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Intra-urban disparities in the use of long-lasting insecticidal nets and spatial vulnerability to malaria in two neighborhoods of Korhogo: Soba and Natio- Ko Badara (Côte d'Ivoire)

Donatié Serge TOURE [1], Konan Rodolphe Mardoché AZONGNIBO [2, *], Konan Fabrice ASSOUHO [3], Ibrahim Kounady OUATTARA [1], Foungoyé Allassane OUATTARA [4] and Mamadou DOUMBIA [4]

[1] *Animal Biology Department of Peleforo Gon Coulibaly University, Korhogo, Côte d'Ivoire.*
[2] *Tropical Geography Institute, Félix Houphouët-Boigny University, Côte d'Ivoire.*
[3] *Animal and Fisheries resources Department, University of San Pedro, Côte d'Ivoire.*
[4] *Animal Production Department, Nangui Abrogoua University, Côte d'Ivoire.*

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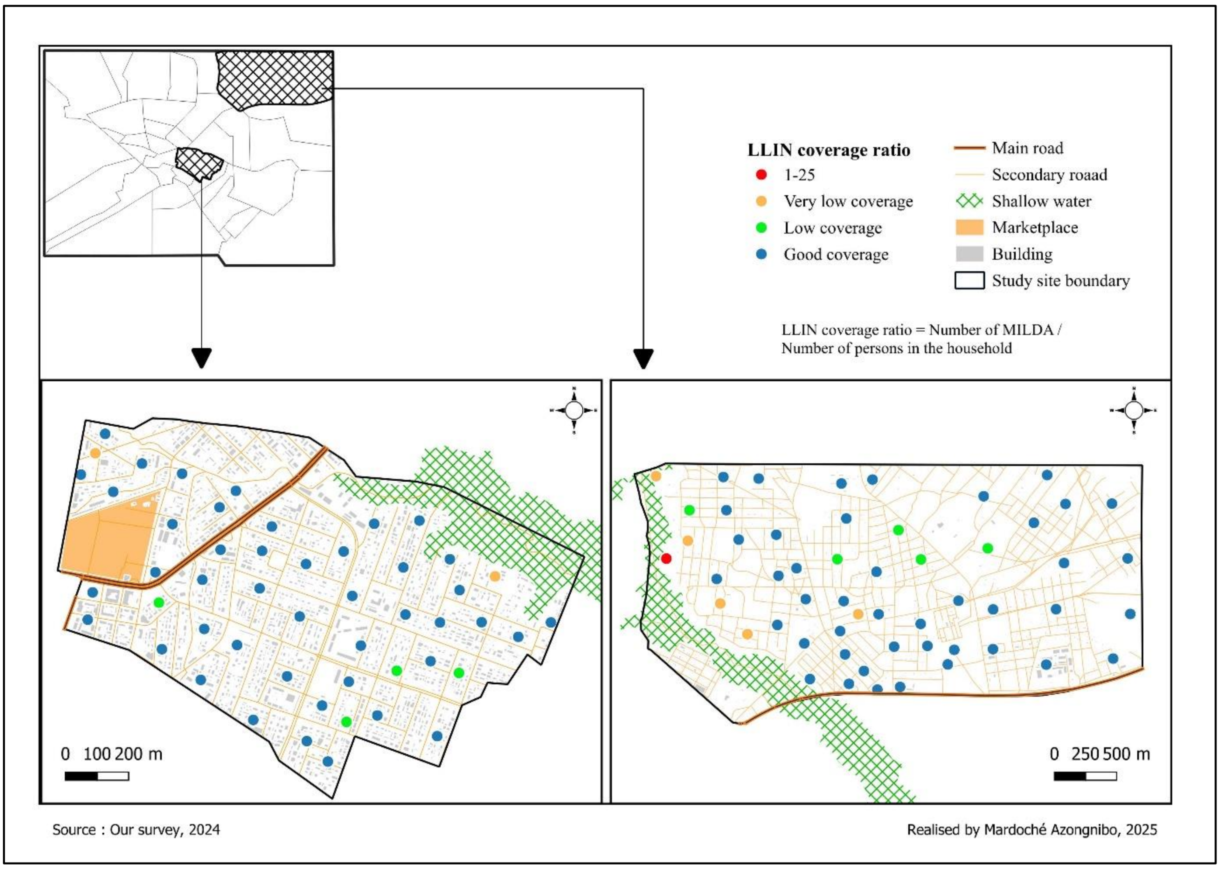
Abstract

This study analyses intra-urban disparities in the ownership, use and perception of long-lasting insecticide-treated mosquito nets (LLINs) in the fight against malaria in two neighbourhoods with different typologies in the city of Korhogo: Soba and Natio-kobadara. Using geolocated household surveys and spatial analyses (Moran's Index and LISA), we identified areas of vulnerability where effective protection remains insufficient despite good reported coverage. The results reveal a discrepancy between ownership, habitual use and actual use, and show that underprotected households are mainly located near the low-lying areas of the neighbourhoods. These observations highlight the need for a territorialized control strategy integrating behavioural communication and geographic targeting.

Keywords: Llin; Malaria; Moran's Index; Soba; Natio-Kobadara; Korhogo

* Corresponding author: Konan Rodolphe Mardoché AZONGNIBO

Graphical summary: Spatial distribution of the LLIN/household ratio in the two neighborhoods



1. Introduction

The control of malaria involves a robust arsenal of measures. The means and methods used to combat the disease continue to be reviewed on a regular basis in order to meet the expectations of populations, namely to be protected against this disease (1–3). Vector control is at the heart of current control measures, and among these, long-lasting insecticide-treated mosquito nets (LLINs) are the most accessible to populations. LLINs are the primary prevention tool recommended by the World Health Organisation (WHO) because they offer dual protection: physical and chemical. Physical protection is provided by preventing mosquito bites during sleep, while chemical protection is provided by the impregnated insecticide, which kills or repels vectors (4).

Large-scale distribution therefore makes it possible to interrupt vector transmission at the community level by reducing the density of infecting Anopheles mosquitoes (5). At the operational and economic level, LLIN represents a simple, sustainable and inexpensive solution, suitable for both rural and urban environments. Their presence in households therefore reflects the implementation of a universal preventive strategy, which is essential for achieving national and international malaria elimination targets (6,7).

Despite progress in the fight against malaria in Côte d'Ivoire, epidemiological data show that transmission persists, including in urban and peri-urban areas. This situation raises questions about the actual effectiveness of LLIN coverage and the regularity of its use by households. Simply owning a mosquito net does not guarantee that it will be used, as socio-demographic, economic, behavioural and environmental factors can influence protection practises (8).

Furthermore, most previous studies have focused on rural areas, often considered to be the most vulnerable, thereby neglecting the complexity of urban areas where contrasting health, social, and spatial contexts coexist (9,10). This study, conducted in urban and peri-urban areas, fills a scientific gap by analysing intra-urban disparities in the use of LLIN and the vulnerability factors specific to these areas. This study aims to analyse the spatial distribution of indicators related to the use of LLIN in two urban and peri-urban neighbourhoods of Korhogo, in order to identify the factors that determine the effective protection of households against malaria.

The expected results will contribute to a better understanding of the behavioural and spatial determinants of mosquito net use, and will provide essential operational information to guide the National Malaria Control Programme (NMCP) interventions towards the most vulnerable households.

2. Materials and methods

2.1. Study site

The city of Korhogo has a Sudanese climate with two alternating seasons (Figure 1). The dry season begins in November and ends in March. The rainy season lasts from May to October, with maximum rainfall in July and August. Annual rainfall varies between 1,100 and 1,600 mm (11). Average temperatures range from 24°C to 33°C. The vegetation in Korhogo, like that of the entire region, consists of wooded savannah (12). With a population of 440,926, Korhogo is the third most populous city in Côte d'Ivoire, behind Abidjan and Bouaké (13). Korhogo, the regional capital of the north, is highly urbanised and the administrative centre of the Savanes District, the Poro region and the Korhogo department. Korhogo's appeal lies primarily in its administrative centralization. The city is home to the headquarters of the regional prefecture and all the state's representative offices in the north of the country (14).

The Soba neighbourhood is one of the core neighbourhoods of the city of Korhogo. It is located in the centre of the city and bordered by the Air France, Petit Paris, Sinistré, Sinistré Extension, Commerce, and administrative neighbourhoods (15). Natio-Kobadara is a peri-urban neighbourhood. A village in the not-too-distant past, it has been overtaken by rapid urbanisation. In Natio-Kobadara, both rural and urban customs can be found (16). The neighbourhood is bordered to the south by the industrial zone and industrial zone extension neighbourhoods, to the north by the Natio-Kobadara extension and Petit Paris extension neighbourhoods, and to the west by the 19th September 2002 and CIDT neighbourhoods (16).

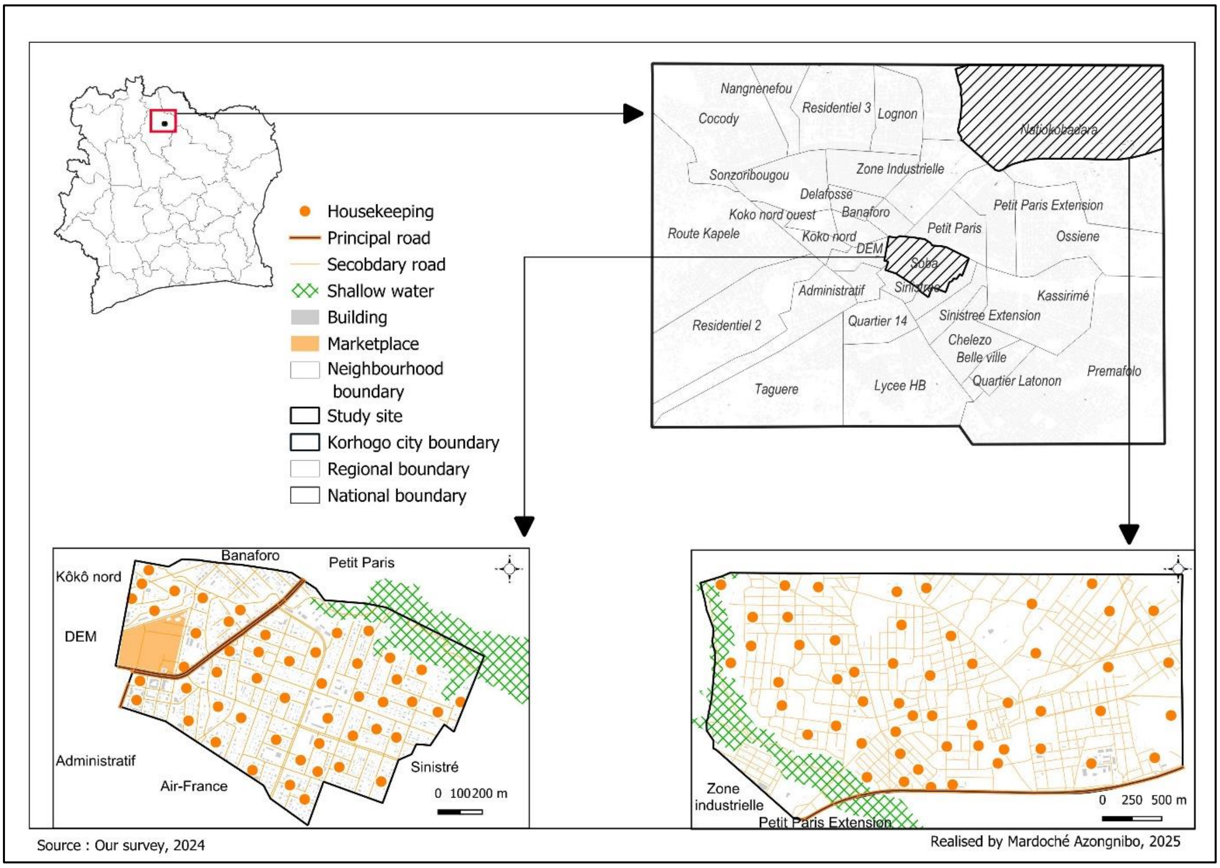


Figure 1 Location of study sites

2.2. Study design and data collection procedure

Authorization was obtained from both institutional authorities and neighborhood leaders before the study was launched. The survey was conducted in January 2025, after the last large-scale free distribution campaign of LLIN to the population. The study population consisted of heads of households or their adult representatives (aged 18 or over). A sample of households was calculated using Schwartz's formula to determine the number of households to be surveyed (17). To conduct parametric analyses, we chose to survey at least 50 households per site. Households were selected at random using a geographic information system (QGIS) (18–20).

The data were collected by trained interviewers using Kobo Toolbox (Kobo Collect and web forms). The questionnaire incorporated skip logic and validation constraints to limit errors, and the GPS coordinates of households were automatically recorded (21). The questionnaire gathered information on LLIN ownership and all associated indicators (LLIN ownership, LLIN use, use at night, knowledge of malaria (symptoms, modes of transmission) and, LLIN/person ratio). A total of 57 households were surveyed in Natio Kobadara and 50 households in Soba. The informed consent of the participants was obtained, guaranteeing the confidentiality of the information collected.

2.3. Data processing and analysis

After collecting data in the field, the data was retrieved in Excel format via the Kobotoolbox server. A verification process was used to correct or eliminate erroneous data. Primary information related to LLIN (possession, using, using on the eve of the survey) was coded in binary form, directly analysed and mapped. Secondary data was obtained through calculation. This included

- LLIN ratio = Number of LLINs owned / Total number of persons in the household
- LLIN Positive Perception Index (IPP) = Maximum possible score / Total score obtained × 100.

The LLIN positive perception index (IPP) is an index that distinguishes between non-use despite ownership and use, which is useful for understanding behavioural barriers (Table I). It was constructed around four observations (LLIN prevents malaria, sleeping under LLIN is good practise, the LLINs distributed are of good quality, and I have confidence in the effectiveness of LLIN) (Table II).

Table 1 Codification of information related to the positive perception index of LLINs

	Score	**Yes**	**No**
LLIN prevents malaria.	25%		
Sleeping under LLIN is good practise.	25%		
The LLIN mosquito nets distributed are of good quality.	25%		
I have confidence in the effectiveness of LLIN.	25%		
Total	100%		
	Score	Yes	No
LLIN prevents malaria.	25%		
Sleeping under LLIN is good practise.	25%		
The LLIN mosquito nets distributed are of good quality.	25%		
I have confidence in the effectiveness of LLIN.	25%		
Total	100%		

Table 2 Interpretation of LLIN's positive perception index

PPI (%)	**Interpretation**
25	Negative perception
50	Mixed perception
75	Positive perception
100	Very positive perception

After calculating the secondary indices, we mapped the different variables and then analyzed the spatial structure of each variable. We evaluated the spatial structure using Moran's global index (22,23). The spatial autocorrelation of indicators related to LLIN was assessed using Moran's global index and Local Moran's I (LISA) analysis, which identified the general trend towards clustering and the precise location of vulnerable areas, respectively. The analyses were performed using QGIS and GeoDa, with a k-neighbor contiguity matrix.

Moran's I and Geary's c Statistics

$$I_{\text{Moran}} = \frac{n}{m} \times \frac{\sum_i \sum_j w_{ij}(z_i - \bar{z})(z_j - \bar{z})}{\sum_i (z_i - \bar{z})^2}$$

$$c_{\text{Geary}} = \frac{n-1}{2m} \times \frac{\sum_i \sum_j w_{ij}(z_i - z_j)^2}{\sum_i (z_i - \bar{z})^2}$$

Where:

- z_i = value of the variable for geographic entity **i**,
- $\bar{z}$ = mean value of the variable,
- i = geographic entity,
- j = neighbors of entity **i**,
- n = total number of geographic entities in the sample,
- m = total number of neighbor pairs,
- $W = [w_{ij}]$ = spatial weights matrix, where elements typically take the value **1** if **i** and **j** are neighbors and **0** otherwise.

This analysis allows us to answer the question of whether households that own, use, etc. are scattered, grouped together or randomly distributed across the two neighbourhoods. Next, we analysed local autocorrelation (LISA / Local Moran's I) (22,23). This step in our reasoning allows us to identify vulnerable areas. Consequently, it allows us to identify the areas to be prioritised in behavioural change interventions in response to LLIN.

3. Results

3.1. Spatial distribution and analysis of indicators related to household LLIN ownership

3.1.1. Possession of LLIN

In both neighbourhoods, the majority of households own LLIN. This reflects good overall coverage following the distribution campaign (Figure 2). However, there are more non-users in Natio-kobadara than in Soba. In Soba, non-owning households are few and scattered, with no notable concentration (I = -0.027). In Natio-Kobadara, there are several clusters of households that do not own LLIN, particularly in the west of the neighbourhood and near the undeveloped outskirts (I = 0.117; p-value = 0.030).

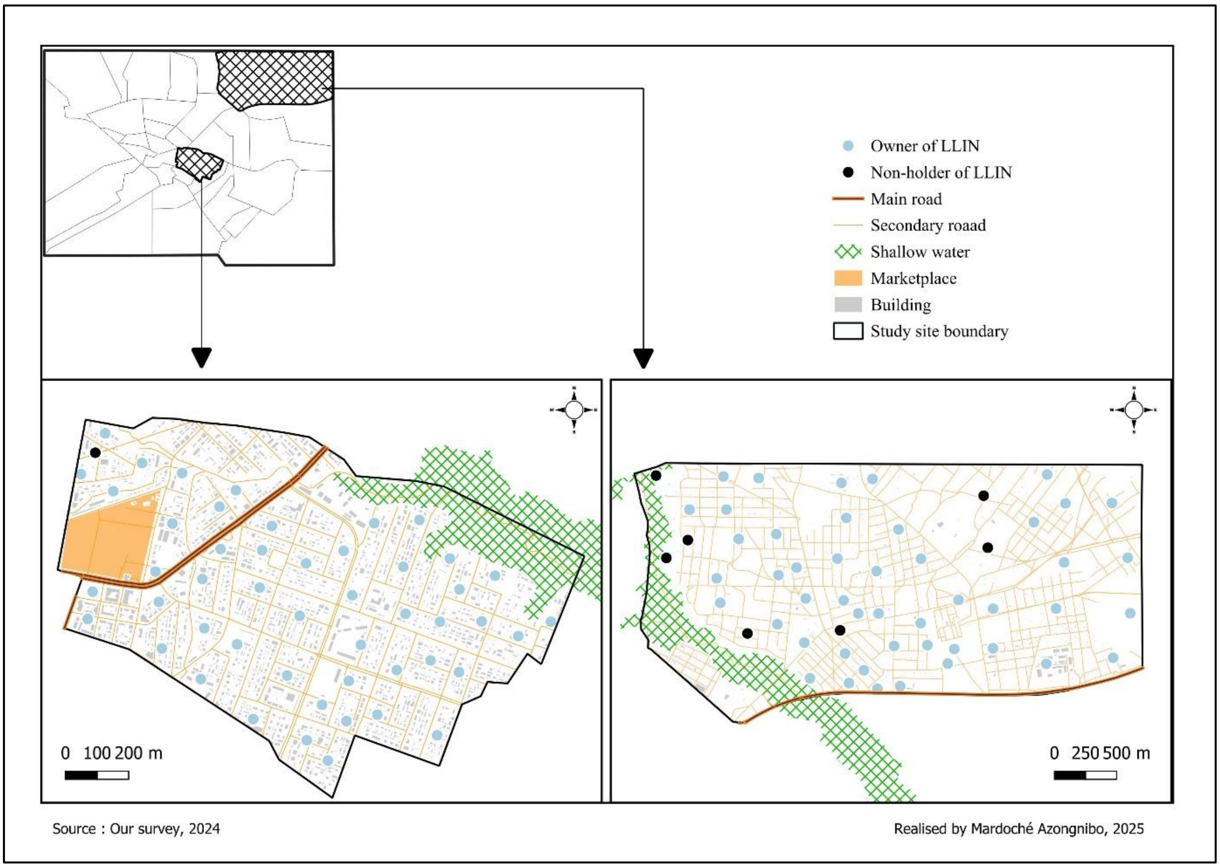


Figure 2 Spatial distribution of LLIN owners in the two neighbourhoods

3.2. The LLIN using

The spatial distribution of LLIN users and non-users reveals a difference between the two neighborhoods (Figure 3). In Soba, the majority of households use LLIN in a virtually uniform manner across the entire neighborhood, resulting in a homogeneous, even random distribution (I = 0.012). Non-users appear in isolated pockets. Although users are in the majority in Natio-kobadara, there are more clusters of non-users, particularly in the west of the neighborhood and on the edge of the lowlands (I=0.246; p-value = 0.100).

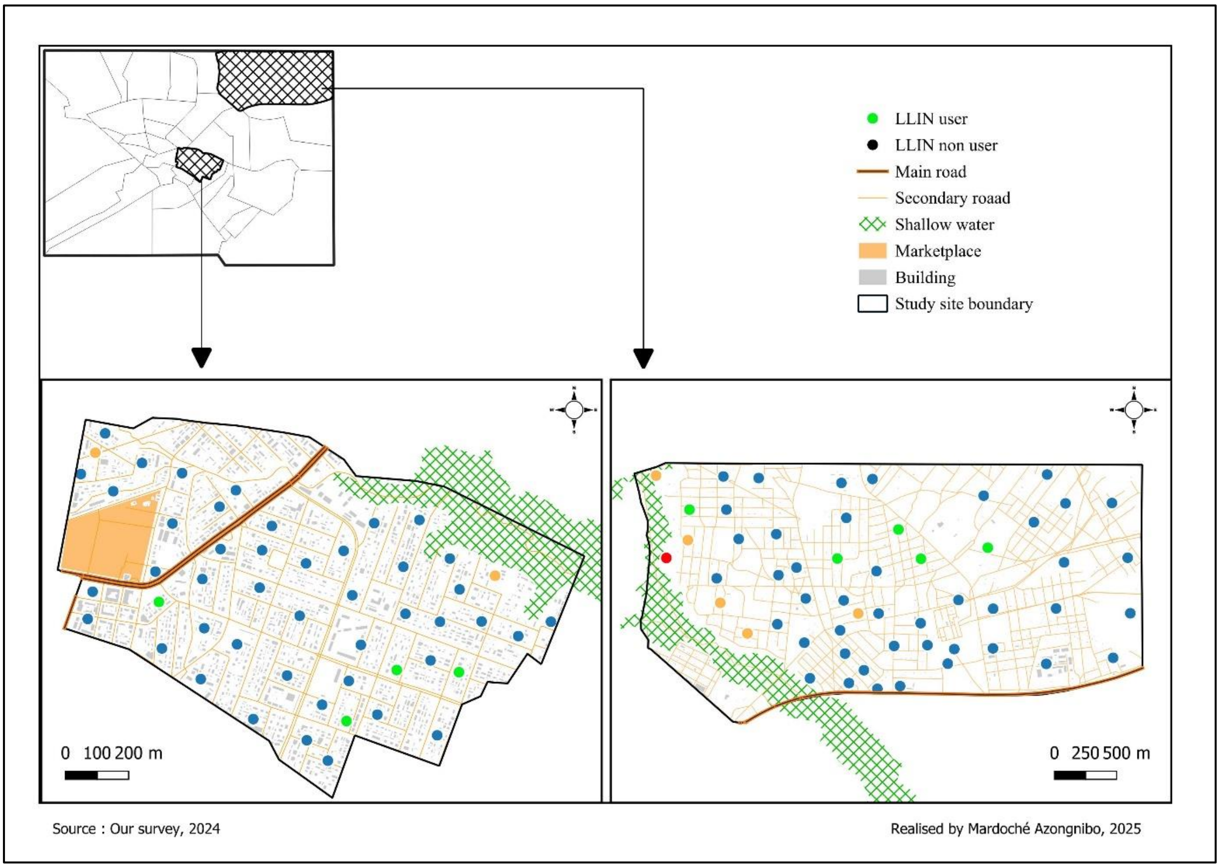


Figure 3 Spatial distribution of LLIN users in the two neighbourhoods

3.3. LLIN using on the eve of the survey

In Soba, the decline in use on the eve of the survey is more pronounced. Although the majority of households have LLIN, several of them did not use it on the night before the survey, suggesting irregularity in protection practices. This situation may reflect a low perception of immediate risk, particularly during periods when vector nuisance is considered low or when night-time heat makes mosquito nets uncomfortable. In Natio-Kobadara, actual usage appears to be more stable overall from one night to the next, but the presence of a core group of non-users located on the western edge, near the lowlands, reveals a persistent spatial vulnerability. The proximity of a wetland, which is potentially conducive to the proliferation of Anopheles mosquitoes, makes this concentration of unprotected households particularly worrying, both from an entomological point of view and in terms of the risk of transmission (I=0.184; p-value = 0.100) (Figure 4).

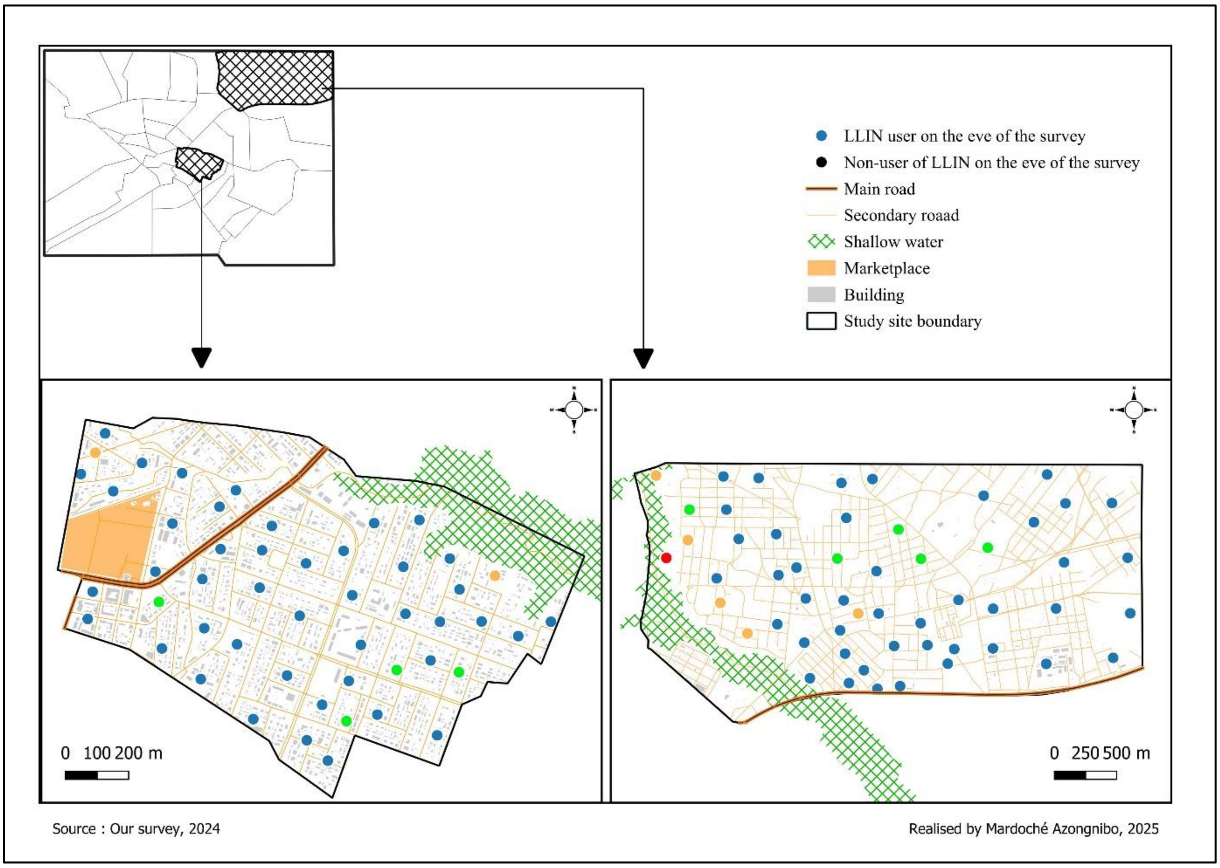


Figure 4 Spatial distribution of LLIN users on the eve of the survey in the two neighbourhoods

3.4. LLIN ratio

The spatial distribution of the LLIN coverage ratio per household in the Soba and Natio-Kobadara neighbourhoods reflects the actual availability of mosquito nets based on household size, which is a direct indicator of protection capacity. In both neighbourhoods, many households are underprotected, despite the generally good ownership rates observed previously (Figure 5).

In Soba, very low coverage is mainly concentrated in the southern and southeastern parts of the neighbourhood, along densely populated secondary roads and near low-lying areas, which increases entomological vulnerability in these under protected but scattered areas (I=-0.049). Nevertheless, there are a few households with very good coverage scattered throughout, suggesting privileged family situations or increased health awareness. In Natio-Kobadara, the neighbourhood has a significant concentration of households with low coverage in an almost homogeneous manner. Households with very low coverage are clearly clustered in the western fringe, on the edge of the low-lying area. Households with good coverage are scattered, with no obvious spatial structure. This configuration indicates a lack of spatial structure in this neighbourhood (I = -0.004).

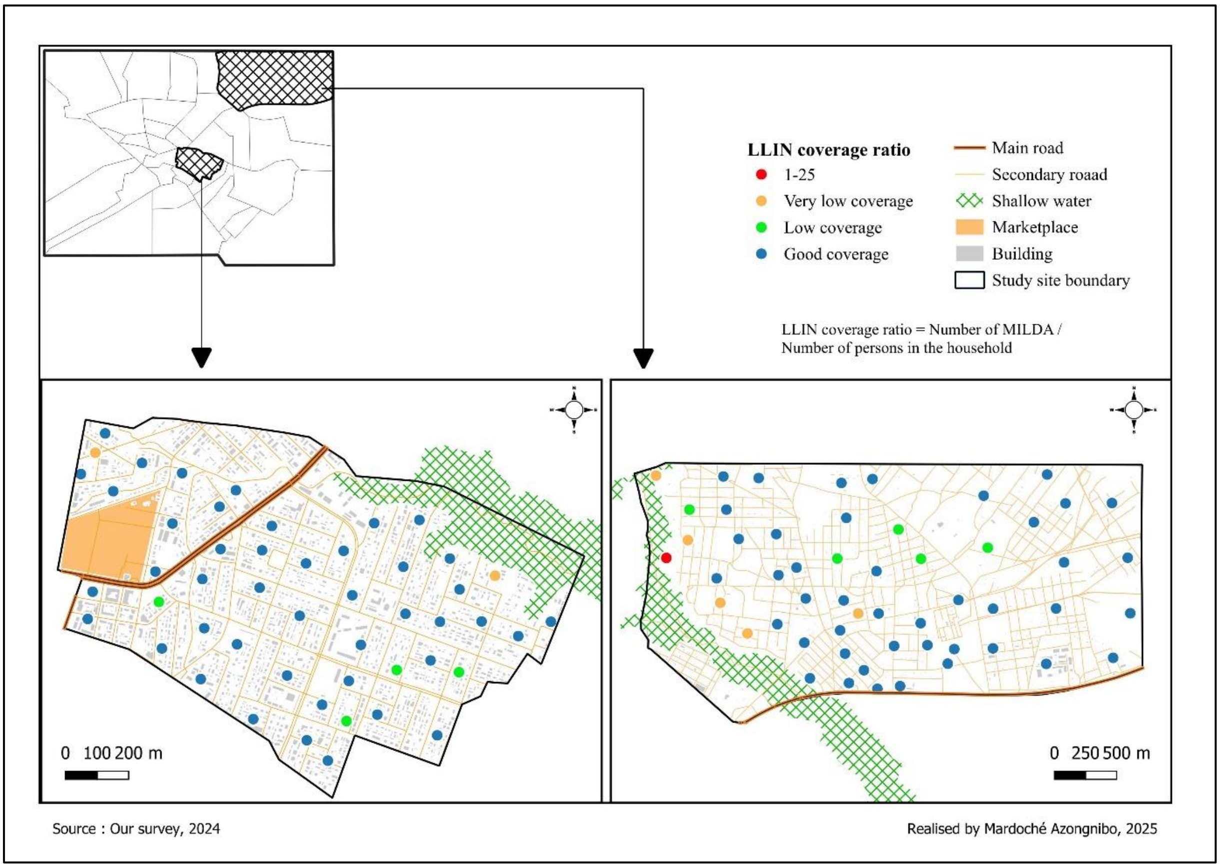


Figure 5 Spatial distribution of the LLIN/household ratio in the two neighborhoods

3.5. LLIN Positive Perception Index (PPI)

In Soba, positive perceptions are in the majority and relatively consistent. Households with low or very low perceptions are mainly located in the east, near the lowlands, and in certain peripheral areas of the neighbourhood (I= -0.109). In Natio-Kobadara, positive perception is also dominant, but less consistent than in Soba. Large pockets of low perception appear in the western fringe, directly bordering the marshy areas and in the southern part of the neighbourhood (I = 0.367; p-value = 0.01) (Figure 6).

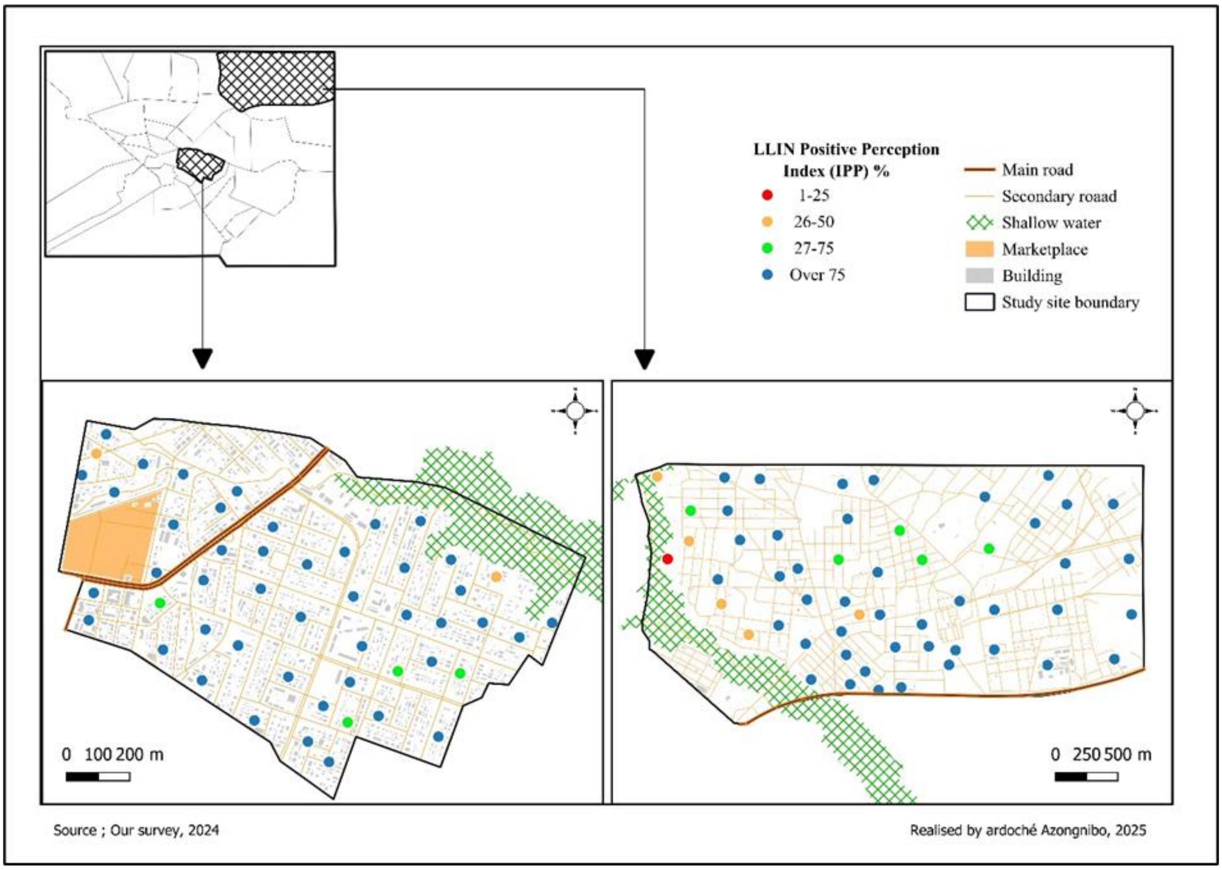


Figure 6 Spatial distribution of the LLIN positive perception index (PPI)

There is a discrepancy between ownership, declared habitual use, and actual use. This discrepancy is geo-localised, confirming that vector risk depends not only on access to prevention methods, but also on behavioural practises rooted in the local area. Although ownership and general use of LLIN are high in both neighbourhoods, actual use on the day before the survey reveals significant intra-urban disparities. In Soba, the decline in actual use suggests behavioural limitations in the adoption of LLIN. In Natio-Kobadara, non-users are mainly concentrated on the edges of stagnant water areas, creating spaces of entomological vulnerability. These results highlight the need for differentiated malaria control strategies, combining behavioural interventions and fine geographical targeting.

4. Discussion

Our work showed high ownership of LLIN in both neighbourhoods, reflecting the effectiveness of the mass distribution campaign carried out in January 2025. This result is consistent with the observations of Sih C and al (2025) (24) in Côte d'Ivoire and those of Koenker H and al (2023) (25) in other African urban contexts, where post-campaign coverage generally reaches high levels in the first few months following distribution.

However, it is important to note that the presence of a mosquito net in the household does not systematically guarantee its effective use. This situation has been widely cited in scientific studies, particularly on malaria in urban areas. Several studies, including those by Buh Nkum C and al (2025) (26) and Merga T and al (2024) (27), highlight a persistent gap between ownership and use, attributed in particular to risk perception, sleeping habits and environmental conditions. The higher proportion of non-users in Natio-Kobadara compared to Soba can be explained by socio-behavioural and structural differences, such as household size, physical environment, ventilation of dwellings, and night-time outdoor sleeping practises, which reduce the incentive for daily use of LLIN. Such situations have been observed in Cameroon by Tchinda VHM and al (2012) (28).

The difference between Soba and Natio-kobadara could also be due to the type of environment. Furthermore, in peri-urban areas such as Natio-kobadara, where urban lifestyles and rural practises overlap, people often have a diminished perception of the risk of malaria transmission. This underestimation of vector risk limits adherence to preventive measures, particularly the systematic use of impregnated mosquito nets at bedtime. Outdoor socialising, residential mobility and greater ventilation of homes reinforce this trend, leading to irregular use of LLIN despite their presence in households. This observation was also made by Djoufounna J and al (2022) (29) in central Cameroon in Makene, as well as by Diop A and al (2023) (30) in three cities in Senegal. It is worth noting that our results highlight the need for targeted awareness-raising activities aimed at households that already have mosquito nets but do not use them regularly, particularly in peri-urban areas. According to the work of, improving usage requires community communication as much as simple material availability.

The using of LLIN on the eve of the survey reveals equally important information. In Soba, the decline in use on the eve of the survey is more pronounced. Although the majority of households there have LLIN. In Natio-Kobadara, actual use appears to be more stable overall from one night to the next, but the presence of a core group of non-users located on the western edge, near the lowlands, reveals a persistent spatial vulnerability. This situation has been observed in Cameroon by Tchinda VHM and al (2012) (28), where the authors explain that use may be limited by night-time heat, ventilation of concessions and sleeping outdoors, which leads to irregular use despite ownership. The work of Adekunle NO and al (2022) (31) in Nigeria reveals that sleeping outside at night is the reason for less use of mosquito nets, even when households have enough of them. Our results are not shared, or at least differ from some studies outside Côte d'Ivoire. Furthermore, according to the work of Yang S et al (2022) (32), usage persists even when the perception of risk is low, as many people use mosquito nets for comfort, to avoid all types of insects, not just mosquitoes. Also, Akello AR and al (2022) (33) have shown that regular usage depends more on availability and sleep patterns than on the perception of risk.

Analysis of the LLIN/household ratio highlights a key point. Despite good overall availability of mosquito nets, several households remain under protected due to the large size of households. This situation reveals the limitations of distribution strategies based on family units rather than on the actual number of individuals to be covered. This situation is shared by Ankomah A and al (2012) (34) in Nigeria. Furthermore, according to them, large households use LLIN less due to space constraints. Standard family distributions do not meet the actual needs of households. Our results also differ from those of Doumbe-Belisse P and al (2021) (35), who argue that areas close to stagnant water are breeding grounds for mosquitoes and have higher rates of night-time bites. This should encourage neighbouring households to own and use LLIN.

Furthermore, the positive perception index (PPI) reveals that perceptions of the effectiveness of LLIN vary depending on residential areas. Areas with low perceptions are mainly located near stagnant water, where vector nuisance is nevertheless greater. This contrast highlights a paradox between high entomological exposure and low preventive adherence. The overlap of these dimensions shows that vulnerability to malaria is both social and spatial. It depends not only on environmental conditions that favour vector proliferation, but also on households' perceptions, knowledge and practises in relation to risk.

Our results are identical to those of Kelly-Hope LA and al (2009) (36), who state that although areas close to lowlands have a higher Anopheles density, the use of LLIN is not systematically higher there. The work of Bamou R and al (2022) (37) in southern Cameroon corroborates our results. Furthermore, according to the authors, the perception of risk varies according to land use patterns, directly influencing adherence to preventive measures. This could explain the controversy. According to the work of Njatosoa AF and al. (2021) (38) in Madagascar, regular use of mosquito nets depends on the spatial organisation of households and local perceptions, not just availability.

5. Conclusion

This study highlights the importance of going beyond traditional indicators of LLIN coverage by incorporating a detailed geospatial approach. Although mosquito net ownership is generally satisfactory in both neighbourhoods, actual use and effective protection of households remain uneven. The identified underprotected areas, particularly on the edge of the lowlands in Natio-Kobadara and in certain peripheral parts of Soba, represent areas where the risk of transmission remains high.

These results show the need to adopt differentiated control strategies, combining complementary distribution, community monitoring, strengthening the positive perception of LLIN, and spatial targeting of vulnerable households. Taking the territorial dimension into account appears essential to strengthen the effectiveness of anti-malaria interventions and move towards a sustainable reduction in transmission in urban and peri-urban areas.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

All authors declare no conflicts of interest related to this study.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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