed.

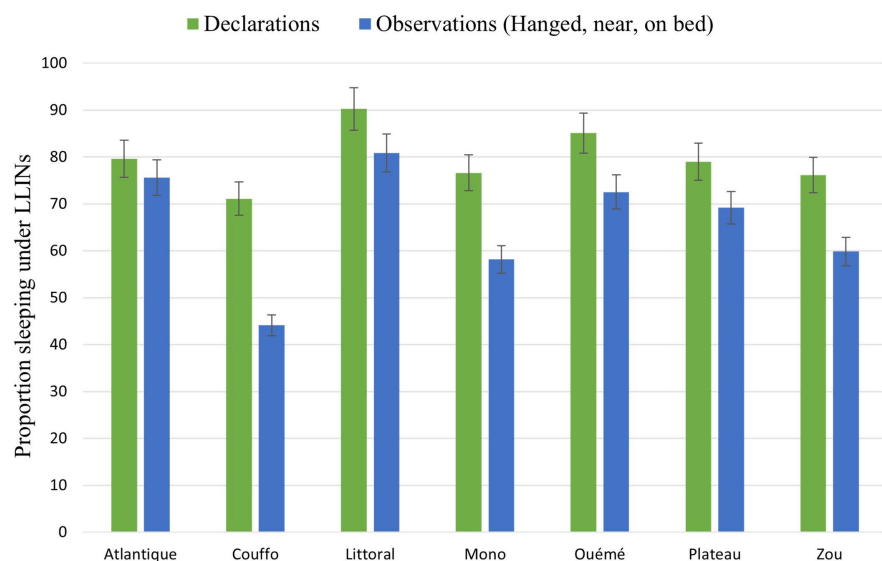
| Department | Municipality | District    | Total LLINs observed in the household | Total LLINs observed in 2023 | Total LLINs hung | Total LLINs hung in 2023 | Total LLINs hung near or over the bed | Total LLINs hung near or over the bed in 2023 | LLINs hung in use (%) | LLINs in use hung near or over the bed (%) |
|------------|--------------|-------------|---------------------------------------|------------------------------|------------------|--------------------------|---------------------------------------|-----------------------------------------------|-----------------------|--------------------------------------------|
| Atlantique | Allada       | Ahounnouzou | 144                                   | 131                          | 136              | 123                      | 136                                   | 123                                           | 94.44                 | 94.44                                      |
|            |              | Sékou       | 176                                   | 111                          | 100              | 53                       | 114                                   | 59                                            | 56.82                 | 64.77                                      |
| Couffo     | Dogbo        | Honto       | 160                                   | 101                          | 55               | 42                       | 100                                   | 78                                            | 34.38                 | 62.5                                       |
|            |              | Tota        | 143                                   | 127                          | 77               | 70                       | 114                                   | 100                                           | 53.85                 | 79.72                                      |

Continued

|          |              |                     |      |      |      |      |      |      |       |       |
|----------|--------------|---------------------|------|------|------|------|------|------|-------|-------|
| Littoral | Cotonou      | 12th arrondissement | 233  | 157  | 153  | 96   | 193  | 122  | 65.67 | 82.83 |
|          |              | 1st arrondissement  | 127  | 118  | 122  | 114  | 124  | 115  | 96.06 | 97.64 |
| Mono     | Grand Popo   | Grand Popo          | 174  | 116  | 87   | 53   | 136  | 86   | 50    | 78.16 |
|          |              | Sazue               | 178  | 111  | 118  | 91   | 132  | 102  | 66.29 | 74.16 |
| Ouémé    | Aguegue      | Avagbodji           | 137  | 131  | 131  | 126  | 133  | 128  | 95.62 | 97.08 |
|          |              | Houedome            | 186  | 134  | 92   | 60   | 136  | 90   | 49.46 | 73.12 |
| Plateau  | Ifangni      | Banigbe             | 206  | 152  | 102  | 63   | 143  | 94   | 49.51 | 69.42 |
|          |              | Ifangni             | 122  | 116  | 106  | 103  | 108  | 104  | 86.89 | 88.52 |
| Zou      | Abomey       | Détouhou            | 155  | 139  | 71   | 62   | 119  | 104  | 45.81 | 76.77 |
|          |              | Dègbé               | 192  | 123  | 138  | 118  | 145  | 123  | 71.88 | 75.52 |
|          | Zone d'étude |                     | 2333 | 1767 | 1488 | 1174 | 1833 | 1428 | 65.48 | 80    |

### 3.3. Self-Reported LLIN Utilization

Overall, 95.72% (872/911; 95% CI: 0.94 - 0.96) of individuals surveyed in households across the seven departments of the study reported having slept under an LLIN the previous night (**Figure 4**). This indicates substantially higher utilization rates compared to those derived from direct observations (**Table 5**).



**Figure 4.** Percentage of LLINs reported as used by households versus those observed hung above sleeping spaces.

In certain arrondissements, such as Honto and Tota in Dogbo commune, the 1st arrondissement of Cotonou, Avagbodji in Aguégués, and Detouhou in Abomey, all surveyed individuals (100%) reported sleeping under an LLIN the night preceding the survey day. The lowest self-reported utilization rate was recorded in Banigbé arrondissement, Ifangni commune, at 81.82% (**Table 5**).

**Table 5.** Self-reported LLIN utilization rates based on individuals who reported sleeping under an LLIN the night preceding the survey.

| Department   | Municipality | District            | Number of households | Number of declarations | Self-reported LLIN utilization rate among individuals who slept under an LLIN |
|--------------|--------------|---------------------|----------------------|------------------------|-------------------------------------------------------------------------------|
| Atlantique   | Allada       | Ahouannouzoun       | 65                   | 61                     | 95.31                                                                         |
|              |              | Sékou               | 66                   | 54                     | 83.08                                                                         |
| Couffo       | Dogbo        | Honto               | 63                   | 65                     | 100                                                                           |
|              |              | Tota                | 63                   | 66                     | 100                                                                           |
| Littoral     | Cotonou      | 12th arrondissement | 65                   | 63                     | 96.92                                                                         |
|              |              | 1st arrondissement  | 66                   | 65                     | 100                                                                           |
| Mono         | Grand Popo   | Grand Popo          | 65                   | 65                     | 98.48                                                                         |
|              |              | Sazue               | 65                   | 64                     | 98.46                                                                         |
| Ouémé        | Aguegues     | Avagbodji           | 64                   | 65                     | 100                                                                           |
|              |              | Houedome            | 65                   | 61                     | 93.85                                                                         |
| Plateau      | Ifangni      | Banigbe             | 65                   | 54                     | 81.82                                                                         |
|              |              | Ifangni             | 65                   | 62                     | 93.94                                                                         |
| Zou          | Abomey       | Détouhou            | 66                   | 65                     | 100                                                                           |
|              |              | Dègbé               | 68                   | 62                     | 98.41                                                                         |
| Zone d'étude |              |                     | 911                  | 872                    | 95.72                                                                         |

### 3.4. Physical Integrity of LLINs

For both the LLINs distributed during the 2023 campaign and all observed LLINs in the study area, fewer than 17% were found to be torn. However, it should be noted that the low proportion of torn LLINs is largely attributable to the fact that older, heavily damaged nets had already been removed and replaced by newer ones. This results in a low quantity of remaining older nets, with a torn rate of 16.97% (396/2,333; 95% CI: 0.15 - 0.18) (Table 6).

**Table 6.** Physical condition of long-lasting insecticidal nets (LLINs).

| All long-lasting insecticidal nets (LLINs) |              |              |                                             |                |             |                                  |                               |
|--------------------------------------------|--------------|--------------|---------------------------------------------|----------------|-------------|----------------------------------|-------------------------------|
| Department                                 | Municipality | District     | Total LLINs observed in surveyed households | Non-torn LLINs | Clean LLINs | Percentage of non-torn LLINs (%) | Proportion of clean LLINs (%) |
| Atlantique                                 | Allada       | Ahouannouzou | 144                                         | 133            | 129         | 92.36                            | 89.58                         |
|                                            |              | Sékou        | 176                                         | 150            | 138         | 85.23                            | 78.41                         |
| Couffo                                     | Dogbo        | Honto        | 160                                         | 123            | 89          | 76.88                            | 55.63                         |
|                                            |              | Toat         | 143                                         | 132            | 111         | 92.31                            | 77.62                         |

**Continued**

|              |            |                     |      |      |      |       |       |
|--------------|------------|---------------------|------|------|------|-------|-------|
| Littoral     | Cotonou    | 12th arrondissement | 233  | 217  | 213  | 93.13 | 91.42 |
|              |            | 1st arrondissement  | 127  | 69   | 118  | 54.33 | 92.91 |
| Mono         | Grand Popo | Grand Popo          | 174  | 151  | 134  | 86.78 | 77.01 |
|              |            | Sazue               | 178  | 147  | 141  | 82.58 | 79.21 |
| Ouémé        | Aguégués   | Avagbodji           | 137  | 88   | 136  | 64.23 | 99.27 |
|              |            | Houedome            | 186  | 161  | 162  | 86.56 | 87.1  |
| Plateau      | Ifangni    | Banigbe             | 206  | 178  | 165  | 86.41 | 80.1  |
|              |            | Ifangni             | 122  | 102  | 119  | 83.61 | 97.54 |
| Zou          | Abomey     | Détouhou            | 155  | 141  | 104  | 90.97 | 67.1  |
|              |            | Dègbé               | 192  | 145  | 133  | 75.52 | 69.27 |
| Zone d'étude |            |                     | 2333 | 1937 | 1892 | 83.02 | 81.09 |

**3.5. Physical Condition and Cleanliness of 2023 Campaign LLINs**

Very few of the recovered LLINs from the 2023 campaign were found to be torn (less than 10%), and consequently, the vast majority—90.34% (1,597/1,767; 95% CI: 0.88 - 0.91)—were in good physical condition and cleanliness (**Table 7**).

**Table 7.** Condition of LLINs from the 2023 distribution campaign.

| 2023 Long-Lasting Insecticidal Net (LLIN) Distribution campaign |              |                     |                                                        |                |       |                                |                                |
|-----------------------------------------------------------------|--------------|---------------------|--------------------------------------------------------|----------------|-------|--------------------------------|--------------------------------|
| Department                                                      | Municipality | District            | Condition of LLINs from the 2023 distribution campaign | Non-torn LLINs | Clean | Percentage of intact LLINs (%) | Percentage of intact LLINs (%) |
| Atlantique                                                      | Allada       | Ahouannouzou        | 131                                                    | 124            | 120   | 94.66                          | 91.6                           |
|                                                                 |              | Sékou               | 111                                                    | 109            | 107   | 98.2                           | 96.4                           |
| Couffo                                                          | Dogbo        | Honto               | 101                                                    | 101            | 78    | 100                            | 77.23                          |
|                                                                 |              | Tota                | 127                                                    | 124            | 107   | 97.61                          | 84.25                          |
| Littoral                                                        | Cotonou      | 12th arrondissement | 157                                                    | 155            | 153   | 98.73                          | 97.45                          |
|                                                                 |              | 1st arrondissement  | 118                                                    | 65             | 111   | 55.93                          | 94.07                          |
| Mono                                                            | Grand Popo   | Grand Popo          | 116                                                    | 110            | 97    | 94.83                          | 83.62                          |
|                                                                 |              | Sazué               | 111                                                    | 110            | 107   | 99.1                           | 96.4                           |
| Ouémé                                                           | Aguégués     | Avagbodji           | 131                                                    | 84             | 130   | 64.12                          | 99.24                          |
|                                                                 |              | Houédomé            | 134                                                    | 132            | 128   | 98.51                          | 95.52                          |
| Plataux                                                         | Ifangni      | Banigbé             | 152                                                    | 149            | 132   | 98.03                          | 86.84                          |
|                                                                 |              | Ifangni             | 116                                                    | 101            | 115   | 87.07                          | 99.14                          |

**Continued**

|     |              |          |      |      |      |       |       |
|-----|--------------|----------|------|------|------|-------|-------|
| Zou | Zou          | Détouhou | 139  | 134  | 100  | 96.4  | 71.94 |
|     |              | Dègbé    | 123  | 122  | 112  | 99.19 | 91.06 |
|     | Zone d'étude |          | 1767 | 1620 | 1597 | 91.59 | 90.34 |

**3.6. LLIN Enumeration and Observed Utilization**

A total of 2,333 LLINs were reported in the 911 households visited across the seven departments. Analyses revealed that 62.04% (1,447/2,332; 95% CI: 0.60 - 0.64) of the LLINs were observed hung above sleeping spaces and were undoubtedly in use. Additionally, LLINs found placed beside sleeping spaces accounted for 17.40% (406/2,332; 95% CI: 0.15 - 0.19). These latter LLINs were also considered in effective use, as confirmed by household heads and the owners of the respective nets (**Table 8**).

**Table 8.** Location of LLINs found in use in households.

| Departement  | Municipality | District            | LLINs<br>observed<br>hanging | LLINs found<br>next to the<br>sleeping area | LLINs found on<br>the sleeping<br>place | Total LLINs<br>observed in<br>households |
|--------------|--------------|---------------------|------------------------------|---------------------------------------------|-----------------------------------------|------------------------------------------|
| Atlantique   | Allada       | Ahouannouzou        | 111                          | 2                                           | 0                                       | 144                                      |
|              |              | Sékou               | 99                           | 12                                          | 1                                       | 176                                      |
| Couffo       | Dogbo        | Honto               | 55                           | 44                                          | 1                                       | 160                                      |
|              |              | Tota                | 76                           | 44                                          | 1                                       | 143                                      |
| Littoral     | Cotonou      | 12th arrondissement | 153                          | 38                                          | 3                                       | 233                                      |
|              |              | 1st arrondissement  | 121                          | 3                                           | 2                                       | 127                                      |
| Mono         | Grand Popo   | Grand Popo          | 87                           | 50                                          | 8                                       | 173                                      |
|              |              | Sazué               | 115                          | 12                                          | 5                                       | 178                                      |
| Ouémé        | Aguégués     | Avagbodji           | 130                          | 4                                           | 1                                       | 137                                      |
|              |              | Houédomé            | 92                           | 51                                          | 5                                       | 186                                      |
| Plateau      | Ifangni      | Banigbé             | 102                          | 37                                          | 8                                       | 206                                      |
|              |              | Ifangni             | 99                           | 6                                           | 1                                       | 122                                      |
| Zou          | Abomey       | Détouhou            | 71                           | 52                                          | 5                                       | 155                                      |
|              |              | Djègbé              | 136                          | 10                                          | 0                                       | 192                                      |
| Zone d'étude |              |                     | 1447                         | 365                                         | 41                                      | 2332                                     |

**4. Discussion**

Four months after the 2023 distribution campaign, the majority of LLINs encountered in the visited households were those distributed during the campaign: 96.30% (1,767/1,833; 95% CI: 0.95 - 0.97). Other types of LLINs were also observed, but in very low proportions (0.02%).

#### 4.1. LLIN Coverage Rate Four Months after the 2023 Campaign

The WHO-recommended coverage threshold of one LLIN per two persons was achieved in 5 out of the 7 communes surveyed, with an average LLIN rate per commune of 0.47 (95% CI: 0.38 - 0.55). These findings are consistent with those from the 2020 campaign in Benin, where the one-net-per-two-people threshold was reached nationally, with 93.3% of households and 94.2% of the population receiving LLINs [12]. Similar high coverage was reported by [13] in western Kenya, with 95% of households owning at least one LLIN following a mass distribution campaign. In Zambia, mass distribution of LLINs to households achieved an 80% coverage rate [14]. High LLIN coverage was also observed in India (98.4%), although household availability remained lower at 59.4% [15]. Nevertheless, some complaints were recorded from individuals who did not receive LLINs. These individuals felt that distributions were not proportional to household size. Certain households, particularly in the Littoral department (Cotonou), reported not receiving LLINs despite possessing coupons. Others had lost their coupons, and some perceived that distribution sometimes occurred based on personal affinities.

#### 4.2. Physical Integrity of LLINs Four Months after the 2023 Campaign

Of the 2,333 LLINs inspected, 83.02% were in good condition four months post-distribution. Those with holes or minor tears but still serviceable represented only 17%. Comparable results were reported by [16] and [17] following the 2014 and 2017 campaigns in Benin. According to [18], 86% of LLINs from the 2017 campaign remained in good condition after one year, with 9% damaged and only 5% requiring replacement. In Zambia, a study showed good physical condition (90.4%) for PermaNet 2.0 and OlysetNet® LLINs 12 months after distribution [19]. Similar findings were observed in Nigeria, with a survival rate of 98.2% for polyester and polyethylene LLINs 12 months post-distribution [20]. In Kenya, 74.9% of LLINs were in good condition, with only 7.8% damaged or torn [13]. Researchers in Afghanistan also reported high physical integrity (97.0% serviceable), with only 3.0% torn [21]. However, the low proportion of torn LLINs observed here is largely attributable to the removal and replacement of older, heavily damaged nets during the 2023 campaign, explaining the low quantity of remaining older nets and the 17% torn rate.

#### 4.3. LLIN Utilization

In our study, LLIN utilization was assessed as a key indicator of population protection against mosquito bites. Overall, 95.73% of surveyed individuals across the seven departments reported sleeping under an LLIN the night preceding the survey. This approach is inherently subject to social desirability bias and recall bias, which may lead to substantial overestimation of actual LLIN use. A similar discrepancy was noted by [17], who reported very high self-reported utilization rates among house-

hold heads in certain northern Benin communes. The same pattern was observed in Afghanistan, with a self-reported utilization rate of 96.3% [21]. In the present study, we did not rely solely on self-reports. We considered LLINs observed hung, beside the bed, or on the bed as in use, yielding more realistic utilization rates around 65.48%. The comparison indicated that observations were statistically in agreement with self-reports in several departments. A comparable observation was made in Uganda by [22], who reported realistic utilization rates of 26.5% based on direct observation following a distribution campaign. When restricting the analysis to only hung LLINs as indicative of use—aligned with self-reports of individuals who slept under an LLIN—no statistical agreement was found between observations and declarations in any department, with self-reported rates substantially exceeding reality (95.72%). Our self-reported rates are even higher than those from studies in Ethiopia 72.2%; [23]; 83.5%; [24], underscoring that self-reported utilization is not always reliable compared to observed reality. Comparative analyses revealed that utilization of standard (pyrethroid-only) LLINs from the 2023 campaign (Yorkool, PermaNet 2.0, Yahe) was 50.98%, markedly lower than that of next-generation LLINs (Olyset-Plus, PermaNet 3.0, Interceptor G2) at 72.40%. The higher utilization observed for next-generation LLINs should be interpreted cautiously, as LLIN type distribution was not uniform across communes, and contextual factors such as seasonality and local perceptions may have influenced use. We considered the position and physical condition of LLINs as key indicators of utilization. There is little doubt that an LLIN hung or placed on/near a bed is in use. Therefore, LLINs found in bags, baskets, or retained in their original packaging were excluded from the utilization category.

The present study demonstrated that the 2023 distribution campaign achieved the WHO-recommended overall utilization rate of 80%. However, rates below 80% were observed in certain villages. LLIN utilization varied significantly across communes and departments ( $P < 0.0001$ ).

## 5. Conclusion

Four months post-distribution, the LLINs from the 2023 campaign predominated in the surveyed households. The overall average coverage rate in the study area was 0.47 LLINs per person (approaching the one-net-per-two-people ratio). The WHO-recommended minimum utilization rate of 80% was achieved across the entire study area. Realistic (observed) utilization rates were consistently lower than self-reported rates by household heads claiming to have slept under an LLIN the night preceding the survey. However, direct field observation techniques provided utilization estimates much closer to reality than self-report methods. Furthermore, utilization rates for standard (pyrethroid-only) LLINs were markedly lower than those for next-generation LLINs.

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### Author Contributions

KDK, RAO, FRA and MA conceived the study and designed the protocol. KDK, MJA, SZH and ZA conducted the field data collection. KDK, RAO and MJA performed the statistical analyses. The first draft of the manuscript was written by KDK, RAO and FRA. MA, RAO, HSO, AS, RA, FT, FRA and LB critically reviewed and edited the manuscript. All authors read and approved the final manuscript.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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## Abbreviations

|     |                                  |
|-----|----------------------------------|
| An  | <i>Anopheles</i>                 |
| ITN | Insecticide-treated mosquito net |