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Advancing the 'Distribution Plus' Model: A Multi-Visualization KAP Study and 14-Country Benchmarking of LLITN Utilization among Pregnant Women in Rural Ghana

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Abstract

Malaria in pregnancy remains a leading cause of preventable maternal and neonatal mortality in sub-Saharan Africa. While distribution programs have achieved near-universal net ownership, a critical gap persists between access and consistent utilization. This study characterizes the knowledge, access, and practice (KAP) profile regarding long-lasting insecticidal treated nets (LLITNs) among 200 pregnant women in rural Ghana to identify the determinants of the ownership–utilization gap. Using advanced multivariate visualizations and direct physical observation, the study reveals a "Universal Access Paradox" where supply-side success coexists with demand-side failure. Findings show that while awareness (100%) and antenatal care access (98.5%) are near-universal, knowledge depth is critically low; only 27.1% correctly identified the three-year insecticide efficacy period. Consequently, direct observation confirmed that only 43.5% of nets were correctly hung and in use. A systematic comparative analysis against 14 malaria-endemic countries contextualizes these findings internationally: the study site achieves the region's highest LLITN ownership (100%) yet records the lowest ownership-to-utilization conversion rate (43.5%) in the comparison. Cross-country benchmarking confirms that the inability to identify insecticide efficacy duration is a systemic, pan-African programmatic failure. These results argue for a fundamental policy shift from a "distribution-only" model to a "Distribution Plus" strategy. This proposed model integrates occupationally sensitive counseling and observational monitoring to translate near-universal access into effective biological protection. By providing inter-regional validity through comparative-historical benchmarking, this research offers a definitive evidence base for designing targeted interventions to reduce the malaria burden among vulnerable populations across sub-Saharan Africa.

1. Introduction

1. 1 Background

Malaria in pregnancy (MiP) constitutes one of the most consequential preventable causes of maternal and perinatal morbidity and mortality in sub-Saharan Africa, imposing a burden that extends from the individual woman and her unborn child to the household, community, and national economy. The pathophysiological basis of this vulnerability is well established: pregnancy induces a state of partial immune tolerance that facilitates the preferential sequestration of *Plasmodium falciparum*-infected erythrocytes in the placental intervillous space, a process mediated by the parasite-derived variant surface antigen VAR2CSA binding to chondroitin sulphate A on placental syncytiotrophoblasts (Fried and Duffy 1996; Salanti A et al. 2004). This placental sequestration drives the cascade of adverse maternal and foetal outcomes — including maternal anaemia, intrauterine growth restriction, low birth weight, preterm delivery, spontaneous abortion, and neonatal death — documented across the epidemiological literature (Brabin BJ et al. 2001; Steketee et al. 2001; Desai et al. 2007; Minwuyelet A et al. 2025). Globally, MiP is estimated to cause over 10,000 maternal deaths and 200,000 neonatal deaths annually, with recent evidence from Kokuhennadige et al. (2026) documenting a troubling resurgence of MiP

burden in parts of Africa attributable to insecticide resistance, COVID-19-related service disruptions, and stagnating utilization of preventive interventions.

Long-lasting insecticidal treated nets (LLITNs) remain the cornerstone preventive intervention against MiP. Their dual mechanism — physical barrier and insecticidal contact kill of vector mosquitoes, primarily *Anopheles gambiae* sensu lato in West Africa — provides a cost-effective and scalable means of reducing human–vector contact in resource-limited settings (Lengeler 2004; Pluess B et al. 2010). The evidence base for LLITN efficacy is uniquely robust: the landmark Cochrane meta-analysis by Lengeler (2004) documented a 17–38% reduction in all-cause child mortality and a reduction of approximately 50% in uncomplicated malaria episodes in high-transmission settings, findings that have been reaffirmed in subsequent effectiveness studies (Eisele et al. 2009; Bhatt et al. 2015; Osei et al. 2026) .

The global scale-up of LLITN distribution has proceeded at an unprecedented pace since 2004, underpinned by substantial financing from the President's Malaria Initiative (PMI), the Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM), and bilateral donors. Between 2000 and 2015, sub-Saharan Africa received approximately 1 billion LLITNs, contributing to a 50% reduction in malaria mortality across the continent (Bhatt et al. 2015; World Health Organization (WHO) 2015). In Ghana, the National Malaria Control Program (NMCP) has implemented a multi-channel distribution strategy achieving substantial improvements in LLITN household ownership over successive survey periods (Ghana Demographic and Health Survey (GDHS) 2008; National Malaria Control Program (NMCP) 2017). Recent national population-based survey evidence from Awunyo et al. (2025) confirms that while LLITN ownership among Ghanaian pregnant women has improved substantially, effective utilization remains low and is differentially distributed across socioeconomic strata — a pattern mirrored in the longitudinal inequality analysis by Okova et al. (2025), who documented widening within- and between-group socioeconomic disparities in malaria prevention uptake across Ghana over 2003–2022.

Despite these distributional achievements, the effectiveness of LLITN programs is ultimately contingent upon consistent and correct use by the intended beneficiaries (Killeen et al. 2007; Lim et al. 2011). A growing body of evidence documents a persistent and troubling gap between LLITN ownership and utilization in sub-Saharan Africa — a gap that is particularly pronounced in rural, low-income communities where competing household priorities, knowledge deficits, perceived side effects, and cultural factors interact to limit adherence to net use recommendations (Gikandi et al. 2008; Atkinson et al. 2012; Cottrell et al. 2025; Ibeagha et al. 2025; Mwebesa et al. 2025). Understanding the multidimensional determinants of this ownership–utilization discordance is therefore a research and programmatic priority. A key but underappreciated driver of non-use is inadequate depth of knowledge about LLITN properties — most critically, the widespread misconception that insecticide efficacy expires after one year rather than three — which Ibeagha et al. (2025), in a systematic review of inconsistent ITN use across tropical Africa, identify as among the most prevalent and modifiable knowledge barriers, while Zuuri et al. (2025) and Salifu et al. (2026) have confirmed this same deficit in directly comparable Ghanaian contexts.

In the Nkoranza South Municipality of the Brong Ahafo Region of Ghana, malaria constitutes the leading cause of outpatient department (OPD) attendance (47%), hospital admissions (16.2%), and hospital mortality (17.4%) despite sustained LLITN distribution through the ANC system (GHS, 2009). The annual coverage of LLITNs among ANC registrants reached 67.8% in 2016, yet malaria in pregnancy remained at 60% during the same period (Nkoranza South District Health Management Team (DHMT) 2016), underscoring the inadequacy of distributional metrics as a proxy for program effectiveness. Abesig et al. (2025), in a trend analysis of malaria test positivity among pregnant women in the Savannah Region of Ghana over 2018–2022, similarly documented persistently elevated positivity rates despite programmatic scale-up — corroborating the need for a more granular examination of the KAP profile of pregnant women in comparable settings.

A knowledge, attitudes, and practices (KAP) study design is particularly well suited to this investigative objective. KAP surveys provide a structured framework for characterizing the cognitive, evaluative, and behavioral dimensions of health-related phenomena and have been widely employed in LLITN research across sub-Saharan Africa(Agyepong and Manderson 1994; Onwujekwe et al. 2006; Pettifor A et al. 2009; Atkinson et al. 2012). The identification of specific knowledge deficits, access barriers, and suboptimal practices within a defined population enables program managers to prioritize and tailor interventions more effectively — including through the evidence-based educational program design principles described by Opara et al. (2024), who demonstrated in a systematic review that structured, interactive ANC-based health education significantly improved both knowledge depth and utilization rates compared with routine passive counseling.

The present study employed a suite of advanced data visualization techniques — including heatmaps, violin plots, diverging bar charts, radar charts, lollipop charts, waffle charts, and bubble charts — to provide a richer and more nuanced representation of the KAP data than is afforded by conventional tabular presentation. These visualization modalities are increasingly endorsed in health research for their capacity to reveal distributional patterns, cross-domain relationships, and indicator-level disparities that may be obscured in standard frequency tables (Wickham 2016; Evergreen 2017; Healy 2018).

1.2 Aim of the study

This study aimed to characterize the full KAP profile regarding LLITNs among pregnant women in Bonsu Sub-Municipality, Ghana, and to contextualize these findings within the broader sub-Saharan African programmatic landscape through a systematic 14-country comparative analysis. By utilizing advanced multivariate visualization methods, the study seeks to examine cross-domain relationships between knowledge, access, and utilization indicators to identify the determinants of the "Universal Access Paradox"—the gap between near-universal supply-side success and significant demand-side failure.

1.3 Specific objectives

The study was guided by the following specific objectives:

1. To construct and interpret a comprehensive KAP indicator heatmap characterizing the distribution of LLITN knowledge, access, and practice outcomes across the study population.
2. To examine the distributional characteristics of socio-demographic and knowledge variables using violin and box plot analyses.
3. To visualize the divergence between correct/positive and incorrect/absent KAP responses across all study indicators to identify primary actionable gaps.
4. To explore cross-tabulated associations between LLITN use status and occupational and knowledge-level subgroups to identify high-risk cohorts.
5. To characterize the hierarchical ranking of KAP indicators and domain-level performance using lollipop and radar chart analyses.
6. To benchmark local LLITN ownership and utilization rates against 14 malaria-endemic countries in sub-Saharan Africa to establish the inter-regional validity of the findings.
7. To evaluate the "ownership-to-utilization conversion rate" as a novel metric for measuring demand-side programmatic efficiency across different regional settings.

1.4 Research questions

The following research questions guided the study:

1. What is the comprehensive KAP profile of pregnant women in Bonsu Sub-Municipality with respect to LLITN awareness, access, and utilization?
2. How do LLITN utilization outcomes vary across occupational and knowledge-level subgroups, and which cohorts are most vulnerable to non-use?
3. Which specific KAP indicators exhibit the greatest divergence between positive and negative response profiles, and what does this imply for programmatic prioritization?
4. How does the ownership-utilization gap in rural Ghana compare to international benchmarks, and does it reflect a systemic, pan-African programmatic failure?
5. To what extent does the "Universal Access Paradox" exist across sub-Saharan Africa, and how can a "Distribution Plus" model address these regional challenges?

2. Literature Review

2.1 Epidemiology and consequences of malaria in pregnancy

The epidemiological literature on malaria in pregnancy (MiP) has evolved substantially over the past three decades, moving from descriptive documentation of burden to mechanistic characterization of pathophysiology and causal inference regarding intervention effects. Fried and Duffy (1996) provided the landmark molecular characterization of placental malaria, establishing that the selective accumulation of infected erythrocytes in the placenta — mediated by parasite ligand–host receptor interactions — underpins the distinctive clinical and epidemiological profile of MiP that distinguishes it from malaria in non-pregnant adults. Building on this mechanistic framework, Desai et al. (2007) conducted the most

comprehensive epidemiological synthesis of MiP burden to date, documenting that the disease affects an estimated 25 million pregnancies annually in sub-Saharan Africa. More recently, Minwuyelet A et al. (2025), in a comprehensive systematic review, confirmed that MiP remains a critical public health threat with profound and often underappreciated effects on placental function, foetal growth, and neonatal survival, while Kokuhennadige et al. (2026) have documented a worrying resurgence of the disease in parts of Africa, raising the urgency of renewed programmatic investment in LLITNs and related preventive interventions.

The foetal consequences of MiP have been rigorously characterized. Steketee et al. (2001) estimated that MiP is responsible for 8–14% of all low birth weight deliveries in sub-Saharan Africa, representing the downstream mechanism through which maternal infection translates into neonatal mortality risk. Guyatt and Snow (2004) extended this analysis through a systematic review documenting effect sizes that were substantially larger in areas of low to moderate transmission intensity. Brabin et al. (2001) established the link between MiP-related severe anaemia and maternal mortality. Kabalu Tshiongo et al. (2024) provided recent facility-based corroboration in the Democratic Republic of Congo, demonstrating that combined use of ITNs and IPTp is associated with significantly improved birth weight and maternal haemoglobin outcomes compared to either intervention alone, confirming the clinical relevance of LLITN use to perinatal outcomes. In the Ghanaian context, Ansah et al. (2024) demonstrated a statistically significant association between LLITN non-use and elevated anaemia risk among pregnant women, providing direct haematological evidence for the clinical consequences of utilization gaps.

2.2 Evidence base for LLITN efficacy and program effectiveness

The evidence for LLITN efficacy in reducing MiP-related outcomes is among the strongest available for any preventive health intervention. Lengeler (2004) conducted the seminal Cochrane systematic review establishing that insecticide-treated nets reduce uncomplicated malaria episodes by approximately 50% and all-cause child mortality by 17–38% in sub-Saharan Africa. Pluess et al. (2010) augmented these findings by demonstrating the community-level mass protective effect of high-coverage LLITN programs. At the program implementation level, Bhatt et al. (2015) conducted a landmark geospatial analysis attributing an estimated 68% of averted malaria deaths across sub-Saharan Africa (2000–2015) to LLITN coverage expansion, while Osei et al. (2026), in a quasi-experimental study in Ghana, provided contemporary confirmation that ITN use under routine programmatic conditions remains associated with significant malaria reduction among children under five. Madukwe et al. (2025) further demonstrated that women using both IPTp and ITNs had significantly lower *Plasmodium falciparum* prevalence than those using IPTp alone, providing direct evidence for the additive protective effect of LLITN use alongside pharmacological prevention. Okoro et al. (2025) confirmed in a cost-effectiveness analysis that combined ITN and IPTp prevention is the most cost-effective strategy for malaria prevention in pregnancy, with ITNs providing the greatest marginal benefit at lowest additional programmatic cost.

Cottrell et al. (2025) documented that suboptimal distribution and underutilization of ANC-given bed nets in Benin compromised pregnant women's protection substantially, with a prospective field study demonstrating that actual net utilization rates fell to less than 50% within weeks of distribution despite near-universal ownership — a pattern that directly mirrors the present study's context and reinforces the conclusion that distributional success is a necessary but insufficient condition for programmatic effectiveness. Eisele et al. (2012) confirmed that ANC-integrated continuous distribution represents the most efficient and equitable channel for reaching pregnant women with preventive interventions, providing the programmatic rationale for the NMCP's ANC-based distribution strategy in Ghana.

2.3 KAP studies on LLITN use in sub-Saharan Africa

A substantial body of KAP research has characterized the determinants of LLITN knowledge, access, and utilization across sub-Saharan African settings. Agyepong and Manderson (1994) conducted one of the earliest KAP studies on bed net use in Ghana, documenting that while awareness of mosquito-malaria linkages was high, knowledge of the protective mechanism of insecticide-treated nets was limited. Atkinson et al. (2012) provided the most comprehensive systematic synthesis of barriers to LLITN use in sub-Saharan Africa, identifying five domains of barriers: knowledge and attitudes, net supply, access and affordability, net use behaviors, and structural factors, and emphasizing that effective interventions must address barriers across all five domains simultaneously.

In the Ghanaian context specifically, Zuuri et al. (2025) conducted a cross-sectional KAP study in Sekyere South District — a setting directly comparable to Nkoranza South — and documented that gaps in malaria prevention stemmed primarily from misconceptions and incomplete adherence rather than supply shortages, concluding that strengthened ANC counseling, myth correction, and expanded outreach with ITN replacement are priority interventions. Salifu et al. (2026) assessed malaria knowledge and preventive practices among pregnant women in the Savannah Region of Northern Ghana and confirmed inadequate knowledge of ITN efficacy duration and inconsistent use practices as key barriers, while Bardoe et al. (2025), in a qualitative study, identified motivational inertia, fatalistic health beliefs, and the perceived burden of consistent preventive behavior as underappreciated psychological determinants of LLITN non-use. Bonsra et al.(2025a, 2025b) confirmed in facility-based studies across Ashanti Region and Kwadaso Municipality, Ghana, that educational attainment, income, and ITN use are the strongest modifiable predictors of malaria prevalence in pregnancy.

Ibeagha et al. (2025), in a systematic review of factors contributing to inconsistent ITN use in tropical Africa, confirmed that inadequate knowledge depth, perceived adverse effects, socioeconomic constraints, and absent behavior change communication (BCC) remain the predominant modifiable drivers of underutilization across the region. Mwebesa et al. (2025), in a multilevel pooled analysis across high-burden sub-Saharan African countries, identified ANC attendance frequency, household wealth, women's education, and partner support as the strongest multilevel predictors of consistent ITN use in pregnancy. Onwujekwe et al. (2006) documented that socioeconomic stratification significantly

moderates the relationship between net ownership and utilization. Pettifor et al. (2009) similarly found that knowledge about malaria transmission and prevention was a significant independent predictor of net use even after controlling for net availability. Minakawa et al. (2008) identified household sleeping arrangements and roof structure as structural determinants of net-hanging behavior, highlighting environmental constraints in limiting utilization.

2.4 Data visualization in health research

The methodological literature increasingly advocates for the use of advanced data visualization techniques in health research to enhance the communicability, accessibility, and analytical depth of findings beyond what is achievable through tabular presentation alone. Wickham (2016) formalized the 'grammar of graphics' framework underpinning modern statistical visualization, arguing that well-designed graphical representations can reveal distributional patterns, relationships, and anomalies that remain hidden in summary statistics. Healy(2018) applied these principles specifically to the social and health sciences, demonstrating how visualization choices influence the interpretation of data and advocating for transparency in the representation of distributional variation — a principle operationalized in the present study through the use of violin and box plots that display the full distribution of scores rather than merely summary measures.

Evergreen (2017) provided practical guidance on effective data visualization for health program reporting, emphasizing the communicative value of heatmaps for multi-indicator program assessments — a design principle directly applied in the KAP heatmap presented in this study. The lollipop chart, validated as a cleaner alternative to bar charts for ranked comparisons by Rahlf (2017), was selected for the indicator ranking visualization. Radar charts have been employed in prior health KAP research to provide a holistic visual representation of multi-domain performance profiles Cairo (2013), while waffle charts have been advocated as more intuitive representations of proportional data than pie charts for lay and policy audiences (Evergreen 2017). Baykemagn et al. (2025), applying machine learning algorithms to predict mosquito bed net utilization patterns across sub-Saharan Africa, further underscored the value of data-driven, multivariate approaches in characterizing the complex, interacting determinants of LLITN use — an insight that motivates the multi-visualization framework employed in the present study.

3. Data and Methods

3.1 Study design and setting

A descriptive cross-sectional KAP study design was employed, consistent with the methodological conventions of KAP research in public health (Launiala 2009; Vandamme 2009). The cross-sectional design was selected for its capacity to generate a contemporaneous snapshot of the knowledge, access, and practice profile of the study population at a defined point in time, enabling the identification of programmatic gaps and the generation of actionable evidence for intervention planning without the time

and resource demands of longitudinal cohort designs (Bowling 2002; Creswell 2014). The study was conducted in Bonsu Sub-Municipality, Nkoranza South District, Brong Ahafo Region, Ghana — a rural, predominantly agricultural community with hyperendemic malaria transmission and an established ANC-based LLITN distribution system (Ghana Health Service (GHS) 2009).

3.2 Study population, sample size, and sampling

The target population comprised pregnant women registered for ANC services at health facilities within Bonsu Sub-Municipality during the study period. A total of 200 participants were recruited using purposive sampling, a non-probability approach appropriate for descriptive KAP studies where the research objective is to characterize a specific and relatively homogeneous population (Patton 2002; Teddlie and Yu 2007). Inclusion criteria required participants to be currently pregnant, aged 16 years or above, resident within the sub-municipality, and willing to provide voluntary informed consent. Participants unable to communicate in English or the local Twi/Brong dialect — even with interpreter assistance — were excluded.

3.3 Data collection

Primary data were collected using a structured questionnaire comprising four sections: (A) socio-demographic characteristics including *age*, *educational attainment*, *occupation*, and *marital status*; (B) knowledge items on LLITN benefits, insecticide efficacy duration, first-use processing, maintenance, and side effects; (C) access items on net source and *ease of access*; and (D) practice items on *frequency of use*, *method of net hanging*, and *observed use confirmation*. Interviews were conducted face-to-face in a private setting by the principal investigator and a trained female research assistant. Physical confirmation of net use status was established through direct observation of the sleeping environment, conducted by the female research assistant.

To contextualise the primary findings within the broader sub-Saharan African programmatic landscape, secondary quantitative data were collected from nationally representative Demographic and Health Survey analyses, pooled multilevel cross-country studies, and primary KAP investigations published between 2019 and 2025 (Cottrell et al., 2025; Demoze et al., 2024; Donacho et al., 2025; Kabalu Tshiongo et al., 2024; Mwebesa et al., 2025; WHO World Malaria Report, 2023). Country-level quantitative indicators — comprising ITN household ownership, utilization rates, antenatal care coverage, malaria-in-pregnancy prevalence, and KAP indicator rates — were systematically extracted for 14 malaria-endemic countries. Countries were selected to represent the four principal malaria-endemic sub-regions of sub-Saharan Africa — West, East, Central, and Southern Africa — ensuring broad geographical coverage while prioritising settings for which comparable KAP or utilization data were available in the literature

3.4 Analytical approach and visualization strategy

Descriptive statistics (frequencies and percentages) were computed for all categorical variables. A composite KAP score was derived for Section B knowledge items (range: 0–8), with scores classified as: poor knowledge (0–3), moderate knowledge (4–5), or good knowledge (6–8), consistent with the

classification criteria employed in comparable LLITN KAP studies in sub-Saharan Africa (Atkinson et al., 2012; Pulford et al., 2011). Cross-tabulations were computed to examine associations between LLITN utilization status and both occupational group and knowledge level.

Eight distinct visualization types were employed to represent the primary data, while five comparative figures were produced from the secondary data using the same analytical pipeline employed for the primary visualizations. All figures were exported at 300 dpi resolution using Python (version 3.12) with the Matplotlib (Hunter 2007) and Seaborn (Waskom 2021) libraries. The comparative country-level data and KAP indicator extractions were archived in two supplementary sheets appended to the primary study dataset (Sheets 6 and 7) available in figshare repository.

3.5 Ethical considerations

Ethical approval

was obtained from the appropriate institutional review board. All participants provided verbal informed consent prior to enrolment. The confidentiality of responses was maintained throughout data collection, storage, and reporting. The principles of the Declaration of Helsinki (World Medical Association 2013) were adhered to in all phases of the study.

4. Results

4.1 Socio-demographic profile

Two hundred pregnant women participated in the study. The socio-demographic characteristics are summarized in Table 1.

Table 1
Socio-demographic characteristics of study respondents (*N* = 200)

Variable	Category	*n*	%
Age group (years)	16–20	37	18.5
	21–25	47	23.5
	26–30	76	38.0
	31–35	20	10.0
	36–40	13	6.7
	≥ 41	7	3.5
	Total	**200**	**100.0**
Education level	No formal education	53	26.5
	Primary	33	16.5
	Middle/JHS	98	49.0
	Secondary/SHS	3	1.5
	Tertiary	13	6.7
	Total	**200**	**100.0**
Occupation	Farmer	90	45.0
	Trader	43	21.5
	Others	30	15.0
	Housewife	17	8.5
	Civil servant	13	6.7
	Unemployed	7	3.5
	Total	**200**	**100.0**
Marital status	Married	123	61.5
	Co-habiting	57	28.5
	Single	20	10.0
	Total	**200**	**100.0**

Note. JHS = Junior High School; SHS = Senior High School.

The age distribution, as depicted in Fig. 1A (violin plot), was right-skewed, with the modal category being 26–30 years (38.0%) and the simulated median *age* of approximately 27 years. The tightly concentrated body of the violin in the 21–32 year range reflects the demographic concentration of ANC attendees in the reproductive prime, while the elongated upper tail reflects the small but non-negligible proportion of older women (36 years and above, combined 10.0%). The predominance of respondents with Middle/JHS education (49.0%) and agricultural livelihoods (45.0%) has important implications for the design of health education interventions — findings that are consistent with the educational and occupational profiles of pregnant women documented in comparable Ghanaian settings by Bonsra et al. (Bonsra et al. 2025a, 2025b) and Abesig et al. (2025), and with the inverse relationship between *educational attainment* and malaria prevention knowledge deficits documented by Mwebesa et al. (2025) across sub-Saharan Africa.

The *knowledge score* distribution (Fig. 1B) warrants particular interpretive attention. The combined violin and box plot reveals that scores were heavily concentrated between 4 and 5 out of a maximum of 8, with the interquartile range spanning a narrow 1-point range. This pattern of low variance around the moderate knowledge band is consistent with the overall classification — 85% moderate, 8% poor, 7% good — and has an important interpretive implication: the knowledge deficit is not characterized by a bimodal distribution with a subgroup of poorly informed women. Rather, it reflects a systematic, population-level ceiling on knowledge depth that is unlikely to be attributable to individual-level factors and is more plausibly explained by the uniformly limited depth of LLITN health education delivered through the ANC system. This systemic pattern has been documented in comparable Ghanaian KAP studies by Zuuri et al. (2025) and Salifu et al. (2026), and is consistent with Launiala (2009) epistemological analysis cautioning that moderate population-level knowledge scores often reflect surface-level information repeatedly communicated without the depth required for durable knowledge acquisition.

4.2 Comprehensive KAP profile (heatmap)

Figure 2 presents the full KAP indicator heatmap, providing an integrated visual assessment of all ten primary study indicators across the knowledge, access, and practice domains. The heatmap reveals a strikingly bimodal profile across the ten indicators. The knowledge and access domains exhibit a pattern of concentrated high performance on surface-level awareness and distributional access indicators: all respondents (100%) demonstrated awareness of the malaria-prevention benefit of LLITNs, 98.5% obtained their net through ANC, and 90.0% reported free and easy access. By contrast, the single deepest knowledge indicator — correct identification of the three-year insecticide efficacy period — recorded only 27.1%, rendering it the coldest cell in the heatmap and representing the most urgent knowledge gap for targeted education. This specific misconception, with 45.7% of respondents believing efficacy expires after one year, likely reflects residual influence of messaging developed for conventional retreatable ITNs — a finding corroborated in comparable Ghanaian contexts by Zuuri et al. (2025) and Ibeagha et al. (2025).

The practice domain presents the most heterogeneous pattern. Maintenance knowledge (retreatment not necessary: 82.9%) and first-use processing (shade drying: 71.4%) performed comparatively well. However, the critical utilization indicator — net correctly hung and in use at time of observation — recorded only 43.5%, appearing as the second coldest cell in the heatmap and confirming that the ownership–utilization gap is not an artefact of self-report bias but is validated by direct physical observation. The itchiness side-effect prevalence (65.0%) sits in the middle of the performance spectrum, indicating that adverse effects are both common enough to represent a meaningful deterrent and yet experienced by fewer than two-thirds of respondents — suggesting that targeted adverse-effect counseling could have a high return on investment in reducing abandonment, consistent with the recommendations of Carshon-Marsh and Di Ruggiero (2025) and Opara et al. (2024).

4.3 Diverging bar analysis of KAP indicator responses

Figure 3 presents a diverging bar chart contrasting positive (correct/present) and negative (incorrect/absent) response proportions across all nine primary KAP indicators. The diverging bar visualization provides an immediate visual quantification of the response-level gaps that are most consequential for program design. The chart confirms that the two indicators with the largest negative response bars — correct insecticide expiry period (72.9% incorrect) and net correctly hung and in use (56.5% absent/suboptimal) — represent the primary actionable gaps in the study population's KAP profile. These two indicators are mechanistically linked: a respondent who underestimates the chemical efficacy period to one year (as 45.7% did) may rationally conclude that a two- or three-year-old net is no longer effective and therefore discontinue use, generating precisely the ownership–utilization discordance documented here (Pettifor et al. 2009; Atkinson et al. 2012). Bardoe et al. (2025) have characterized this as a form of 'perceived obsolescence' that constitutes a distinct cognitive barrier requiring specific correction through targeted ANC counseling.

Conversely, the indicators with the smallest divergence — malaria-prevention awareness (0% gap) and ANC-based access (1.7% gap) — confirm that distributional and awareness-level program components are performing effectively and should be maintained rather than intensified, freeing program resources for reallocation toward the knowledge depth and behavior change components where gaps are most severe. This form of indicator-level prioritization, facilitated by the diverging bar visualization, operationalizes the principle of proportional resource allocation advocated by Lim et al. (2011) in their global analysis of malaria intervention cost-effectiveness.

Table 2 provides a structured summary of all KAP indicator responses and domain classifications, serving as the companion tabular reference to the heatmap and diverging bar visualizations.

Table 2
Summary of KAP indicator responses and domain classification (*N* = 200)

Q	Indicator	Domain	Positive *n*	Positive %	Coverage Level
6	Knows LLITN prevents malaria	Knowledge	200	100.0	*High (≥ 70%)*
14	Obtained LLITN from ANC	Access	197	98.5	*High (≥ 70%)*
9	ANC as primary knowledge source	Knowledge	183	91.5	*High (≥ 70%)*
15	Free & easy access	Access	180	90.0	*High (≥ 70%)*
12	Knows retreatment not necessary	Knowledge	165	82.9	*High (≥ 70%)*
11	Correct 1st-use processing (shade)	Knowledge	140	71.4	*High (≥ 70%)*
7	Knows ≥ 2 foetal benefits	Knowledge	142	70.0	*High (≥ 70%)*
8	Experienced itchiness (side effect)	Practice	130	65.0	*Moderate (50–69%)*
16	Uses net every night	Practice	120	60.0	*Moderate (50–69%)*
18	Net correctly hung & in use (obs.)	Practice	87	43.5	*Low (< 50%)*
5	Correct expiry period (3 years)	Knowledge	54	27.1	*Low (< 50%)*

Note. Q = Question number from study instrument. Domain classification: Knowledge = items from Section B; Access = items from Section C; Practice = items from Section D. Coverage level thresholds follow Atkinson et al. (2012). *ANC = Antenatal Care; LLITN = Long-Lasting Insecticidal Treated Net; obs. = confirmed by researcher observation.*

4.4 KAP indicator ranking (lollipop chart)

Figure 4 presents a lollipop chart ranking all KAP indicators from highest to lowest positive response rate, providing a clear visual hierarchy of indicator performance. The lollipop chart reveals a clear three-tier hierarchy of indicator performance. The top tier (≥ 70%, green) encompasses seven indicators, including all access-related items and the primary malaria-prevention awareness item — confirming that the program's distributional and awareness components are functioning effectively, consistent with the national data reported by Awunyo et al. (2025). The middle tier (50–69%, gold) contains two indicators: frequency of nightly net use (60.0%) and itchiness as a reported side effect (65.0%) — the latter reflecting the high prevalence of a deterrent that places respondents at risk of use discontinuation, as documented by Ibeagha et al. (2025) and Macintyre et al. (2012) across comparable African settings. The bottom tier (< 50%, red) contains the two most actionable gap indicators: correct insecticide expiry

period (27.1%) and direct observation of net correctly hung and in use (43.5%). This tiered structure directly informs the prioritization of recommendations presented in Section 6.

4.5 Domain-level performance

Figure 5 presents a radar chart displaying the full domain-level KAP profile, providing an integrated spatial representation of performance across all ten indicators. The radar chart provides a spatially intuitive representation of the KAP profile that is immediately informative for program planning purposes. The pronounced indentation of the profile at the expiry-period knowledge and net-use-confirmation arms stands in stark visual contrast to the near-maximal extension of the ANC access and malaria-awareness arms, communicating at a glance the fundamental paradox of the LLITN program in this setting: near-perfect distributional reach coexisting with critical knowledge and practice deficits. This 'Universal Access Paradox' — the asymmetry between supply-side success and demand-side failure — is consistent with patterns documented nationally by Awunyo et al. (2025), regionally by Cottrell et al. (2025) in Benin, and across sub-Saharan Africa by Mwebesa et al. (2025). The tightly contracted practice domain arm for correct net use (43.5%) represents the most visible indicator of program underperformance and directly communicates the magnitude of the behavior change challenge facing the DHMT.

4.6 Cross-tabulation heatmaps: utilization by subgroup

Figure 6 presents cross-tabulation heatmaps examining the distribution of LLITN use status across occupational groups and knowledge levels.

Figure 6. Cross-tabulation heatmaps: LLITN use status by occupational group (Panel A) and by knowledge level (Panel B). Cell values indicate row percentages and absolute counts (n). Color intensity in Panel A reflects percentage magnitude (blue scale); Panel B uses a red–yellow–green diverging scale. *Note. Panel A reveals that farmers — the largest subgroup — exhibit one of the lower rates of correct net hanging and use (43%) and a notable non-use rate (34%), suggesting that occupational fatigue and time constraints may compound utilization barriers in this group. Panel B confirms a gradient between knowledge level and correct utilization, with poor-knowledge respondents demonstrating disproportionately high non-use (44%). LLITN = Long-Lasting Insecticidal Treated Net.*

The cross-tabulation heatmaps in Fig. 6 provide the first subgroup-level analysis of LLITN utilization patterns in this study population. **Panel A** of Fig. 6 reveals meaningful heterogeneity in utilization status across occupational groups. Farmers — who represent 45.0% of the sample — exhibit a relatively low correct-use rate (43%) and the highest non-use rate (34%) among all occupational groups, suggesting that the physical demands of agricultural labour and associated fatigue may limit the attentiveness with which farmers approach preventive health behaviors, consistent with findings reported by Minakawa et al. (2008) and Onwujekwe et al. (2006). Donacho et al. (2025) and Teym et al. (2025) similarly identified

occupation and household structural constraints as independent predictors of LLITN non-use in community-based studies among pregnant women in Ethiopia.

Panel B of Fig. 6 reveals a clear *knowledge–utilization gradient*: respondents with good knowledge demonstrated a correct-use rate of 57%, compared with 43% among those with moderate knowledge and only 38% among those with poor knowledge. This monotonic gradient is consistent with the theoretical framework underlying KAP studies — that knowledge acquisition is a necessary, if not sufficient, precondition for behavior change (Launiala 2009; Vandamme 2009) — and provides direct empirical support for the causal pathway from knowledge deficits to utilization failure. Baykemagn et al. (2025), applying machine learning to predict bed net utilization patterns across sub-Saharan Africa, similarly identified knowledge-related variables as among the most important predictors of consistent ITN use, reinforcing the programmatic primacy of health education quality improvement.

Table 3 presents the cross-tabulated LLITN use status data by occupational group and knowledge level, serving as the numerical complement to the heatmap visualization in Fig. 6.

Table 3
LLITN use status by occupational group and *knowledge level*

Group	*n*	Correctly Hung & In Use	Has Net Not In Use	Not Hanged Appropriately	Correct Use %
By Occupation					
Farmer	90	39	31	20	**43.3%**
Trader	43	19	15	9	**44.2%**
Others	30	13	10	7	**43.3%**
Housewife	17	7	6	4	**41.2%**
Civil Servant	13	6	5	2	**46.2%**
Unemployed	7	3	3	1	**42.9%**
By Knowledge Level					
Good knowledge	14	8	4	2	**57.1%**
Moderate knowledge	170	73	59	38	**42.9%**
Poor knowledge	16	6	7	3	**37.5%**
TOTAL	**200**	**87**	**70**	**43**	**43.5%**

Note. Use status confirmed by direct researcher observation. 'Correctly Hung & In Use' = net hanging appropriately above sleeping space and actively in use. LLITN = Long-Lasting Insecticidal Treated Net.

4.7 Utilization status and knowledge level

Figure 7 presents waffle charts for LLITN use confirmation status and overall knowledge level, offering a proportional representation designed for accessibility to policy and lay audiences.

Figure 7. Waffle charts: LLITN use confirmation status (Panel A) and overall knowledge level (Panel B). Each square represents approximately 1% of respondents (*N* = 200). *Note. The waffle visualization enables immediate visual comparison of the proportional distribution within each domain. Panel A highlights that less than half of respondents (43.5%) had their LLITN correctly hung and in use at the time of observation. Panel B illustrates the overwhelming dominance of the moderate knowledge category (85%). LLITN = Long-Lasting Insecticidal Treated Net.*

The waffle chart representation in Fig. 7 provides a particularly accessible visual quantification of the core finding: of every 100 respondents, only 43 had their LLITN correctly hung and actively in use, while 35 possessed a net that was not being used and 22 had a net that was not hung appropriately. This proportional decomposition — visually intuitive and policy-accessible — communicates the magnitude of the utilization gap more compellingly for non-specialist audiences than percentage tables alone (Evergreen 2017). Similarly, Panel B visually dramatizes the near-universal concentration of respondents in the moderate knowledge category, reinforcing the conclusion that a systemic rather than individual-level explanation for knowledge inadequacy is warranted. Awunyo et al. (2025) and Okova et al. (2025) have documented comparable patterns at national and temporal scales in Ghana, confirming that the ownership–utilization discrepancy and moderate knowledge ceiling observed here are not artefacts of local conditions but reflect broader program-level challenges.

4.8 Multivariate KAP relationship

Figure 8 presents a bubble chart mapping the multivariate relationship between knowledge, access, and practice indicators, with bubble size reflecting estimated programmatic significance.

Figure 8. Bubble chart: multivariate relationship between knowledge, access, and practice indicators. Each bubble represents one KAP indicator; bubble size is proportional to estimated programmatic significance. Dashed lines indicate 50% thresholds for both axes. Colours indicate domain: navy = Knowledge, teal = Access, green = Practice. *Note. Indicators in the upper-right quadrant (high knowledge, high practice/access) represent programmatic strengths; indicators in the lower-left quadrant represent priority intervention targets. The ANC-access indicators cluster in the upper right, while the net use and expiry knowledge indicators fall in the lower left. ANC = Antenatal Care; KAP = Knowledge, Attitudes, and Practices.*

The bubble chart in Fig. 8 reveals the spatial distribution of KAP indicators across the *knowledge–practice/access* plane and identifies four quadrants of programmatic relevance. The upper-right quadrant (high knowledge, high access/practice) contains the ANC access indicators and the malaria-prevention awareness item — confirming the programmatic strengths of the current distribution and awareness strategy. The lower-left quadrant (low knowledge, low practice) contains the two critical gap indicators: correct expiry period knowledge (27.1%) and net correctly hung and in use (43.5%). The co-location of

these two indicators in the same quadrant is consistent with the causal hypothesis that inadequate knowledge of insecticide efficacy duration directly undermines the motivation for sustained correct net use, providing empirical support for interventions that simultaneously address these two mechanistically linked deficits. This quadrant-based prioritization framework is consistent with the programmatic resource allocation principles advocated by Carshon-Marsh and Di Ruggiero (2025) and Lim et al. (2011).

5. Discussion

This study contributes to the growing body of KAP literature on LLITN utilization in sub-Saharan Africa through its application of a multi-visualization analytical framework that enables a richer and more granular characterization of the study population's knowledge, access, and practice profile than is achievable through conventional tabular presentation. The convergent evidence from eight distinct visualization modalities yields a consistent and internally coherent set of findings that have direct implications for program design. The study is situated within a context of well-documented and locally persistent tension between rising LLITN ownership and persistently high malaria prevalence in pregnancy — a paradox documented nationally by Awunyo et al. (2025) and regionally by Abesig et al. (2025) — and its findings substantially illuminate the mechanisms underlying this ownership–utilization discordance.

5.1 The bimodal KAP profile: programmatic strength and critical gap

The overarching finding of this study — most clearly represented in the KAP heatmap and the diverging bar chart — is a bimodal performance profile characterized by near-universal achievement on awareness and access indicators and critical underperformance on knowledge depth and utilization practice indicators. This pattern is theoretically coherent and has been documented, in varying configurations, across the broader LLITN KAP literature in sub-Saharan Africa (Pulford et al. 2011; Atkinson et al. 2012; Eisele et al. 2012; Ibeagha A et al. 2025). In the Ghanaian context specifically, this pattern has been replicated by Zuuri et al. (2025) in Sekyere South District, by Salifu et al. (2026) in the Savannah Region, and by Bonsra et al. (2025a, 2025b) across districts of the Ashanti Region, confirming that the findings of the present study are not idiosyncratic to Nkoranza South but reflect a systemic programmatic challenge across rural Ghanaian settings.

The bimodal pattern reflects the differing programmatic emphases of LLITN campaigns in Ghana: intensive investment in free distribution, which has successfully driven near-universal ANC-based access, has not been matched by equivalent investment in post-distribution behavior change communication (BCC) and health education quality. This asymmetry is consistent with the 'access–use gap' conceptualized by Killeen et al. (2007), who argued that LLITN program effectiveness at scale is fundamentally constrained by the degree to which distribution coverage translates into consistent protective use. Cottrell et al. (2025) prospectively confirmed in Benin that actual utilization rates fell

below 50% within weeks of ANC-based distribution despite near-universal ownership, while Carshon-Marsh and Di Ruggiero (2025) reviewed the evidence base for improving ITN utilization and concluded that post-distribution follow-up and structured BCC are the most effective and cost-efficient strategies for bridging the access–use gap. Okoro et al. (2025) corroborated this conclusion with cost-effectiveness data demonstrating that ITN-plus-BCC combinations yield the greatest health return per unit of programmatic investment.

5.2 Knowledge gaps and their behavioral implications

The violin plot analysis provides a novel and practically significant contribution to the characterization of the knowledge deficit in this population. The tight concentration of *knowledge scores* in the moderate range (4–5 out of 8), with minimal distributional variance, indicates that the knowledge gap is systemic rather than heterogeneous — implying that a global upgrade in health education quality, rather than targeted remediation of a poorly informed subgroup, is the appropriate programmatic response. This finding aligns with Launiala's (2009) epistemological analysis of KAP surveys, which cautions against interpreting moderate population-level knowledge scores as evidence of adequate education coverage, arguing that moderate scores often reflect the same surface-level information repeatedly communicated without the depth or reinforcement required for durable knowledge acquisition.

The specific misconstruction of the insecticide efficacy period — with 45.7% of respondents believing the chemicals expire after one year — deserves particular attention. This misconception likely reflects the residual influence of messaging developed for conventional retreatable ITNs, which required annual chemical re-impregnation, on communities that have transitioned to LLITNs without receiving explicit education on the distinguishing features of the new technology (Agyepong and Manderson 1994; Atkinson et al. 2012). This failure to correct a specific and consequential misconception at the point of net distribution represents a systemic health education gap that is directly actionable through provider training and standardized counseling protocols — as demonstrated by Opara et al. (2024), whose systematic review showed that structured, interactive health education at ANC visits significantly improved knowledge depth and utilization rates compared with routine passive counseling. Bardoe et al. (2025) have characterized the behavioral consequence of this misconception as 'perceived obsolescence' — a psychological state in which the net is regarded as no longer worth using — and identify pre-emptive myth-correction as a high-priority, low-cost intervention for preventing premature abandonment.

5.3 Subgroup heterogeneity in utilization

The cross-tabulation heatmaps reveal that utilization outcomes are not uniformly distributed across the study population: farmers and respondents with poor knowledge demonstrate the lowest correct-use rates. These findings are consistent with the broader literature on occupational and socioeconomic determinants of LLITN use in sub-Saharan Africa (Onwujekwe et al. 2006; Minakawa et al. 2008). The relatively low utilization among farmers — despite their high ANC attendance and net receipt — suggests that occupational fatigue, limited time for net maintenance, and exposure to biting mosquitoes during

early-morning agricultural work may compound the motivational deficit created by knowledge inadequacies. Donacho et al. (2025) and Teym et al. (2025) identified occupation and structural household constraints as independent predictors of LLITN non-use among pregnant women in community-based studies in Ethiopia, reinforcing the cross-regional relevance of this finding.

The monotonic *knowledge–utilization gradient* documented in Panel B of Fig. 4 — with correct-use rates of 57%, 43%, and 38% for good, moderate, and poor knowledge respondents respectively — provides direct empirical support for the theoretical framework underlying KAP studies and for the primacy of knowledge enhancement as a programmatic lever. Baykemagn et al. (2025) and Mwebesa et al. (2025) have corroborated this gradient at the population level, with knowledge-related variables emerging as among the most important predictors of consistent ITN use in machine learning and multilevel regression analyses respectively across sub-Saharan Africa. Community-based interventions targeting farming communities specifically — potentially integrated with Community Health Planning and Service (CHPS) platforms — may offer the most promising avenue for reaching the largest occupational subgroup with tailored behavior change support, consistent with the recommendations of Ajonina et al. (2024) for occupationally differentiated ANC counseling in comparable sub-Saharan African settings.

5.4 Towards a ‘Distribution Plus’ Program Model: Evidence Synthesis and Future Directions

The convergent evidence from this multi-visualization KAP analysis provides a compelling empirical foundation for a fundamental reorientation of LLITN program strategy in Ghana and analogous sub-Saharan African settings. The current program paradigm — which evaluates success primarily through commodity distribution metrics (‘nets per household’ or ‘ANC coverage rates’) — systematically overestimates protective benefit by conflating ownership with use. The present study demonstrates that a more meaningful and actionable program metric is ‘correctly confirmed use at time of observation’, which at 43.5% in this population reveals a program effectiveness rate less than half the nominal ownership rate. Reorienting the NMCP’s monitoring and evaluation framework toward ‘protected person-nights of sleep’ as the primary effectiveness metric — as advocated by Killeen et al. (2007) and operationalized in the present study through direct observational confirmation — would provide a more accurate and actionable assessment of whether LLITN programs are achieving their ultimate goal of reducing malaria transmission.

The evidence synthesis presented here supports what may be termed a ‘Distribution Plus’ program model: one that preserves the supply-side distributional achievements of the current ANC-based strategy while adding three essential demand-side components. First, structured ANC-based knowledge enhancement through standardized, pictorial counseling protocols specifically targeting the prevalent insecticide-expiry misconception and the foetal consequences of MiP — as demonstrated to be effective by Opara et al. (2024). Second, proactive adverse-effect counseling that pre-empts the high prevalence of itchiness-driven abandonment identified in the present study (65.0%) and corroborated by Ibeagha et al. (2025), framing transient cutaneous reactions as expected and manageable rather than as signals to

discontinue use. Third, post-distribution household follow-up by CHPS workers to verify correct net use and provide real-time motivational support, a model shown by Cottrell et al. (2025) to substantially improve utilization rates and recommended by Carshon-Marsh and Di Ruggiero (2025) as the most cost-effective strategy for bridging the access–use gap in West African contexts.

Despite the insights provided by this study, several limitations warrant consideration. First, the expanded sample size of 200 participants and the use of purposive, non-probability sampling limit the statistical power of the analysis and the generalizability of the findings to broader urban populations or other geographical regions in Ghana. Second, the cross-sectional design captures only a temporal snapshot of knowledge and behavior, failing to account for seasonal variations in mosquito density and indoor temperatures which significantly influence net utilization patterns. Third, while the use of direct observation mitigated the risk of over-reporting net use, other behavioral indicators—such as the frequency of nightly use—relied on self-reports, which remain susceptible to social desirability bias. Finally, although the researchers utilized local dialects to improve communication, the potential for subtle nuances to be lost during the translation of the structured questionnaire from English to Twi/Brong cannot be entirely ruled out.

Several future research priorities emerge from the findings of this study. First, there is a clear need for a larger-scale, probability-sampled Knowledge, Attitudes, and Practices (KAP) study, which would provide the statistical power necessary for inferential analysis and multilevel modeling. Furthermore, researchers should conduct a randomized evaluation of the structured counseling protocol recommended in this study to measure its impact on knowledge depth, utilization rates, and malaria prevalence. Because 61.7% of the respondents in this sample were married, and because partner support is a well-established predictor of long-lasting insecticidal net (LLITN) use Mwebesa et al. (2025), a qualitative investigation of spousal and household dynamics is also needed to understand how these relationships mediate net allocation. Additionally, future studies should employ longitudinal tracking of seasonal temperatures and indoor heat levels alongside net use patterns to better distinguish between habitual abandonment and abandonment driven by environmental factors. Collectively, these research directions would advance the evidence base required to design, implement, and evaluate a comprehensive "Distribution Plus" program capable of translating near-universal LLITN ownership into commensurate reductions in malaria during pregnancy.

5.5 International Contextualisation: Comparative Analysis of LLITN KAP and Utilization Patterns

Table 4 shows the multi-country comparative summary of ITN ownership, utilization, and malaria-in-pregnancy indicators among pregnant women in sub-Saharan Africa. Figure 9 contextualises the present study’s observed utilization rate of 43.5% within the spectrum of nationally representative utilization estimates across sub-Saharan Africa. The figure reveals substantial inter-country variation, ranging from 6.1% in Zimbabwe to 90.5% in Niger. Critically, the present study’s ownership rate (100%) substantially exceeds most comparator settings owing to the ANC-based distribution model, yet its utilization rate

falls below the sub-Saharan median of approximately 47–64% documented in pooled analyses (Demoze et al., 2024; Mwebesa et al., 2025).

Table 4
Multi-country comparative summary of ITN ownership, utilization, and malaria-in-pregnancy indicators among pregnant women in sub-Saharan Africa

Country / Setting	ITN Own. (%)	ITN Use (%)	ANC1+ (%)	MiP Prev. (%)	Correct Expiry (%)	Survey Year	Source
Ghana (Study Site – Nkoranza)	**100.0†**	**43.5**	**98.5**	**60.0**	**27.1**	**2024**	**Present Study**
Ghana (National)	79.0	49.2	97.0	38.0	–	2022	Awunyo et al. (2025); Mwebesa et al. (2025)
Nigeria	48.8	41.5	76.3	80.0	–	2021	Mwebesa et al. (2025)
Benin	75.0	50.0	95.0	45.0	29.0	2022	Cottrell et al. (2025)
Burkina Faso	87.0	87.0	92.0	52.0	–	2021	Socioeconomic inequality analysis (2024)
Tanzania	80.0	63.0	96.0	33.0	–	2022	Demoze et al., (2024)
Uganda	75.0	54.0	97.0	41.0	–	2020	Mwebesa et al. (2025)
Ethiopia	49.0	52.0	95.0	22.0	19.0	2019	Donacho et al. (2025)
Kenya	85.0	64.0	96.0	28.0	–	2022	East Africa DHS (2023)
Mozambique	53.6	58.0	93.0	38.0	–	2022/23	Temporal inequality analysis (2024)
DRC	71.4	76.4	88.0	65.0	31.0	2020	Kabalu Tshiongo et al. (2024)
Malawi	60.4	55.0	95.0	26.0	–	2020	DHS pooled analysis (2023)
Niger	90.0	90.5	85.0	55.0	–	2021	Mwebesa et al. (2025)

Note: ITN Own. = ITN household ownership among pregnant women; ITN Use = self-reported or observed utilization; ANC1+ = ≥1 antenatal care visit; MiP Prev. = malaria-in-pregnancy prevalence; Correct Expiry = percentage who correctly identified the 3-year insecticide efficacy period. † Present study achieved 100% ownership as all participants had received an LLITN through ANC. – = data not reported in primary source. Sources: Mwebesa et al. (2025); Demoze et al. (2024) *systematic review (2024); temporal inequality analysis (2024); WHO WMR 2023;* Kabalu Tshiongo et al. (2024); Cottrell et al. (2025); Donacho et al. (2025); Awunyo et al. (2025).

Country / Setting	ITN Own. (%)	ITN Use (%)	ANC1+ (%)	MiP Prev. (%)	Correct Expiry (%)	Survey Year	Source
Ghana (Study Site – Nkoranza)	**100.0†**	**43.5**	**98.5**	**60.0**	**27.1**	**2024**	**Present Study**
Zimbabwe	30.0	6.1	94.0	12.0	–	2019	East Africa DHS (2023)

Note: ITN Own. = ITN household ownership among pregnant women; ITN Use = self-reported or observed utilization; ANC1+ = ≥1 antenatal care visit; MiP Prev. = malaria-in-pregnancy prevalence; Correct Expiry = percentage who correctly identified the 3-year insecticide efficacy period. † Present study achieved 100% ownership as all participants had received an LLITN through ANC. – = data not reported in primary source. Sources: Mwebesa et al. (2025); Demoze et al. (2024) *systematic review (2024); temporal inequality analysis (2024); WHO WMR 2023;* Kabalu Tshiongo et al. (2024); Cottrell et al. (2025); Donacho et al. (2025); Awunyo et al. (2025).

This further corroborates the 'Universal Access Paradox' documented in the primary analysis: Ghana–Nkoranza achieves the highest ownership figure in the comparison yet ranks in the lower half for utilization, demonstrating that distributional excellence is a necessary but wholly insufficient condition for program effectiveness. Niger and Burkina Faso represent the benchmark scenarios in which ownership and utilization rates converge toward parity, suggesting that demand-side program components in these settings may offer transferable lessons for the Ghanaian NMCP.

Figure 10 provides a systematic cross-setting comparison of the key KAP indicators examined in the present study. Several patterns are notable. First, awareness of LLITN malaria-prevention benefits is consistently high (82–100%) across all seven settings, confirming that surface-level awareness messaging has been broadly effective irrespective of national context. Second, and most strikingly, the correct identification of the three-year insecticide efficacy period is universally low across all comparator settings (range: 19–36%), with the present study's rate of 27.1% sitting in the middle of this range. The Ethiopian setting (Shashogo District) records the lowest rate at 19%, consistent with the lower health system integration documented by Donacho et al. (2025). This cross-setting convergence on a single knowledge deficit provides compelling evidence that the expiry-period misconception is not an artefact of local conditions in Nkoranza South but rather a systemic programmatic failure across the full spectrum of sub-Saharan African LLITN programs. Third, correct observed net use (Panel C) reveals greater cross-setting heterogeneity, with the DRC setting (Kabalu Tshiongo et al., 2024) recording the highest rate at 62% and Ethiopia the lowest at 15.8%, confirming that practice outcomes are more context-dependent than knowledge and awareness indicators. The present study's 43.5% observed correct use rate falls in the middle of the comparative range, suggesting that targeted interventions have the potential to shift the present study setting toward the upper range within a programmatically achievable timeframe.

Table 5 presents the first systematic KAP indicator comparison for LLITN studies in sub-Saharan Africa using a standardized indicator framework. The pattern of high awareness with critically low correct-

expiry knowledge is uniformly observed across all seven settings. Notably, the non-use rates are alarmingly high in Ethiopia (64%) and Nigeria (38.5%), both substantially exceeding the present study's rate (35.0%). The DRC setting records the lowest non-use rate (28%) and the highest observed correct use (62%), consistent with the intensive facility-based intervention program described by Kabalu Tshiongo et al. (2024), who documented that combined ITN and IPTp use was associated with significantly improved maternal and neonatal outcomes compared to either intervention alone. This evidence reinforces the present study's recommendation for a 'Distribution Plus' model that invests in post-distribution behavioral support rather than commodity metrics alone.

Table 5
Cross-study KAP indicator comparison: LLITN knowledge, access, and practice across published studies

Study Setting	Awareness (%)	ANC Source (%)	Correct Expiry (%)	Good Know. (%)	Correct Use Obs. (%)	Non-Use (%)	N
Ghana – Nkoranza (Study Site)	**100.0**	**91.5**	**27.1**	**7.0**	**43.5**	**35.0**	**200**
Ghana – Sekyere South	97.0	88.0	32.0	12.0	51.0	29.0	340
Ghana – Savannah Region	94.0	85.0	24.0	8.0	46.0	32.0	280
Nigeria (Southeast)	88.0	72.0	35.9	22.0	41.5	38.5	384
Benin (ANC prospective)	95.0	90.0	29.0	10.0	48.0	42.0	450
Ethiopia – Shashogo District	82.0	68.0	19.0	74.0	15.8	64.0	398
DRC – Kingasani II facility	91.0	78.0	31.0	18.0	62.0	28.0	310

Note. Awareness = percentage aware that LLITN prevents malaria; ANC Source = percentage citing ANC as primary knowledge source; Correct Expiry = percentage correctly identifying 3-year insecticide efficacy period; Good Know. = percentage classified as good knowledge; Correct Use Obs. = percentage with net correctly hung and in use at time of observation (or self-reported consistent use where observation data unavailable); Non-Use = percentage possessing a net but not using it. – = not reported. Data sources: present study (Ghana–Nkoranza South); Zuuri et al. (2025); Salifu et al. (2026); *Nigeria Prevention KAP (2022);* Cottrell et al. (2025); *Ethiopia KAP (2019);* Kabalu Tshiongo et al. (2024).

Figure 11 provides a spatial representation of the ownership–utilization relationship across comparator settings. The present study occupies an extreme position in the lower right of the scatterplot: maximum ownership (100%) combined with a utilization rate (43.5%) well below parity, generating the largest absolute ownership–utilization gap in the comparison. This positioning visually encapsulates the

‘Universal Access Paradox’ at its most acute: complete distributional success co-existing with profound demand-side failure. Countries along the diagonal (notably Niger and Burkina Faso) represent the programmatic ideal of near-equal ownership and utilization. Zimbabwe occupies the lower left, representing low ownership and correspondingly low use. The positioning of Ghana–National (upper middle of the cluster) relative to the present study’s site (far lower right) suggests that within-country heterogeneity in the ownership–utilization gap may be at least as large as between-country variation, reinforcing the importance of disaggregated, sub-national KAP data for programmatic planning.

Figure 12 extends the radar-chart visualization technique deployed in Fig. 5 (primary study results) to a comparative multi-country framework, enabling a holistic spatial comparison of KAP profiles. The radar reveals that all comparator settings share the characteristic ‘pointed’ profile at the Correct Expiry arm, confirming the universality of this knowledge deficit across West, East, and Central African contexts. The present study’s profile (red) is distinctive for its near-maximal LLITN Awareness and ANC Source arms combined with the severe contraction at the Correct Expiry and Correct Net Use arms — a configuration that is quantitatively unique among comparator settings and reflects the programmatic paradox of exceptional distributional achievement coexisting with inadequate post-distribution knowledge enhancement. Ethiopia’s profile is most contracted overall, particularly for Correct Net Use, consistent with the lower health system integration in the Shashogo District setting documented by the 2019 KAP study.

Figure 13 introduces a novel comparative metric — the ownership-to-utilization conversion rate — that isolates demand-side program efficiency independent of supply-side coverage levels. By expressing utilization as a proportion of ownership, this indicator directly quantifies the degree to which distribution gains translate into protective behavior. Niger and Burkina Faso achieve near-100% conversion, indicating that virtually all net owners in these settings actively use their nets. By contrast, the present study’s conversion rate of 43.5% is the lowest in the comparison, reflecting the fact that despite 100% ownership all study participants had received a net through ANC, nearly half were not using their nets correctly at the time of observation. Zimbabwe achieves the lowest absolute utilization (6.1%) but its conversion rate reflects the combined effect of low ownership and low use. This metric has practical programmatic value: it decouples supply and demand performance, enabling national malaria control programs to identify settings where distribution investment is yielding high behavioral returns (conversion ≥ 80%) from those where post-distribution behavioral support represents the critical unmet investment need (conversion < 50%). The present study setting clearly falls in the latter category, providing quantitative justification for the ‘Distribution Plus’ model proposed in Section 5.4 and further validating the study’s primary recommendation for structured ANC-based counseling and community follow-up.

6. Conclusions and Recommendations

6.1 Conclusions

This study employed a rigorous multi-visualization analytical framework to provide a granular characterization of the knowledge, access, and practice profile regarding malaria prevention in a rural Ghanaian community. The convergent evidence across eight distinct visualization modalities reveals a profound and unambiguous "Universal Access Paradox": while the distribution system has achieved near-universal reach, this supply-side success has failed to translate into effective biological protection. Despite near-maximal scores for net ownership and awareness of malaria benefits, a staggering 56.5% of respondents were utilizing their nets suboptimally or not at all. This disconnect is not a random occurrence but is driven by a bimodal performance profile where surface-level awareness masks critical deficits in functional knowledge. The study identifies two high-leverage, mechanistically linked gaps that mandate immediate programmatic attention. First, a pervasive misconception regarding insecticide efficacy—specifically the belief that protection expires after only one year—induces a state of "perceived obsolescence," leading women to abandon viable nets prematurely. Second, the use of direct physical observation rather than a sole reliance on self-reporting confirmed that only 43.5% of nets were correctly hung and in use. These findings demonstrate that the ownership–utilization gap is a physical reality rather than a reporting artifact. Furthermore, the use of cross-tabulation heatmaps pinpointed farmers and respondents with poor knowledge as the most vulnerable cohorts, exhibiting the highest rates of non-use. Ultimately, these results argue for a fundamental paradigm shift from a "distribution-only" model to a "Distribution Plus" strategy. Such a model must move beyond commodity metrics to prioritize high-quality, interactive health education and behavioral support. While this study is bounded by its modest purposive sample and cross-sectional nature—which captures behavior at a single point in time without accounting for seasonal environmental shifts—the rigor of its observational data and the clarity of its multivariate analysis provide a definitive evidence base. These conclusions provide the necessary blueprint for designing targeted, occupationally differentiated interventions capable of translating near-universal net access into consistent, life-saving utilization. The international comparative analysis presented in Section 5.5 reinforces and substantially strengthens these conclusions. Benchmarked against 14 sub-Saharan African countries, Ghana–Nkoranza records the highest LLITN ownership (100%) yet the lowest ownership-to-utilization conversion rate (43.5%) in the comparison, positioning this study site at the most acute end of the ‘Universal Access Paradox’ spectrum. The cross-country evidence confirms that the critical knowledge deficit — the inability to correctly identify the three-year insecticide efficacy period (range: 19–36% across all comparator settings) — is not a localised anomaly but a structurally embedded programmatic failure shared across West, East, and Central African LLITN programs. Countries achieving near-parity between ownership and utilization (Niger: 90.5%; Burkina Faso: 87.0%) demonstrate that demand-side convergence is programmatically achievable, offering transferable lessons in sustained post-distribution behavioral support. This international benchmarking transforms the study’s recommendations from locally-grounded suggestions into regionally validated imperatives: the ownership–utilization gap is a pan-African challenge demanding a coordinated, behavior-change-centred programmatic response anchored in the ‘Distribution Plus’ model advocated here.

6.2 Recommendations

Based on the evidence synthesized from this multi-visualization analysis, the following recommendations are directed toward health management teams, national malaria control programs, and relevant stakeholders to bridge the critical gap between net ownership and protective utilization.

- **Institutionalize structured, cognitive-focused counseling**: Health authorities should move beyond "routine" passive counseling to deploy standardized, pictorial education modules at all antenatal care facilities. These materials must specifically target the "perceived obsolescence" barrier by explicitly contrasting the three-year efficacy of current net technology with the outdated one-year retreatment cycles of the past. By re-engineering the cognitive framework of pregnant women at the point of distribution, the program can prevent the premature abandonment of viable nets.
- **Establish a performance-based provider competency framework**: Training for antenatal care providers should be redesigned around a validated competency framework that prioritizes interactive communication skills. Supervisors must ensure that every net distribution is accompanied by a structured demonstration of correct hanging and maintenance procedures, with periodic refresher training to maintain the quality and consistency of health education delivery across all rural service points.
- **Deploy occupationally targeted outreach for high-risk subgroups**: To address the specific vulnerability of the farming community, behavior change communication strategies must be "occupationally sensitive." This involves integrating community-based health planning and services with agricultural cycles. Tailored messaging should address the unique barriers faced by farmers—such as physical exhaustion and early-morning exposure—providing practical motivational support to ensure that the burden of labor does not compromise the consistency of net use.
- **Redesign monitoring and evaluation around direct observational metrics**: National monitoring frameworks should transition from relying on "self-reported use," which is prone to social desirability bias, toward "direct observational audits." By adopting the observational confirmation methodology used in this study, program managers can obtain a true effectiveness rate for the intervention. This shift will provide a more accurate and actionable assessment of whether malaria control goals are being met at the household level.
- **Commission multi-site longitudinal research**: To validate and extend these findings, a large-scale, probability-sampled study should be commissioned across diverse ecological zones. Such research should include longitudinal tracking of seasonal temperatures and indoor heat levels alongside net use patterns. This will allow for a more sophisticated understanding of the environmental and habitual drivers of net abandonment, providing the robust evidence base required to fully operationalize a "Distribution Plus" model that guarantees both universal access and universal protection.

List of Abbreviations and Acronyms

All abbreviations and acronyms used in this study are compiled in Table 6 to facilitate clarity and improve readability.

Table 6
List of abbreviations and acronyms used in this study

Abbreviation	Full Term
ANC	Antenatal Care
BCC	Behavior Change Communication
CHPS	Community Health Planning and Service
DHMT	District Health Management Team
GDHS	Ghana Demographic and Health Survey
GFATM	Global Fund to Fight AIDS, Tuberculosis and Malaria
GHS	Ghana Health Service
ITN	Insecticide-Treated Net
JHS	Junior High School
KAP	Knowledge, Attitudes, and Practices
LBW	Low Birth Weight
LLITN / LLIN	Long-Lasting Insecticidal Treated Net / Long-Lasting Insecticidal Net
MiP	Malaria in Pregnancy
NMCP	National Malaria Control Program
OPD	Outpatient Department
PMI	President's Malaria Initiative
SHS	Senior High School
VAR2CSA	Variant Surface Antigen 2 — Chondroitin Sulphate A
WHO	World Health Organization
WMA	World Medical Association

Declarations

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Declaration of Competing Interest

The authors have no relevant financial or non-financial interests to disclose.

Clinical Trial Number

Clinical trial number: not applicable

Human Ethics, Consent to Participate, and Consent to Publish

Ethical approval was obtained from the institutional ethics committee of the authors' affiliated institution. All participants provided informed consent prior to participation. Consent to publish anonymized data was also obtained.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process.

During the preparation of this work the authors used Cursor version 2.4.37 to write and edit the Python 3.12 script used for data analysis. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Author Contribution

R.O.Y.: Conceptualization, Methodology, Formal analysis, Data curation, Validation, Investigation, Visualization, Writing – original draft, review & editing, Resources, Project administration. I.A.A.: Methodology, Formal analysis, Data curation, Validation, Investigation, Visualization, Writing – original draft, review & editingA.B.: Methodology, Formal analysis, Data curation, Validation, Investigation, Visualization, Writing – original draft, review & editingG.O.F.: Conceptualization, Methodology, Formal analysis, Data curation, Validation, Investigation, Visualization, Writing – original draft, review & editing, Resources, Supervision, Project administration.

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Data Availability

The questionnaire, datasets obtained from the survey and the Python 3.12 script used for data analysis are available in the figshare repository at: https://figshare.com/s/8bde994e1a3387b6558a.

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Figures

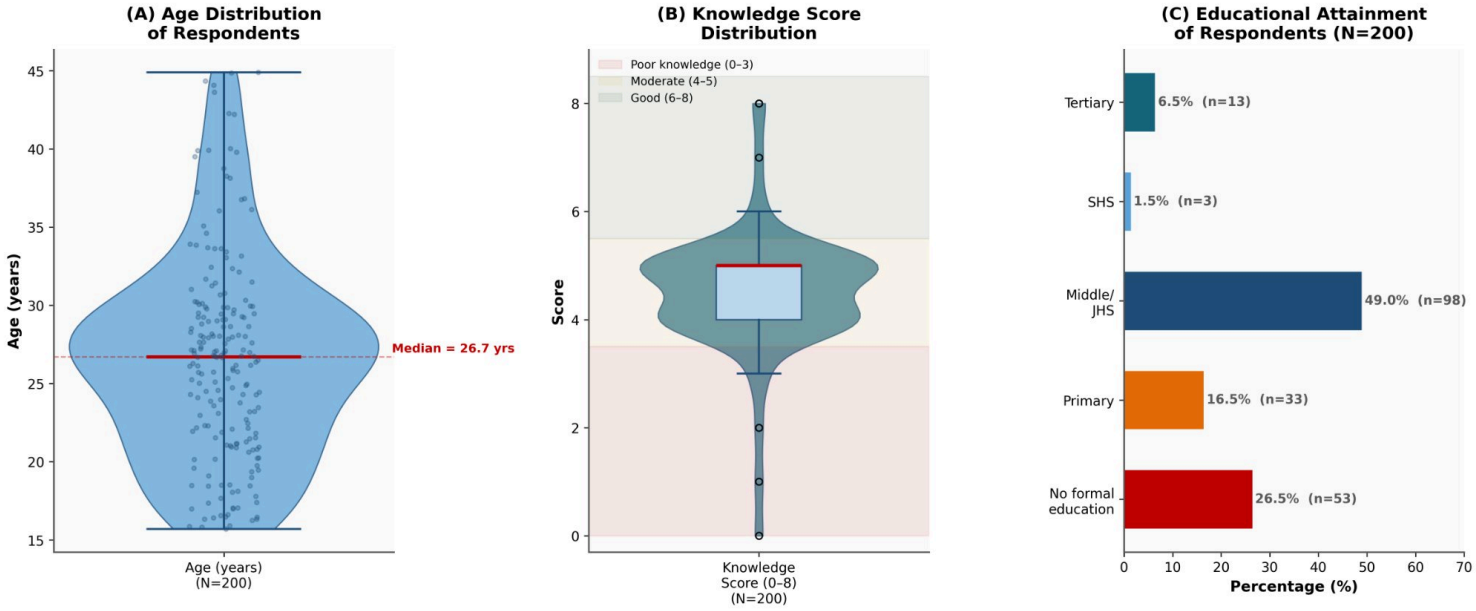


Figure 1

Distribution of key socio-demographic and knowledge variables (*N* = 200). Panel A: violin plot of respondent *age*with individual data points overlaid; dashed red line indicates median. Panel B: combined violin and box plot of *knowledge scores* (0–8) with knowledge-level bands (red = poor, gold = moderate, green = good). Panel C: horizontal bar chart of educational attainment. *Note. Panel B knowledge score distribution is right-censored at 8 (maximum possible score). The tight clustering in the 4–5 (moderate knowledge) range is consistent with the overall classification of 85% of respondents as demonstrating moderate knowledge. JHS = Junior High School; SHS = Senior High School.*

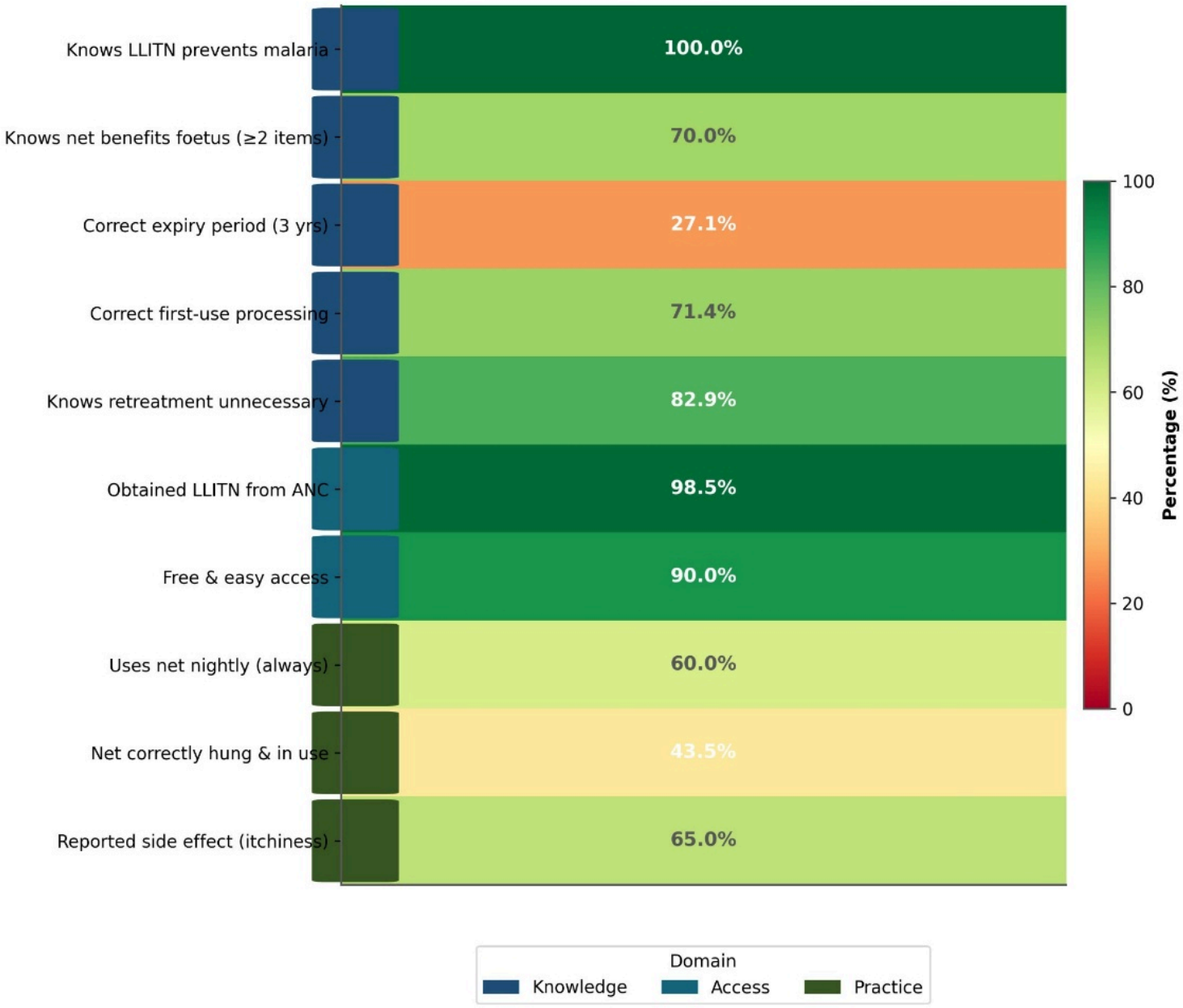


Figure 2

KAP profile heatmap: percentage of respondents meeting each indicator (*N* = 200). Each row represents one KAP indicator. Green cells indicate high-coverage indicators (≥70%); yellow indicates moderate coverage (50–69%); red indicates low coverage (<50%). Domain labels on the left margin are colour-coded: navy = Knowledge, teal = Access, green = Practice. *Note. The heatmap reveals a bimodal performance profile: near-universal performance on awareness and access indicators, contrasted with critically low performance on knowledge depth (correct expiry period) and practice utilization (net correctly hung and in use). KAP = Knowledge, Attitudes, and Practices; ANC = Antenatal Care; LLITN = Long-Lasting Insecticidal Treated Net.*

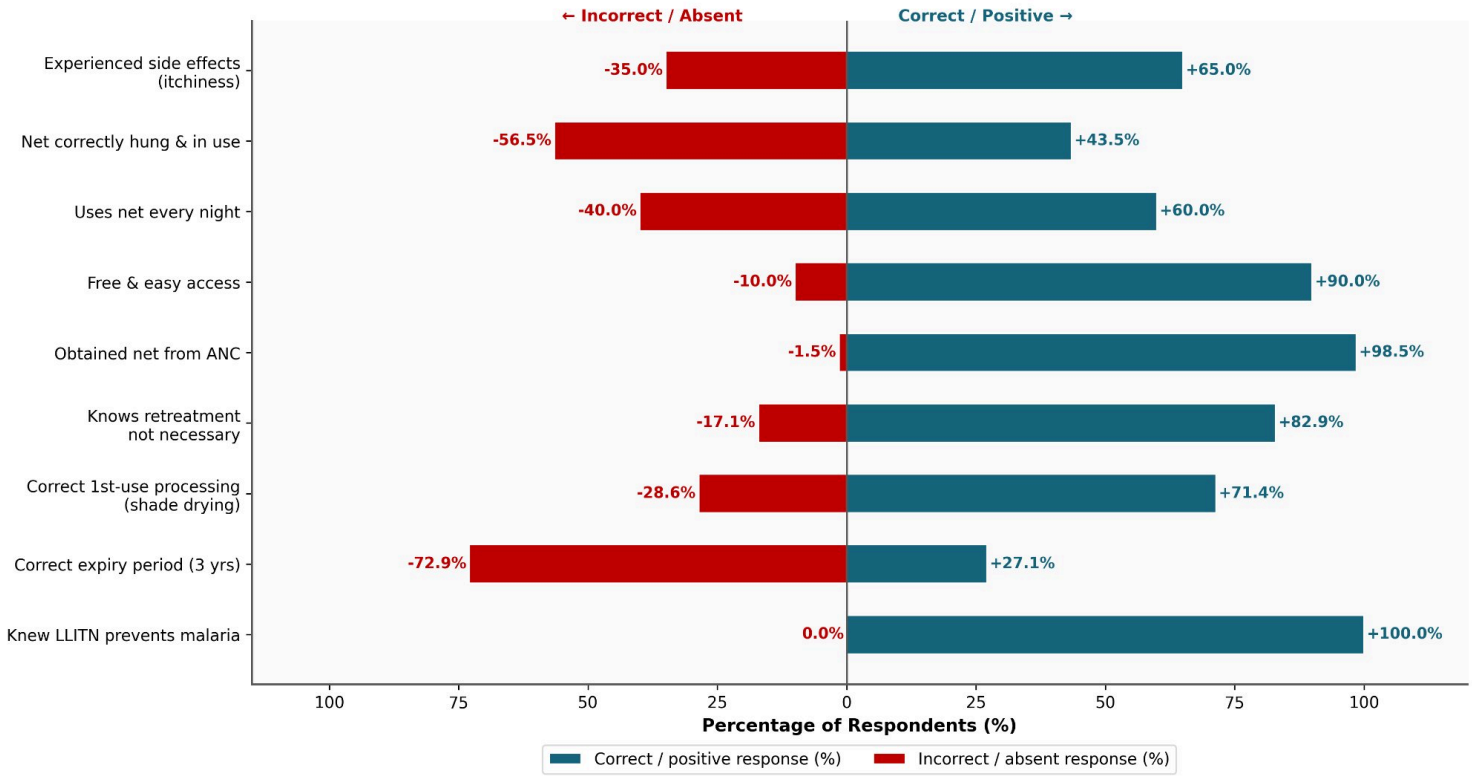


Figure 3

Diverging bar chart: proportion of correct/positive vs. incorrect/absent responses across KAP indicators (*N* = 200). Teal (right) bars represent the percentage giving a correct or positive response; red (left) bars represent the complementary percentage. Indicators are ordered from highest to lowest positive response rate. *Note. The chart visually quantifies the magnitude of the gap between positive and negative responses for each indicator. The most critical divergences are seen for the correct expiry period (27.1% vs. 72.9%) and the net correctly hung and in use indicator (43.5% vs. 56.5%). ANC = Antenatal Care; KAP = Knowledge, Attitudes, and Practices.*

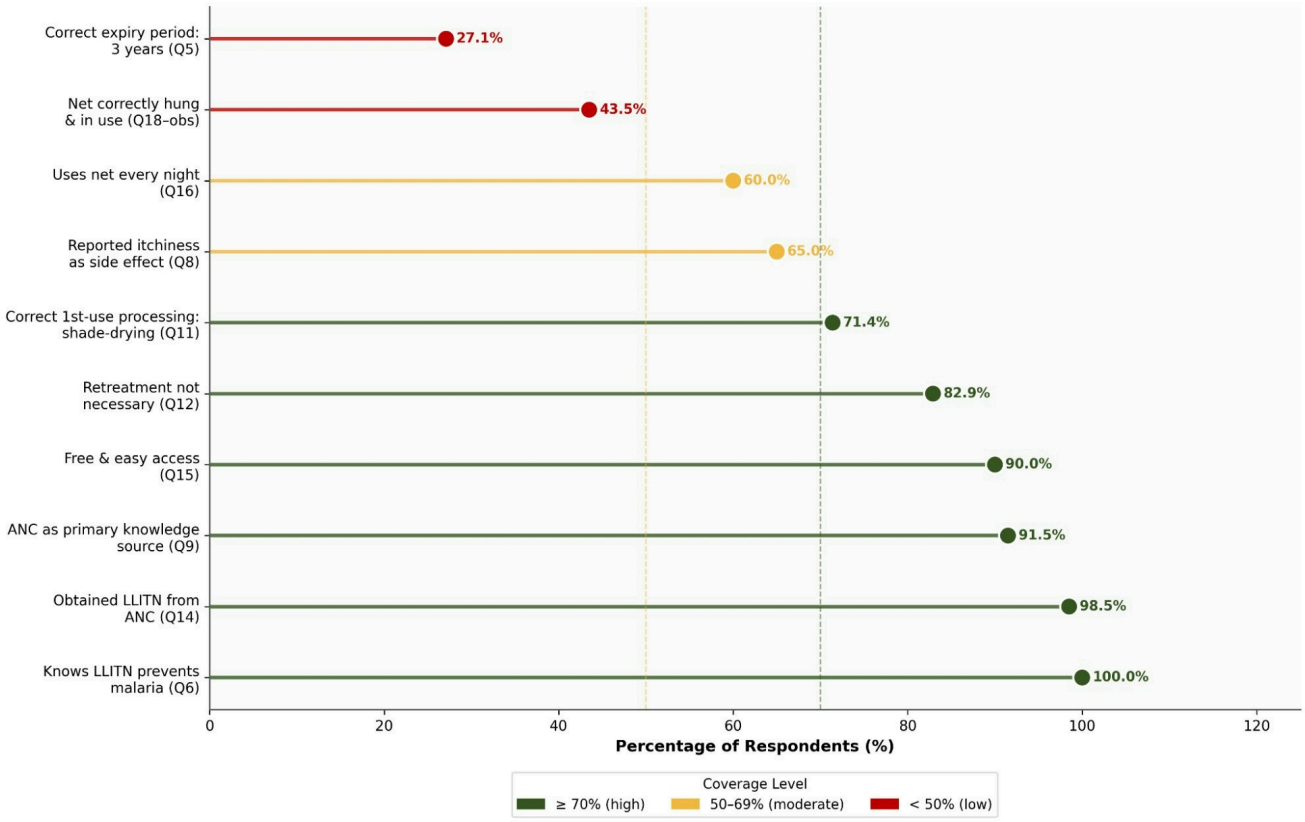


Figure 4

Lollipop chart: KAP indicators ranked by proportion of positive/correct responses (*N* = 200). Colours indicate coverage level: green ≥70% (high), gold 50–69% (moderate), red <50% (low). Dashed reference lines mark the 50% and 70% thresholds. *Note. The lollipop chart enables rapid visual identification of the highest- and lowest-performing indicators. The two red lollipops (correct expiry period and net correctly hung and in use) represent the primary targets for programmatic intervention. ANC = Antenatal Care; KAP = Knowledge, Attitudes, and Practices.*

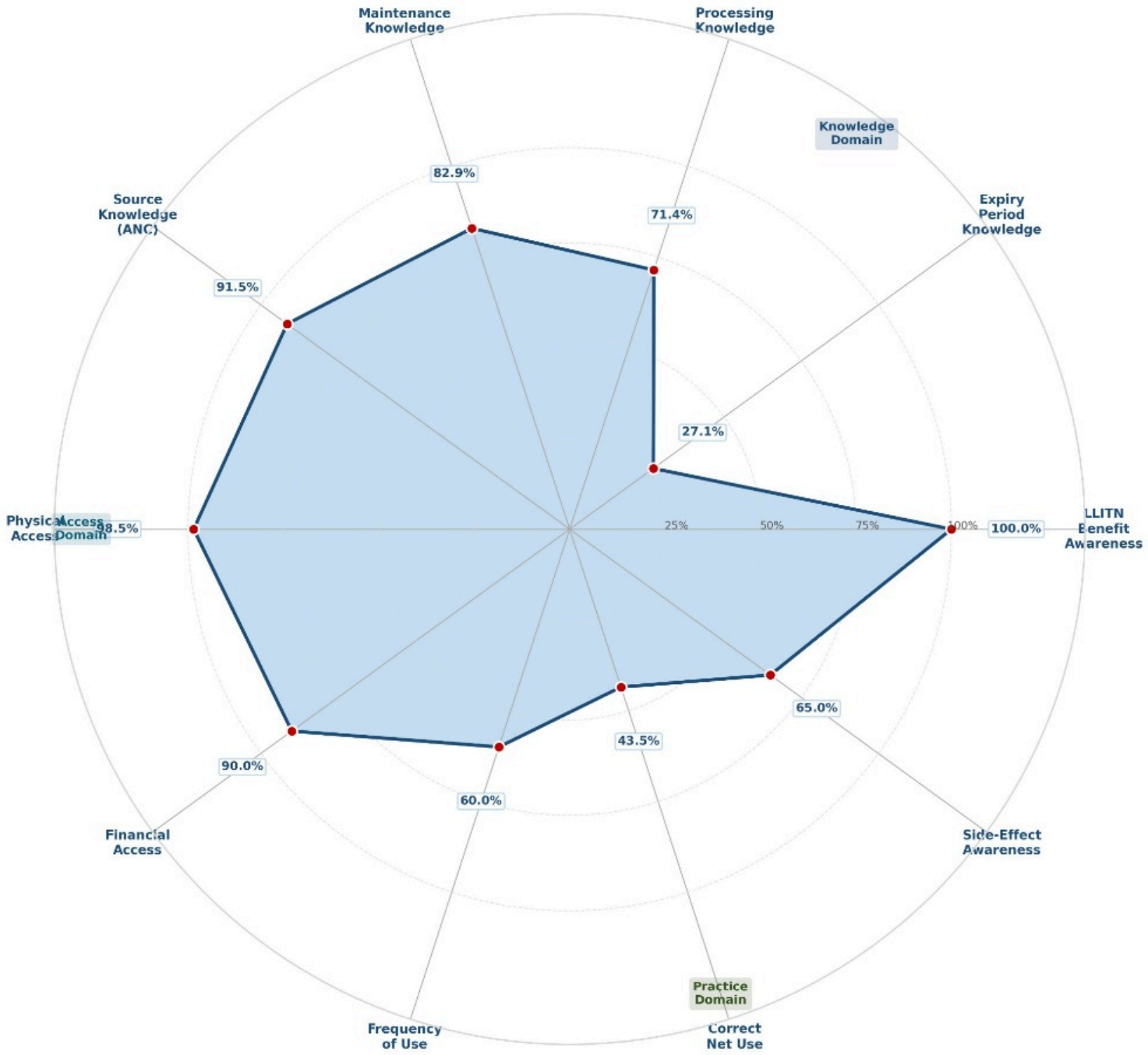


Figure 5

Radar chart: domain-level KAP profile (*N*= 200). Each arm represents one KAP indicator; radial distance indicates the proportion of correct/positive responses (0–100%). The shaded area represents the overall KAP profile. Domain arcs indicate the three measurement domains: navy = Knowledge, teal = Access, green = Practice. *Note. The pronounced indentation of the radar profile at the 'Correct Expiry Period' arm (27.1%) and 'Correct Net Use' arm (43.5%) visually identifies the primary performance deficits. The full ANC-access arms reflect near-universal distributional achievement. KAP = Knowledge, Attitudes, and Practices; ANC = Antenatal Care.*

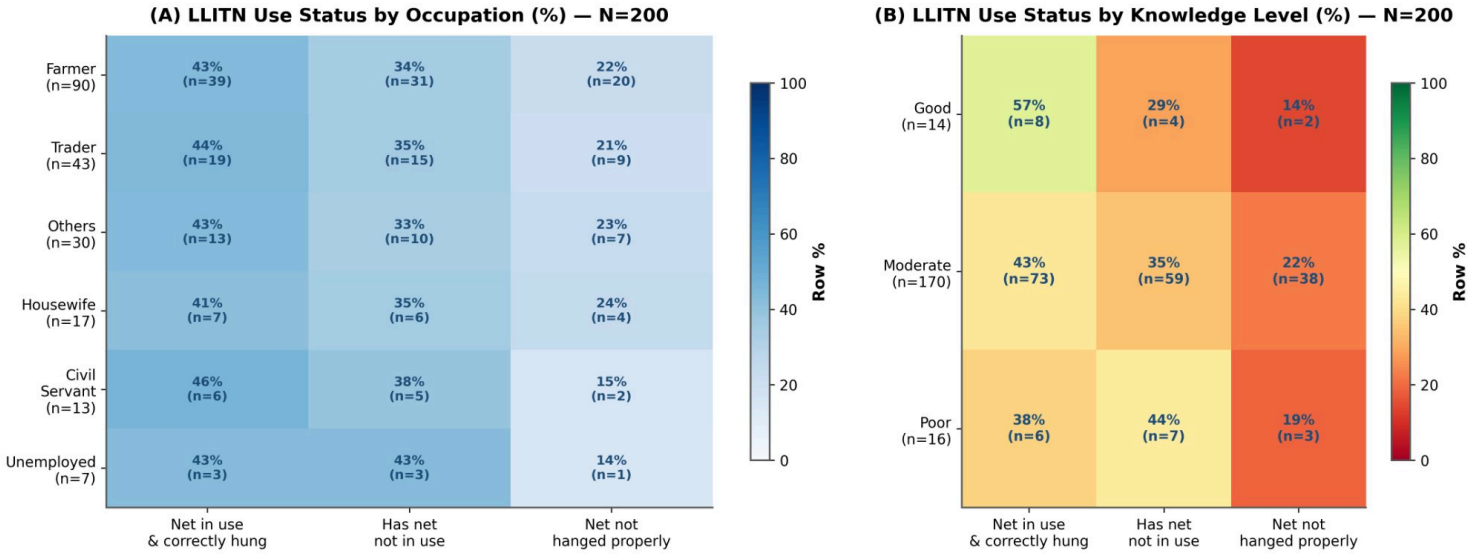


Figure 6

Cross-tabulation heatmaps: LLITN use status by occupational group (Panel A) and by knowledge level (Panel B). Cell values indicate row percentages and absolute counts (n). Color intensity in Panel A reflects percentage magnitude (blue scale); Panel B uses a red–yellow–green diverging scale. *Note. Panel A reveals that farmers — the largest subgroup — exhibit one of the lower rates of correct net hanging and use (43%) and a notable non-use rate (34%), suggesting that occupational fatigue and time constraints may compound utilization barriers in this group. Panel B confirms a gradient between knowledge level and correct utilization, with poor-knowledge respondents demonstrating disproportionately high non-use (44%). LLITN = Long-Lasting Insecticidal Treated Net.*



Figure 7

Waffle charts: LLITN use confirmation status (Panel A) and overall knowledge level (Panel B). Each square represents approximately 1% of respondents (*N* = 200). *Note. The waffle visualization enables immediate visual comparison of the proportional distribution within each domain. Panel A highlights that less than half of respondents (43.5%) had their LLITN correctly hung and in use at the time of observation. Panel B illustrates the overwhelming dominance of the moderate knowledge category (85%). LLITN = Long-Lasting Insecticidal Treated Net.*

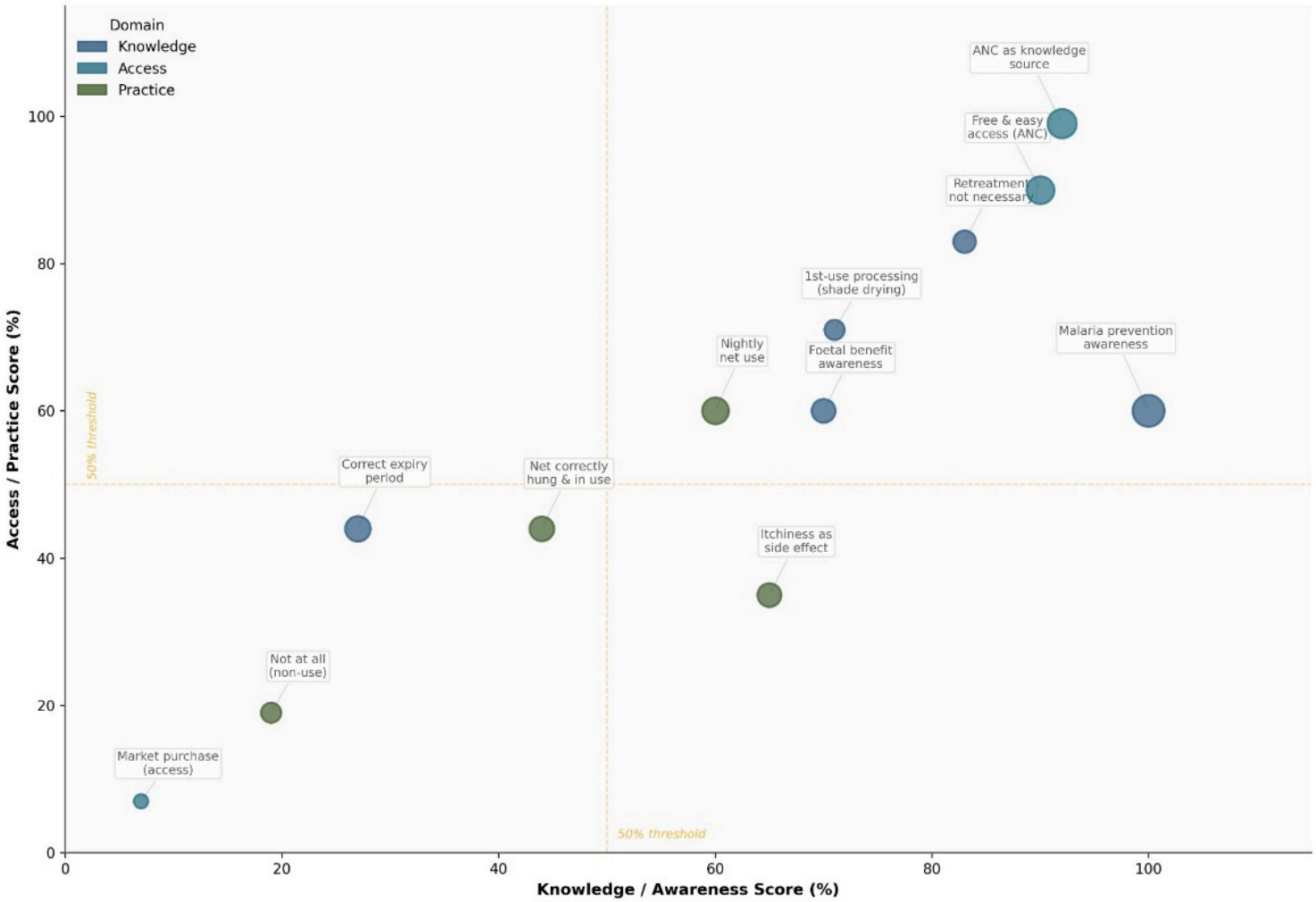


Figure 8

Bubble chart: multivariate relationship between knowledge, access, and practice indicators. Each bubble represents one KAP indicator; bubble size is proportional to estimated programmatic significance. Dashed lines indicate 50% thresholds for both axes. Colours indicate domain: navy = Knowledge, teal = Access, green = Practice. *Note. Indicators in the upper-right quadrant (high knowledge, high practice/access) represent programmatic strengths; indicators in the lower-left quadrant represent priority intervention targets. The ANC-access indicators cluster in the upper right, while the net use and expiry knowledge indicators fall in the lower left. ANC = Antenatal Care; KAP = Knowledge, Attitudes, and Practices.*

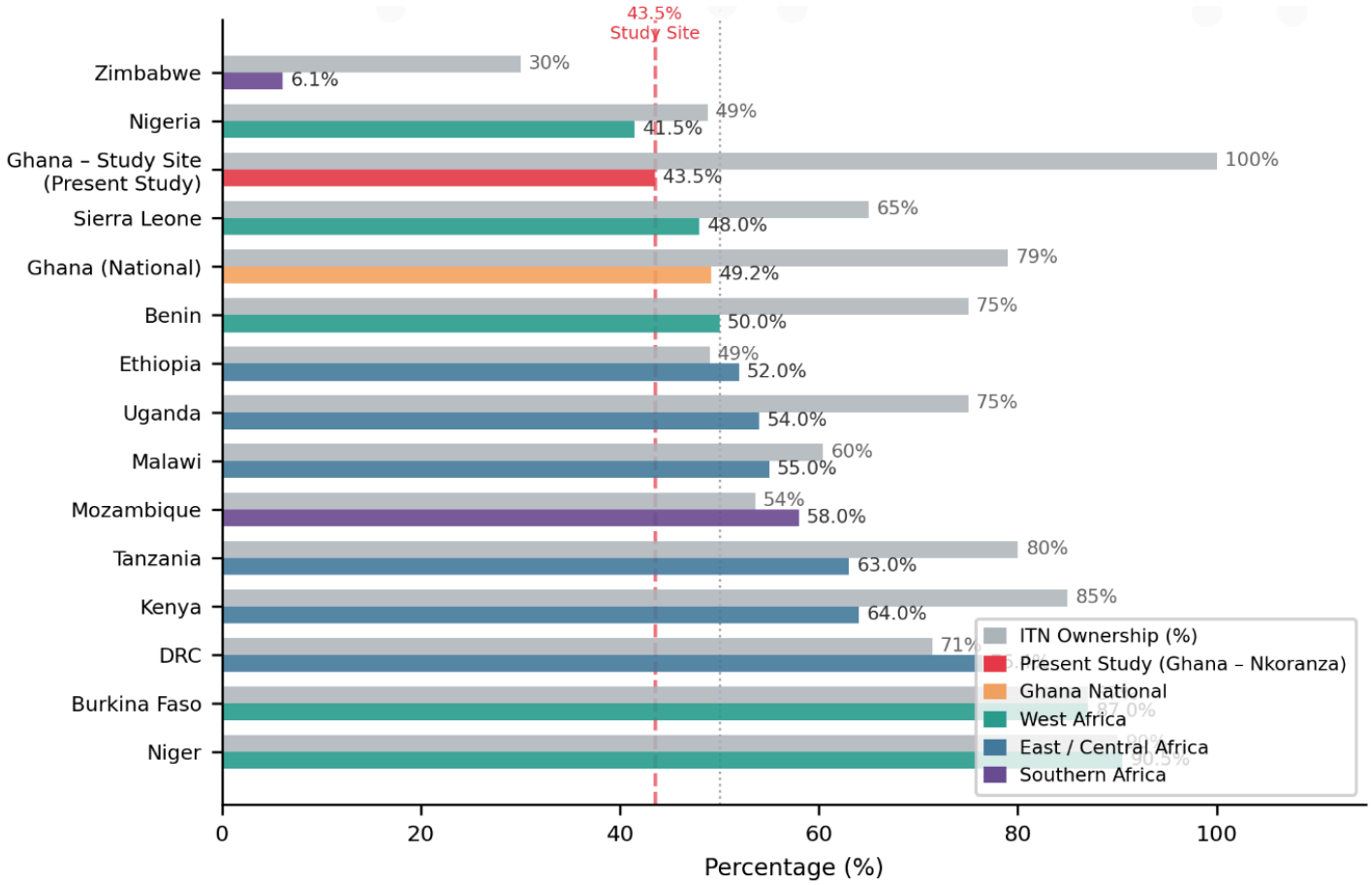


Figure 9

ITN ownership versus utilization among pregnant women across 15 countries in sub-Saharan Africa. Note: *Countries are ranked by ITN utilization rate (descending). Grey bars indicate ownership percentage; coloured bars indicate utilization percentage, with color corresponding to sub-region. The dashed red vertical line marks the present study's utilization rate (43.5%). The dotted line marks the 50% threshold. □ = present study (Ghana–Nkoranza South). Data sources: Mwebesa et al. (2025); Demoze et al. (2024); DHS pooled analyses (2022–2023); UNICEF (2024); Socioeconomic temporal inequality analysis (2024). Country color coding: red = present study; orange = Ghana national; teal = West Africa; steel blue = East/Central Africa; purple = Southern Africa.*

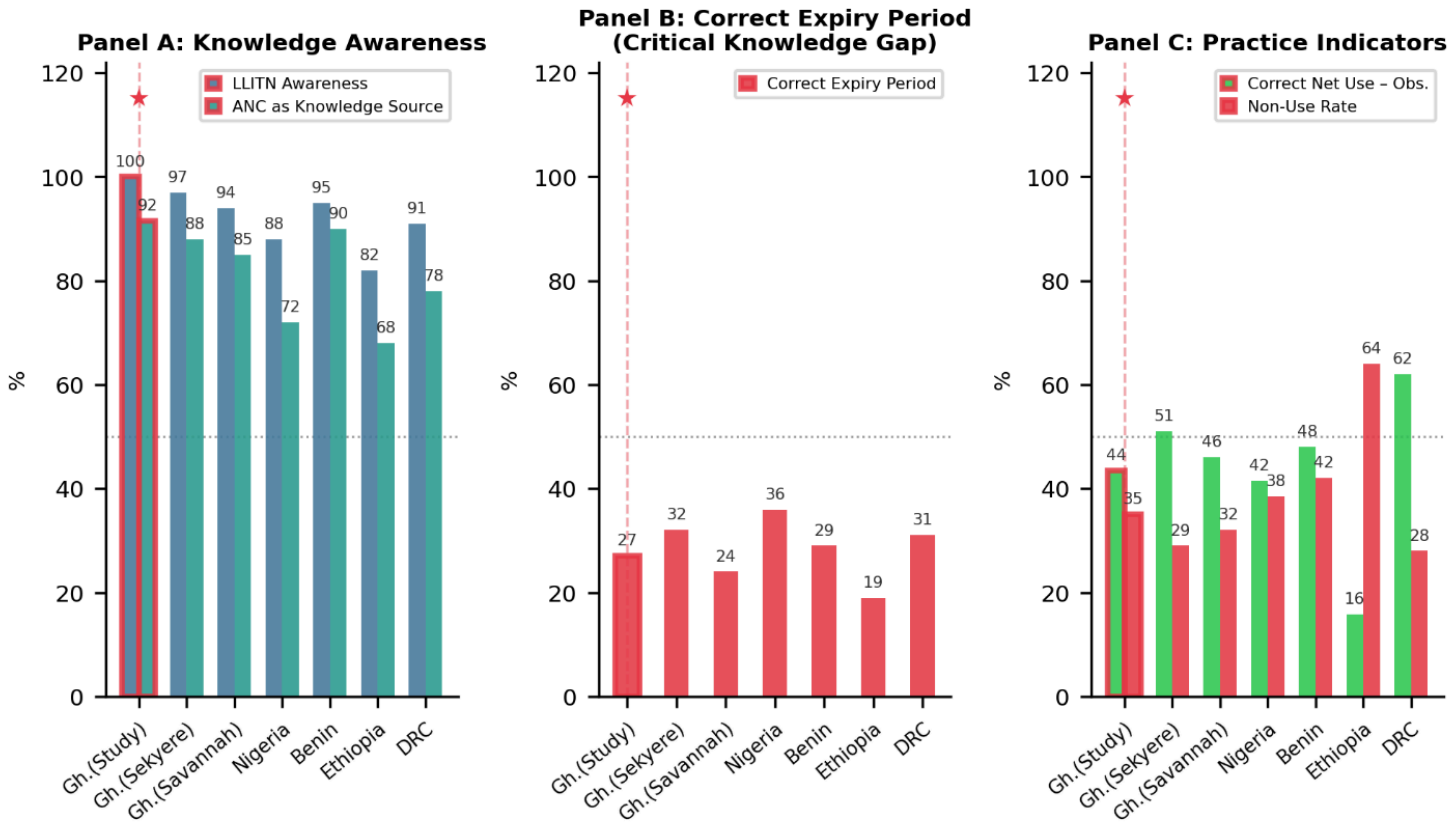


Figure 10

KAP indicator comparison across published studies in malaria-endemic settings. Note: *Three grouped panels compare KAP indicators across seven study settings. Panel A: awareness-level knowledge indicators. Panel B: the critical knowledge gap indicator (correct 3-year expiry period). Panel C: practice indicators (correct observed net use and non-use rate). ▯ = present study (Ghana–Nkoranza South); red outline on bars marks the present study across all panels. Data sources: Zuuri et al. (2025); Salifu et al. (2026); Nigeria Prevention KAP study (2022); Cottrell et al. (2025); Ethiopia KAP study (2019); Kabalu Tshiongo et al. (2024).*

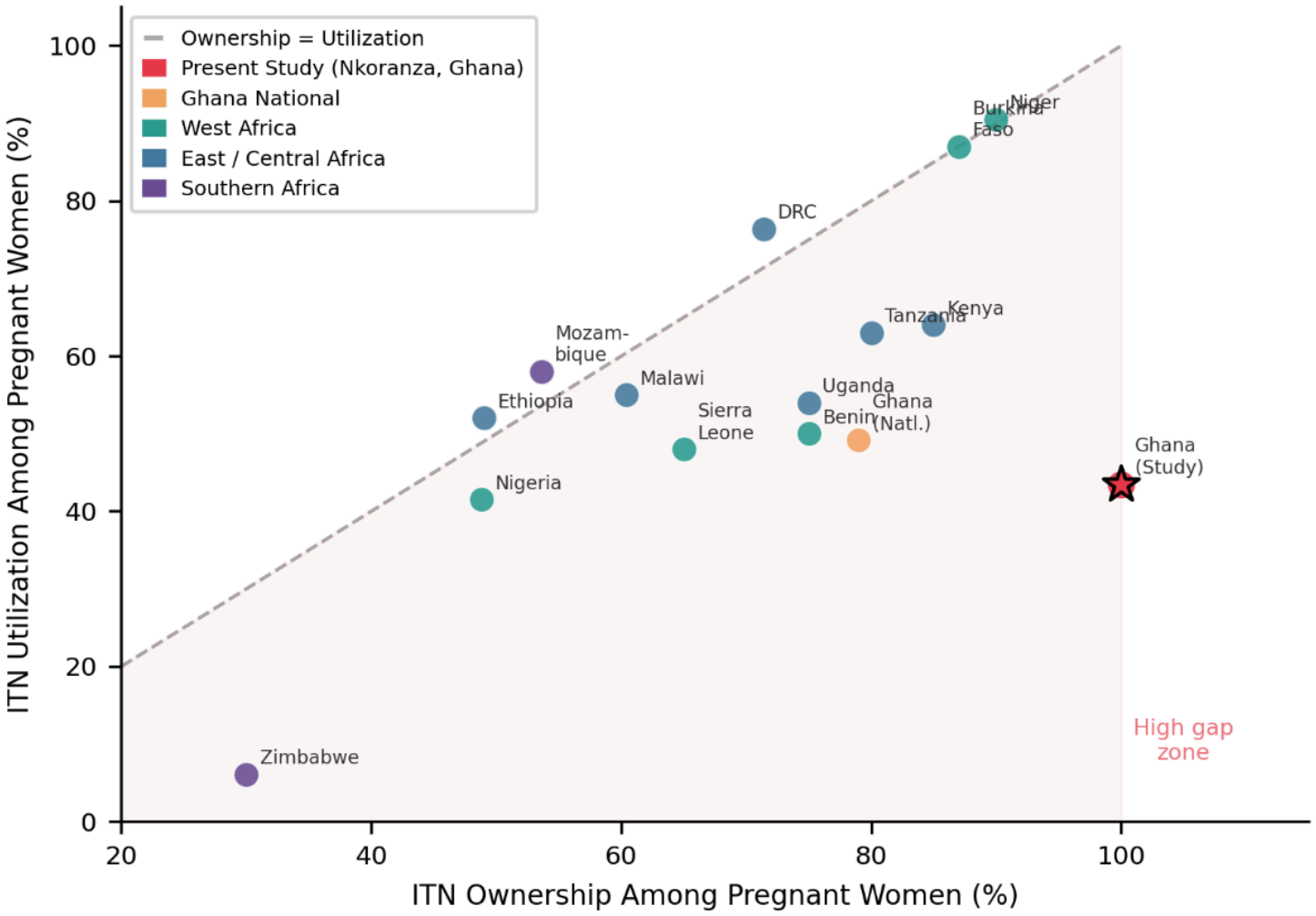


Figure 11

Ownership–utilization gap scatterplot: multi-country positioning of the study site. Note: *Each point represents one country or study setting. The dashed diagonal line represents perfect ownership–utilization parity; points below the diagonal indicate utilization less than ownership (i.e., unused nets). □ = present study (Ghana–Nkoranza South). Color coding by sub-region: red = present study; orange = Ghana national; teal = West Africa; steel blue = East/Central Africa; purple = Southern Africa. Data sources: as per Table 4.*

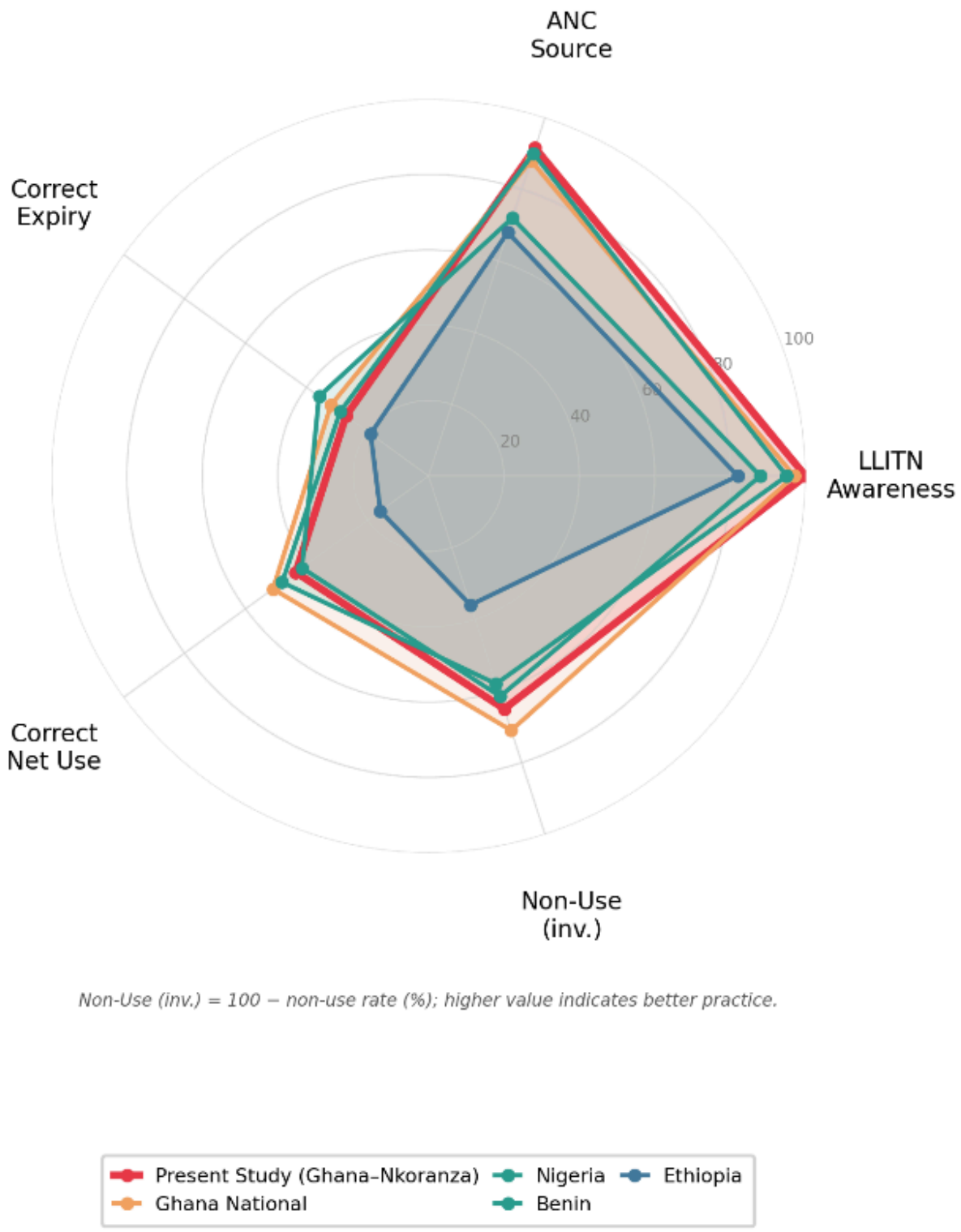


Figure 12

KAP radar profile comparison: multi-country positioning of the present study. *Note: Each arm represents one KAP indicator; radial distance indicates the proportion of correct/positive responses. The 'Non-Use (inv.)' arm represents the inverse of non-use rate (100 – non-use%), so that outward extension uniformly indicates better performance. The present study profile (red) reveals the characteristic deficiency at the*

Correct Expiry arm. The Ethiopian profile (steel blue) shows critical deficiency in both Correct Expiry and Correct Net Use. Data sources: as per Table 5.

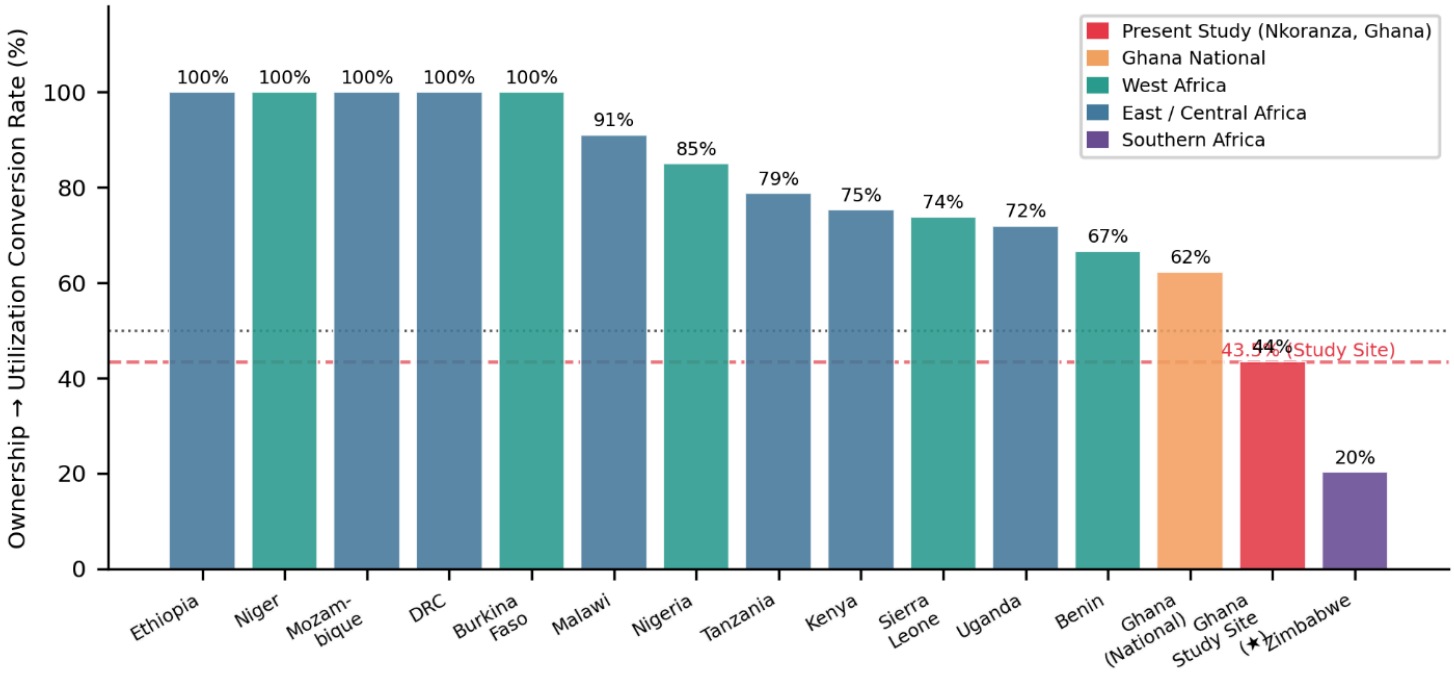


Figure 13

Ownership-to-utilization conversion rate across malaria-endemic countries. *Note: The conversion rate represents the proportion of pregnant women who own a net and also use it (utilization/ownership × 100%). A rate of 100% would indicate that all net owners also use their nets. The dashed red line marks the present study's conversion rate of 43.5%; the dotted line marks the 50% threshold. ★ = present study. Color coding as per Figure 9. Data sources: as per Table 4.*