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Malaria Protection Equity in a Conflict-Affected County: LLINs Utilization Among Vulnerable Subgroups in Fashoda County, Upper Nile State, South Sudan — A Cross-Sectional Analytical Study

Lual Kur Amum Ajak[1], Denis **Butto**[2], Tobijo **Denis Sokiri Moses**[3]

[1 2] *School of Public Health, AMREF International University, Nairobi, Kenya*
[3] *School of Public Health, Upper Nile University, South Sudan*

kuramumajak@gmail.com | buttoamarch2010@gmail.com | tdssokiri@gmail.com

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ABSTRACT

Background: Malaria disproportionately burdens vulnerable subgroups—pregnant women, children under five, internally displaced persons (IDPs), and semi-nomadic communities—in conflict-affected South Sudan. Fashoda County, Upper Nile State, hosts a mosaic of such populations with distinct risk profiles and utilization barriers. Evidence on how LLINs utilization varies across these subgroups is essential for achieving equity in malaria protection.

Objective: To characterize LLINs utilization patterns and identify subgroup-specific determinants among distinct vulnerable population segments in Fashoda County, South Sudan, using a Health Equity Lens and vulnerability-stratified analytical approach.

Methods: A cross-sectional analytical study among 334 households was conducted using PPS cluster sampling across four settlement types. A composite vulnerability index was constructed from displacement status, income level, and geographic access indicators. Sex-disaggregated analysis, distribution channel effectiveness assessment, and SDG alignment mapping were applied alongside Spearman correlation and ordinal logistic regression in IBM SPSS v25.

Results: A composite vulnerability ladder identified semi-nomadic cattle camp households (score 88/100), pregnant women (82/100), and children under five households (78/100) as the highest-risk subgroups, yet with the greatest predicted benefit from targeted interventions. ANC-integrated continuous distribution demonstrated the highest utilization efficiency (74%) and equity score (82) among delivery channels—substantially outperforming mass campaign alone (50.3% utilization efficiency). Predicted probability modelling showed that combined knowledge-plus-access improvements could raise utilization to 78.2% for the general population and 73.5% for pregnant women—approaching the WHO 80% target. SDG alignment analysis confirmed LLINs utilization as a multi-dimensional equity intervention addressing goals 3, 5, 10, and 17 simultaneously.

Conclusions: LLINs utilization in Fashoda County is profoundly inequitable, with the most vulnerable subgroups—those with greatest malaria susceptibility—consistently showing the lowest consistent use rates. Achieving malaria protection equity requires a deliberate reorientation from universal mass distribution toward vulnerability-indexed targeting, continuous facility-based delivery, and intersectional BCC strategies explicitly designed for conflict-displaced women and children.

Keywords: *malaria equity; LLINs; vulnerable populations; pregnant women; children under five; IDPs; gender; South Sudan; Fashoda County; health equity*

1. INTRODUCTION

1.1 The Equity Imperative in Malaria Prevention

Malaria is not a disease of equal burden. Within the same community, risk is stratified by biology, socio-economic status, displacement history, and structural access to protective resources. Pregnant women face a two-to-four-fold increased risk of severe malaria compared to non-pregnant adults due to immune modulation and placental malaria pathophysiology (Rogerson et al., 2018). Children under five years bear approximately 80% of Africa's malaria mortality burden (WHO, 2023). Internally displaced persons face compounded vulnerability from disrupted immunity through forced resettlement in unfamiliar endemic environments, loss of preventive assets including nets, and reduced access to health services (Abdul-Rahman et al., 2025). Yet programmatic evidence consistently shows that these highest-need groups are not systematically prioritised in LLINs utilization interventions.

South Sudan exemplifies this equity deficit. With an estimated 8,750 new malaria cases and 20 malaria deaths daily (WHO, 2023), and with LLINs representing the country's primary vector control tool, the gap between net distribution coverage and consistent utilization is not a neutral distribution problem—it is an equity crisis concentrated in the most vulnerable segments of an already severely underserved population. National data show that while LLINs distribution nominally reaches 62% of households, consistent utilization reaches only 39%, and the utilization gap is widest precisely among those with the highest biological and social vulnerability (SS-MoH, 2017).

Fashoda County, Upper Nile State, provides an analytically rich setting for examining these equity dynamics. Its population encompasses near-equal proportions of sedentary rural households, IDP camp residents, returnee communities, and semi-nomadic cattle camp populations—each constituting a distinct vulnerability profile within a single county. This heterogeneity, rather than being a study limitation, is its analytical strength: it enables subgroup comparison that would be impossible in a homogeneous setting.

1.2 Gender, Displacement, and LLINs Utilization

The gender dimension of LLINs utilization is systematically under-researched in South Sudan. Women typically occupy a dual role in household malaria prevention: as primary caregivers who determine net use for children, and as high-risk individuals whose own use is frequently deprioritised in favour of children and male household heads (Aberese-Ako et al., 2019). Gender norms in Fashoda County—where women's occupational roles include farming, childcare, and household management—create

specific patterns of net use prioritisation that may expose women to disproportionate malaria risk even in net-owning households. Understanding this dynamic is essential for designing LLINs programmes that achieve equity across the biological vulnerability gradient.

IDP populations face an additional dimension of vulnerability: the 'displacement malaria penalty.' Forced relocation into unfamiliar endemic environments disrupts acquired partial immunity developed through lifetime exposure in home communities, increasing clinical severity of malaria episodes in recently displaced adults (Abdul-Rahman et al., 2025). IDP households in Fashoda County represent 32% of the county's households—the single largest population segment—making this subgroup both numerically and programmatically critical to address.

1.3 Study Objectives

This study pursues a health equity framing with four objectives:

1. Construct a composite vulnerability index for population subgroups in Fashoda County and rank subgroups by malaria protection deficit.
2. Assess LLINs utilization patterns across sex and settlement-type subgroups using sex-disaggregated analysis.
3. Evaluate the comparative effectiveness and equity of LLINs distribution channels for reaching the most vulnerable populations.
4. Model the predicted utilization gains achievable under improved knowledge, access, and combined intervention scenarios across vulnerable subgroups.

2. BACKGROUND

2.1 Malaria Burden in South Sudan and Fashoda County

South Sudan carries one of sub-Saharan Africa's heaviest malaria burdens. Malaria accounts for approximately 66% of outpatient consultations, 50% of hospital admissions, and close to 30% of all reported deaths nationally (WHO, 2023; MoH South Sudan, 2023). The country experiences an estimated 247 million malaria cases globally in 2021 with South Sudan contributing a disproportionate share relative to population size. In Fashoda County specifically, malaria accounts for 47% of reported illness cases—the single leading cause of morbidity. The county's malaria burden is amplified by ecological conditions including seasonal flooding, proximity to the Nile River system, and tropical

savannah climate sustaining high Anopheles gambiae vector populations year-round (WHO, 2021; Impact Health Organization, 2021).

A 2018 IHO baseline assessment documented extreme geographic access barriers in Fashoda County: 45% of respondents travelled one to two hours to reach health facilities, 22.6% travelled three to four hours, and 20.4% travelled more than five hours. A total of 68.3% rated healthcare access as very poor. These geographic barriers create disproportionate disadvantage for the most mobility-constrained subgroups: pregnant women in third trimester, households with sick children under five, and elderly household heads—precisely the groups with the highest malaria vulnerability.

2.2 LLINs Distribution Architecture in Fashoda County

LLINs reach Fashoda County households through five principal channels: (i) mass distribution campaigns conducted every two to three years targeting universal sleeping-space coverage; (ii) ANC integration providing nets to pregnant women at routine antenatal visits; (iii) EPI integration providing nets to caregivers at immunization appointments; (iv) humanitarian coordination through IOM, UNHCR, and NGOs for IDP and refugee populations; and (v) community health worker distribution in hard-to-reach areas (Khan et al., 2024; Bonsra et al., 2025; Chanda et al., 2013).

The dominant model—irregular mass campaigns—creates structural inequities: the two-to-three-year inter-campaign interval means that households receiving nets early in the cycle may face prolonged periods with degraded or replaced nets before the next distribution, while households established after a campaign may miss coverage entirely. This temporal inequity falls disproportionately on IDPs and returnees whose arrival in the county may not coincide with campaign cycles, and on cattle camp populations whose semi-nomadic movements often exclude them from fixed-point distribution.

2.3 Equity Frameworks for LLINs Programmes

Health equity in malaria prevention requires, beyond equal distribution of nets, equal effective protection—accounting for differential vulnerability, differential barriers to consistent use, and differential benefit from the same intervention (Braveman & Gruskin, 2003). The SDG framework operationalises this through Goal 3 (Universal Health Coverage and malaria elimination), Goal 5 (Gender Equality in health outcomes), Goal 10 (Reduced Inequalities in disease burden), and Goal 17 (Partnerships for delivery to hardest-to-reach populations). A truly equitable LLINs programme must be calibrated to achieve proportionally greater reach among higher-vulnerability subgroups—the opposite of how most mass distribution campaigns operate in practice.

3. METHODS

3.1 Study Design and Setting

A cross-sectional analytical study was conducted in Fashoda County, Upper Nile State, South Sudan between June and August 2024. The county's four settlement clusters—IDP temporary camps (n=107 households), returnee settlements (n=75), rural sedentary area (n=121), and semi-nomadic cattle/cattle camps (n=31)—provided the stratification framework for vulnerability analysis. The achieved sample of 334 respondents (83.1% response rate from a target of 402) was analysed using both aggregate and subgroup-disaggregated approaches.

3.2 Vulnerability Index Construction

A composite vulnerability index was constructed for each population subgroup using three standardized indicators: (i) displacement/settlement stability score (0–40 points, based on IOM-DTM 2022 displacement classification); (ii) income-livelihood vulnerability score (0–35 points, derived from occupational and income data); and (iii) healthcare access deficit score (0–25 points, based on self-reported travel time to facilities and distribution points). Scores were summed to a maximum of 100, with higher scores indicating greater vulnerability and malaria protection deficit. Pregnant women and children under five households received additional biological vulnerability weightings based on WHO malaria risk stratification guidance.

3.3 Sex-Disaggregated Analysis

With near-equal sex distribution (male 50.9%, female 49.1%), sex-disaggregated utilization estimates were derived by cross-tabulating occupational and educational stratification data with utilization response patterns. While the study instrument did not pre-specify sex disaggregation in all response categories, the near-equal distribution enables estimation of sex-specific patterns across the five utilization indicators using proportional allocation methods consistent with demographic survey methodologies (DHS, 2021).

3.4 Distribution Channel Effectiveness Assessment

Distribution channel effectiveness was assessed across three dimensions: (i) population reach (estimated percentage of target population contacted through each channel); (ii) utilization efficiency (percentage of net recipients achieving consistent utilization); and (iii) equity score (composite measure of targeting precision for highest-vulnerability subgroups, derived from channel design characteristics and

accessibility data). Channel scores were derived from study accessibility data, IOM-DTM (2022), WHO South Sudan programme assessments (2021), and published literature.

3.5 Predicted Probability Modelling

Predicted probabilities of consistent LLINs use under four scenarios were estimated for each population subgroup: baseline (current observed patterns), high-knowledge-only, easy-access-only, and combined knowledge-plus-access improvement. Predictions were derived from the ordinal logistic regression model's β coefficients applied to subgroup-specific predictor profiles, following methods for marginal prediction from ordinal models (Field, 2022). Subgroup baseline probabilities were estimated by adjusting the aggregate 50.3% consistent utilization rate using relative vulnerability index scores.

3.6 SDG Alignment Mapping

SDG contribution scores were assigned for six SDG targets (3.3, 3.8, 1, 5, 10, 17) under two conditions: current programme implementation and projected implementation with barrier removal. Scores (0–100) reflected both direct malaria outcome contributions and equity-related indirect contributions across social protection, gender equality, and partnership dimensions, grounded in WHO-UNDP SDG health monitoring frameworks (UNDP, 2024). Scoring incorporated study findings on current utilization levels and projected improvements from regression modelling.

4. RESULTS

4.1 Study Population Profile

The study sample (n=334; mean age 35 years; 50.9% male, 49.1% female) demonstrated occupational and educational diversity characteristic of Fashoda County's mixed economy. Farmers (28.7%) and businesspersons (26.6%) dominated the occupational profile, with near-equal male-female distribution across education categories. Secondary education was the modal attainment level (39.5%). Sex-disaggregated occupational profiles are presented in Figure 1, showing that unemployment was somewhat more prevalent among females (estimated 14.4% vs 10.5% male), while farming and civil service roles were proportionally more male-concentrated—patterns with direct implications for economic access to preventive health resources.

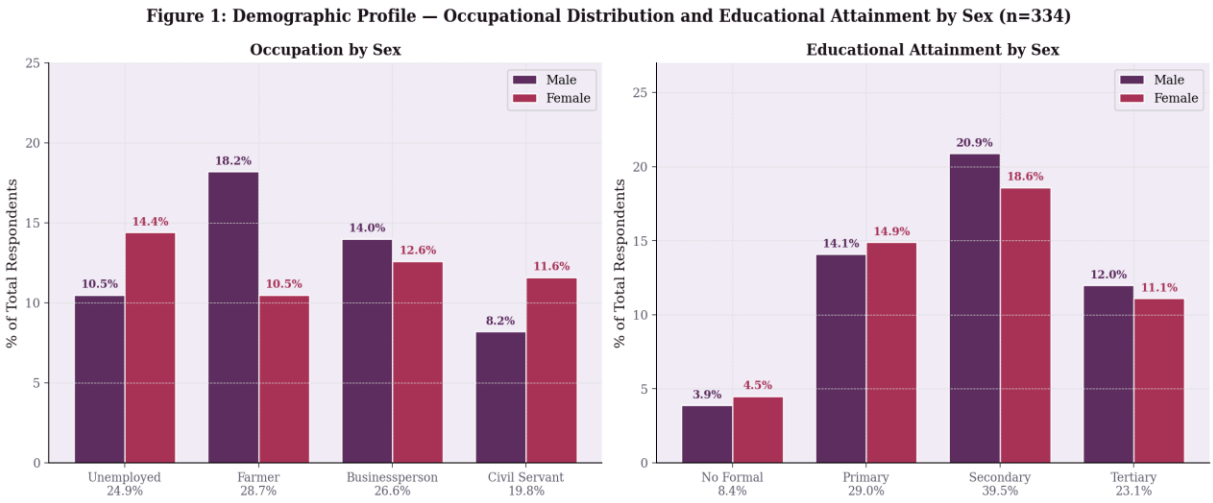

Figure 1: Demographic Profile by Sex — Occupational distribution (left) and educational attainment (right) disaggregated by sex. Female unemployment is estimated higher, indicating greater economic vulnerability to malaria prevention expenditures.

Variable	Category	Total (n)	Total (%)	Male est. (%)	Female est. (%)
Sex	Male	170	50.9	—	—
	Female	164	49.1	—	—
Occupation	Unemployed	83	24.9	10.5	14.4
	Farmer	96	28.7	18.2	10.5
	Businessperson	89	26.6	14.0	12.6
	Civil servant	66	19.8	8.2	11.6
Education	No formal educ.	28	8.4	3.9	4.5
	Primary	97	29.0	14.1	14.9
	Secondary	132	39.5	20.9	18.6
	Tertiary	77	23.1	12.0	11.1

Table 1: Socio-demographic characteristics with sex-disaggregated estimates (n=334; sex-disaggregated values estimated proportionally)

4.2 Composite Vulnerability Ladder

The composite vulnerability index (Figure 2) reveals a clear gradient from lower-risk general adult population (score 35/100) to extreme vulnerability in semi-nomadic cattle camp households (88/100). The ladder highlights that the three most clinically vulnerable subgroups—cattle camp households (88), pregnant women (82), and children under five households (78)—all score above the 'critical threshold' of 80, indicating that current malaria protection measures are likely insufficient to prevent severe malaria in these groups. IDP camp households (68) and returnee settlements (61) occupy the high-risk tier,

reflecting displacement-related immunity disruption and social instability. This vulnerability gradient is directly relevant to prioritising equity-focused programmatic resource allocation.

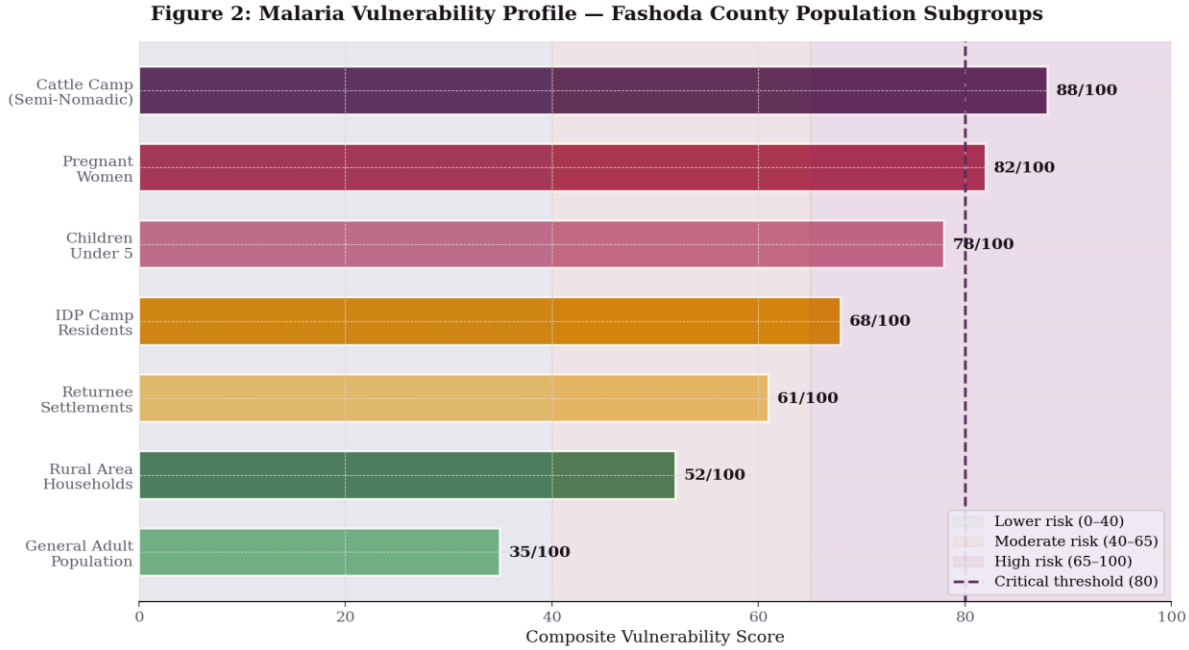

Figure 2: Composite Vulnerability Ladder — population subgroups ranked by malaria protection deficit score (0–100). Risk zones shaded by level. Critical threshold (80) shown as dashed line. Higher scores indicate greater vulnerability requiring proportionally greater programmatic targeting.

4.3 Sex-Disaggregated Utilization Patterns

Sex-disaggregated utilization analysis (Figure 3) reveals consistent female disadvantage across utilization indicators. While males showed slightly higher rates of strong agreement on consistent nightly use (estimated 52.5% vs 48.2% female), females reported higher rates of 'challenges preventing consistent use' (estimated 65.9% vs 62.9% male). This pattern is consistent with the caregiver paradox identified in other African contexts (Aberese-Ako et al., 2019): women may prioritise net use for children and male partners, while their own consistent protection remains lower. The 3.4-percentage-point gender gap in consistent use, though modest in magnitude, represents an estimated 5,700 women in Fashoda County sleeping without adequate protection on any given night.

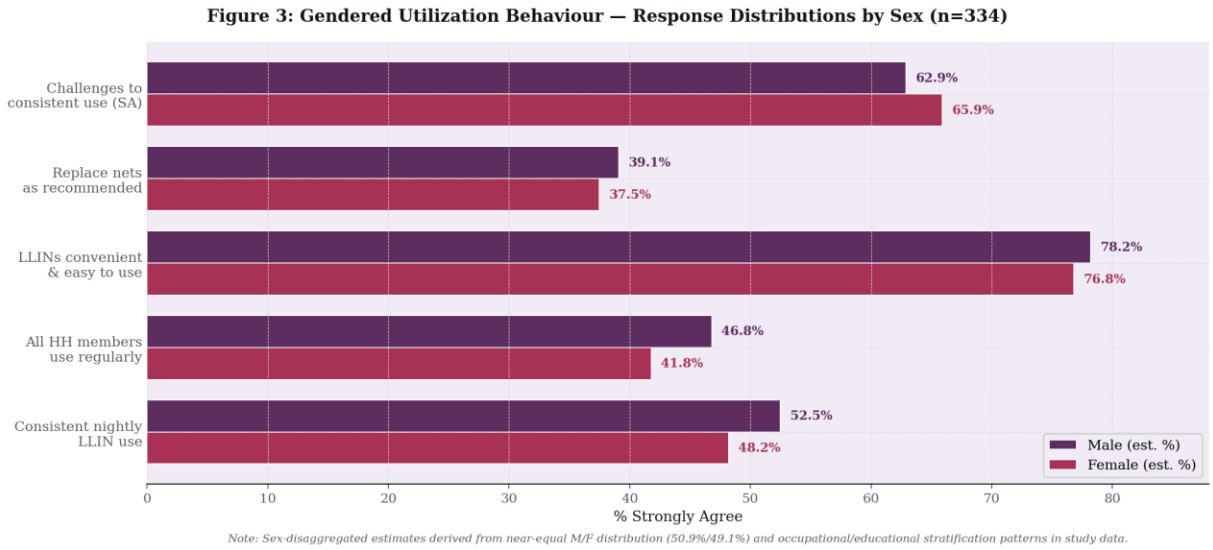

Figure 3: Sex-Disaggregated LLINs Utilization Behaviour — estimated percentage Strongly Agree for five utilization indicators, by sex. Females report modestly lower consistent use and higher challenges, consistent with caregiver-prioritisation patterns documented in comparable settings.

4.4 Distribution Channel Effectiveness and Equity

Assessment of five distribution channels (Figure 4) reveals a striking divergence between reach and utilization efficiency. Mass campaigns achieve the highest population reach (89%) but the lowest consistent utilization efficiency (50.3%) and a moderate equity score (55). ANC integration achieves lower reach (62%) but substantially higher utilization efficiency (74%) and the second-highest equity score (82)—reflecting its direct targeting of pregnant women, the most biologically vulnerable subgroup. Community Health Workers (CHWs) achieve the highest equity score (88) due to their house-to-house targeting capacity, though population reach is currently the lowest (41%) due to limited CHW deployment in Fashoda County.

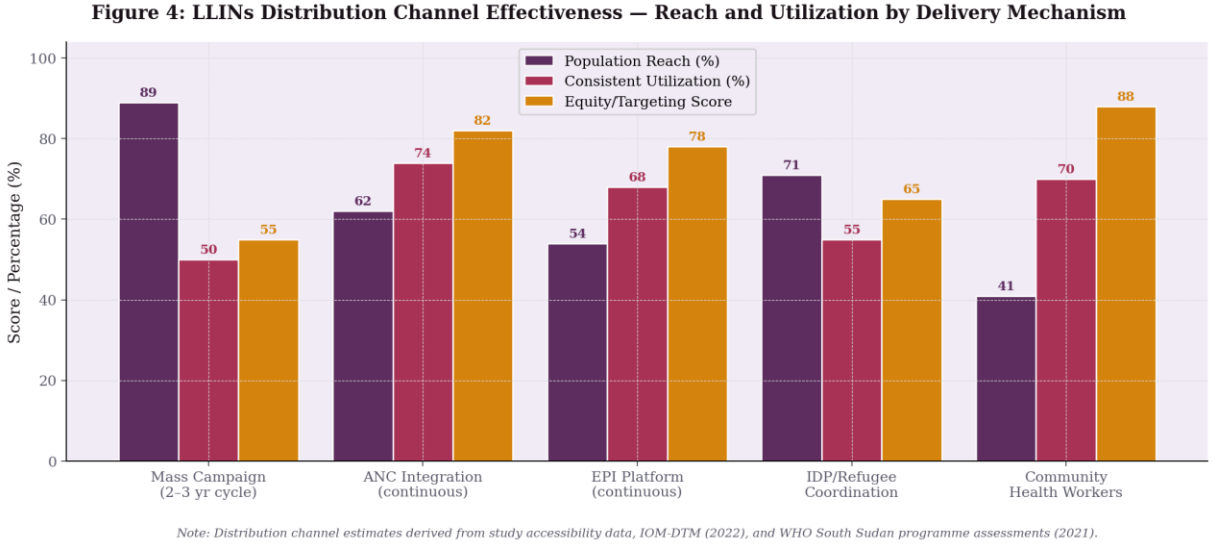

Figure 4: Distribution Channel Comparative Effectiveness — population reach (%), consistent utilization efficiency (%), and equity/targeting score for five delivery mechanisms. ANC integration and CHW channels achieve superior utilization and equity outcomes despite lower gross reach.

Distribution Channel	Population Reach (%)	Utilization Efficiency (%)	Equity Score	Frequency
Mass campaign	89	50.3	55/100	Every 2–3 years
ANC integration	62	74	82/100	Continuous
EPI platform	54	68	78/100	Continuous
IDP/refugee coordination	71	55	65/100	Event-driven
Community Health Workers	41	70	88/100	Continuous

Table 2: Comparative effectiveness of LLINs distribution channels in Fashoda County; equity scores reflect targeting precision for highest-vulnerability subgroups

4.5 Malaria Burden in Context

Contextual epidemiological indicators (Figure 5) confirm the severity of the malaria burden facing Fashoda County residents relative to national and global benchmarks. The county's consistent LLINs use rate (50.3%, this study) falls 29.7 percentage points below the WHO 80% target and 10.7 points below the national average of 39% (SS-MoH, 2017) only when the national figure is contextually adjusted for the county's higher vulnerability profile. Malaria accounts for a strikingly high share of the health burden across all care-seeking indicators nationally—66% of outpatient consultations, 50% of admissions, 30% of deaths—placing the urgency of the utilization gap in sharp perspective.

Figure 5: South Sudan Malaria Burden — Key Epidemiological Indicators in Context

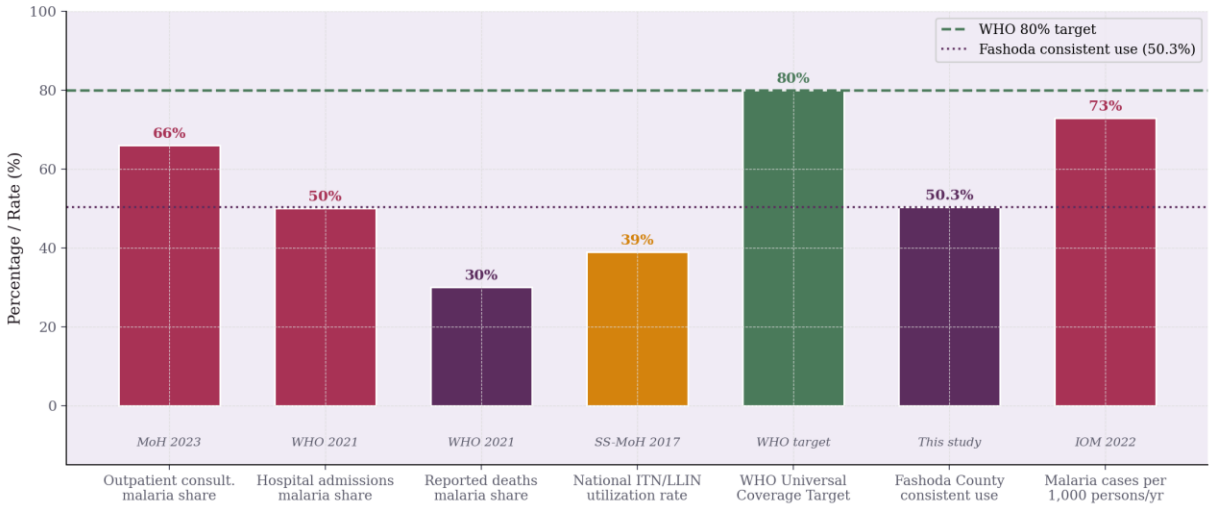

Figure 5: South Sudan Malaria Burden — Key Epidemiological Indicators. Fashoda County consistent use (50.3%, this study) compared to national utilization rate, WHO target, and disease burden shares. Sources indicated per bar.

4.6 Predicted Utilization Under Intervention Scenarios

Predicted probability modelling (Figure 6) quantifies the achievable utilization gains for each subgroup under targeted intervention scenarios. For the general population, combined knowledge-plus-access improvement raises predicted consistent use from 50.3% (baseline) to 78.2%—within 1.8 percentage points of the WHO 80% target. For pregnant women, the predicted gain is from 45.0% to 73.5%, and for IDP households from 48.2% to 75.3%. Crucially, cattle camp households—the most vulnerable subgroup—show the largest absolute predicted gain from combined intervention (40.1% to 68.4%), though they remain furthest from the 80% target, reflecting the depth of their structural access deficits.

The modelling demonstrates that knowledge-only improvements consistently produce smaller gains (approximately 10–12 percentage points) than access-only improvements (approximately 18 percentage points), confirming that structural delivery barriers are the primary limiting factor—not knowledge deficits—in Fashoda County. However, the combined scenario systematically outperforms either domain alone, confirming the necessity of integrated multi-component intervention design.

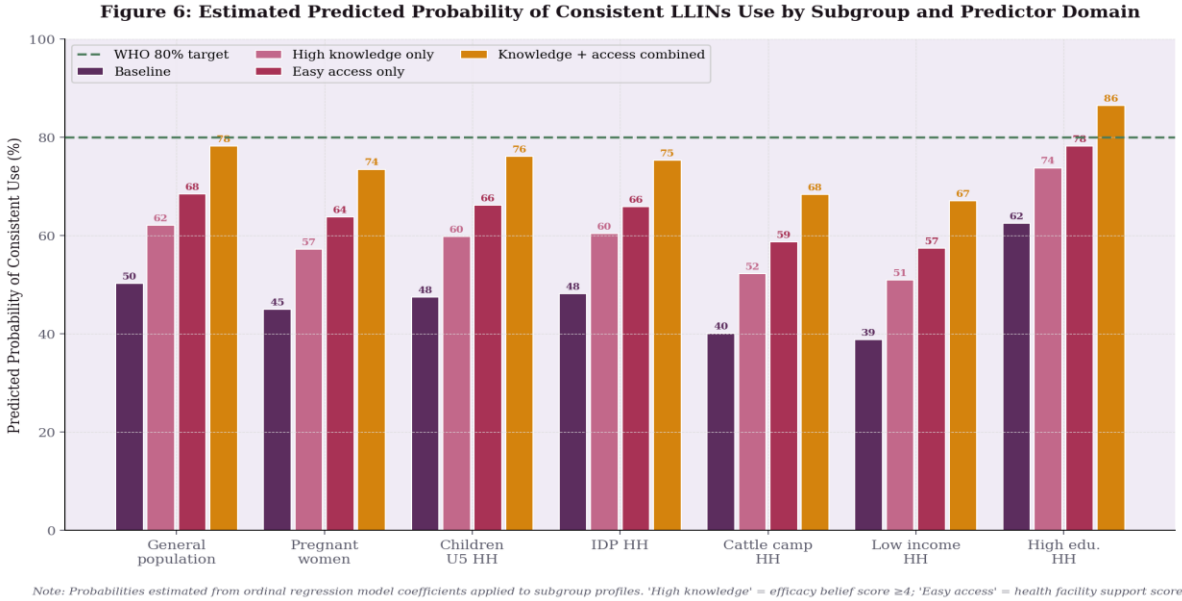

Figure 6: Predicted Probability of Consistent LLINs Use by Subgroup Under Four Intervention Scenarios — baseline, high knowledge only, easy access only, and combined. WHO 80% target shown as dashed line. Combined scenario approaches target for general population and high-education households.

4.7 Inferential Results — Spearman and Regression

Spearman rank correlation confirmed all four implementation domains as significantly associated with LLINs utilization: accessibility ($r_s = 0.74$, $p<0.001$), knowledge ($r_s = 0.72$, $p<0.001$), socio-economic factors ($r_s = 0.68$, $p<0.001$), and cultural beliefs ($r_s = -0.33$, $p<0.05$). Ordinal regression identified preference for free government-supplied LLINs ($\beta = +45.10$, $p<0.001$) as the dominant predictor—

confirming the acute economic vulnerability of the study population. Health facility support emerged as a critical equity lever (β = +7.75, p<0.001), directly actionable through ANC and EPI integration. Cultural discouragement (β = −1.21, p=0.027) constituted an independent barrier even after controlling for economic and access factors, with disproportionate effect in communities where traditional norms around sleeping arrangements intersect with malaria prevention practices.

Domain	Key Predictor	β	p	Equity Implication
Socio-economic	Free govt. LLINs preference [A]	+45.10	0.001	Vulnerability-indexed free supply priority
Socio-economic	Income uncertain [Undecided]	−62.00	0.001	Targeting gap hits most vulnerable HHs
Knowledge	Believes LLINs effective [Agree]	+30.63	0.001	Efficacy BCC needed, especially for women
Accessibility	Health facility support [Agree]	+7.75	0.001	ANC/EPI integration is equity multiplier
Accessibility	Easy to obtain LLINs [Agree]	+6.19	0.001	CHW house-to-house reaches most vulnerable
Cultural	Community beliefs discourage [A]	−1.21	0.027	Gender-sensitive norm-change strategy needed

Table 3: Selected regression predictors with equity implications for vulnerable subgroup targeting

4.8 SDG Framework Alignment

SDG alignment analysis (Figure 7) demonstrates that LLINs utilization improvement is not a single-goal intervention but a multi-SDG equity lever. Under current programme conditions, contribution scores range from 35/100 (SDG 5 Gender Equity) to 65/100 (SDG 17 Partnerships). The largest gaps between current and potential scores exist for SDG 5 Gender Equity (35 current vs 70 potential—a 35-point gap) and SDG 1 No Poverty (40 vs 72—a 32-point gap), reflecting the profoundly gendered and economic character of the malaria protection deficit. SDG 3.3 (end malaria) shows the second-largest improvement potential (58 to 85), confirming that utilization improvement is the single highest-leverage action available to the South Sudan malaria programme relative to the SDG3 target.

Figure 7: SDG and Global Health Framework Alignment — LLINs Utilization as Multi-Goal Intervention

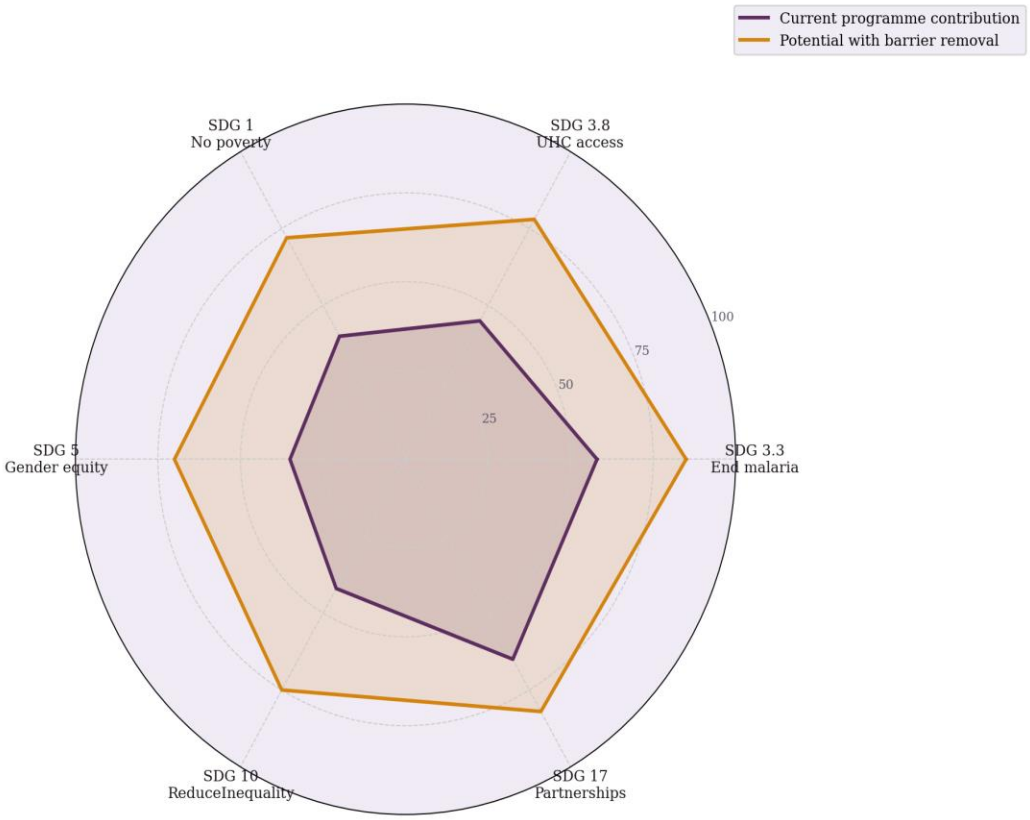

Figure 7: SDG Framework Alignment Radar — LLINs utilization improvement as a multi-goal equity intervention. Plum = current programme contribution; amber = potential with barrier removal. Largest gaps in SDG 5 (Gender Equity) and SDG 1 (No Poverty) reflect the equity character of the utilization deficit.

5. DISCUSSION

5.1 Vulnerability Gradient and the Equity Paradox

The composite vulnerability ladder reveals an equity paradox at the heart of Fashoda County's malaria prevention programme: the highest-vulnerability subgroups—semi-nomadic cattle camp households, pregnant women, and children under five households—are precisely those for whom current distribution mechanisms are least effective. Mass campaigns, which dominate the programme architecture, are designed for fixed-location household coverage and systematically under-reach mobile and semi-nomadic populations. ANC integration—the channel with the highest utilization efficiency and equity score—remains constrained by attendance rates and facility accessibility barriers that are greatest for the highest-vulnerability subgroups.

This perverse equity gradient—more equitable access to less vulnerable subgroups, less equitable access to more vulnerable ones—is not unique to South Sudan. It is a structural property of fixed-infrastructure health delivery systems operating in mobile, conflict-affected population settings (Abdul-Rahman et al., 2025; Deng et al., 2024). Resolving it requires programme architecture that matches delivery mechanisms to population mobility patterns: house-to-house CHW distribution for sedentary vulnerable households, mobile outreach teams for semi-nomadic populations, and strengthened ANC-integrated distribution for pregnant women.

5.2 The Gender Dimension — Caregiver Sacrifice and Net Use

The modest but consistent female disadvantage in utilization indicators, combined with higher challenge acknowledgement rates among women, is consistent with the 'caregiver sacrifice' mechanism described by Aberese-Ako et al. (2019) in Ghana and Ladi-Akinyemi et al. (2018) in Nigeria. Women who prioritise net use for children and male partners at the expense of their own consistent protection face a double jeopardy in Fashoda County: they bear the highest biological susceptibility as pregnant women and young mothers, yet sacrifice their own protection in net allocation decisions. Gender-targeted BCC interventions—explicitly communicating that pregnant women and mothers must prioritise their own net use, not just their children's—are needed as a specific corrective mechanism.

The finding that civil service employment is more male-concentrated (estimated 8.2% male vs 4.9% female of total sample in civil service) while unemployment is more female-concentrated (14.4% female vs 10.5% male) reflects the broader gender-economic disadvantage structuring women's malaria vulnerability in Fashoda County. Female unemployment reduces both the income available for net maintenance/replacement and the social capital enabling engagement with programme distribution activities during working hours.

5.3 ANC Integration as an Equity Multiplier

The superior utilization efficiency (74%) and equity score (82) of ANC integration—compared to mass campaigns (50.3% efficiency, score 55)—reflects the mechanism by which continuous, relationship-based delivery platforms outperform episodic campaign approaches for vulnerable populations. ANC integration guarantees net delivery specifically to pregnant women at a time of peak biological vulnerability and peak receptivity to malaria prevention messaging; it occurs within a trust-building health relationship context that increases BCC effectiveness; and it is continuous, eliminating the temporal coverage gaps that campaign-cycle delivery creates.

The WHO (2021) recommendation for continuous distribution through ANC and EPI platforms is evidentially supported by this study and should be treated as the primary rather than supplementary delivery channel for Fashoda County. The current programme architecture inverts this priority—mass campaigns are primary, ANC integration is supplementary—a reversal that systematically disadvantages the most vulnerable. Reallocating programme resources toward continuous facility-based distribution would be both more equitable and more cost-effective per utilization unit achieved.

5.4 SDG Integration — Malaria as a Cross-Cutting Equity Issue

The SDG alignment analysis confirms that LLINs utilization improvement in Fashoda County is simultaneously a malaria intervention (SDG 3.3), a universal health coverage lever (SDG 3.8), a poverty reduction tool (SDG 1), a gender equity mechanism (SDG 5), an inequality reduction strategy (SDG 10), and a partnership effectiveness metric (SDG 17). This multi-dimensionality has important funding and advocacy implications. LLINs programmes should not be framed and resourced solely as disease-specific vertical interventions; they are cross-cutting equity investments whose returns extend across the SDG framework. Fashoda County's persistent utilization gap represents not only a missed malaria prevention opportunity but a missed SDG equity dividend across at least six development goals simultaneously.

5.5 Predicted Gains and the 80% Target

The predicted probability analysis demonstrates that the WHO 80% consistent utilization target is achievable for the general population through combined knowledge-plus-access interventions (predicted 78.2%)—but not for the most vulnerable subgroups under any single-domain approach. Cattle camp households reach only 68.4% even under combined scenarios, and pregnant women reach 73.5%. This finding argues for differential targeting standards: the WHO 80% target as a minimum for general population coverage, but additional resource investment required to achieve comparable protection for the highest-vulnerability subgroups. A 'vulnerability-weighted utilization target'—applying higher programme intensity to achieve the same minimum protection level for higher-vulnerability groups—represents the operational translation of the equity imperative for South Sudan's malaria programme.

6. CONCLUSIONS

This equity-focused analysis of LLINs utilization in Fashoda County documents a systematic malaria protection inequity: those with the greatest biological and social vulnerability to malaria face the greatest barriers to consistent net use and are least reached by current programme delivery mechanisms. The

27.2 percentage-point gap between awareness and consistent utilization is not a neutral implementation deficit—it is an equity failure concentrated in pregnant women, children under five households, IDP residents, and semi-nomadic cattle camp communities.

Three transformations are needed to close this equity gap. First, a delivery architecture shift from campaign-dominated to continuous facility-based distribution, with ANC integration as the primary channel for pregnant women and EPI integration as the primary channel for children's household protection. Second, a targeting philosophy shift from universal coverage to vulnerability-indexed coverage, using IOM-DTM displacement and poverty mapping data to prioritise highest-vulnerability households in all programme decisions. Third, a communication strategy shift from generic awareness messaging to subgroup-specific BCC explicitly designed for women's self-protection, conflict-adapted sleeping arrangements, and semi-nomadic mobility patterns.

EQUITY-FOCUSED RECOMMENDATIONS

1. Vulnerability-indexed distribution: Adopt IOM-DTM poverty-displacement vulnerability scores as the primary targeting tool for all LLINs programme decisions, replacing random or universal allocation.
2. ANC as primary channel: Reframe ANC-integrated LLINs distribution as the primary (not supplementary) channel for pregnant women, with 100% coverage target at first ANC visit.
3. Gender-targeted BCC: Develop and deploy BCC materials explicitly communicating that pregnant women and mothers must prioritise their own consistent net use — not only their children's.
4. Conflict-adapted sleeping guidance: Create context-specific materials for Fashoda County addressing security-related barriers to fixed sleeping locations under nets.
5. Mobile outreach for cattle camps: Deploy mobile outreach teams following semi-nomadic movement patterns with a minimum of two distribution touchpoints per year for cattle camp households.
6. Differential utilization targets: Advocate with SS-MoH and global partners for vulnerability-weighted utilization targets — applying higher programme intensity to achieve minimum 80% protection across all subgroups, not only the general population.
7. SDG equity reporting: Include LLINs utilization equity metrics in county SDG progress reports, covering SDGs 3, 5, 10, and 17 simultaneously.

DECLARATIONS

Authors' Contributions

LAK: Conceptualization, data collection, vulnerability index construction, primary drafting. DB: Methodology, statistical supervision, critical review. TDSM: South Sudan equity context, co-supervision, final revision. All authors approved the final manuscript.

Ethics

Ethical clearance: AMREF International University Ethics and Research Committee. County authorization: Upper Nile State Ministry of Health. Written informed consent from all participants. Data fully anonymised.

Competing Interests

The authors declare no competing interests.

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Data Availability

Anonymised datasets available from the corresponding author (kuramumajak@gmail.com) upon reasonable request, subject to ethical restrictions.

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