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Sociodemographic and Environmental Determinants of Insecticide Treated Net Utilization among Reproductive Age Women in Liberia: A Multilevel Analysis

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ABSTRACT

In Liberia, malaria remains hyperendemic with a year-round transmission despite a major scale-up of ITN distribution. The 2022 Liberia Malaria Indicator Survey indicated high household ownership but persistently low utilization among women of reproductive age. Understanding why women do not use available ITNs is essential for closing this ownership–use gap and reducing preventable malaria morbidity and mortality among mothers and children. The study used nationally representative data from the 2022 Liberia Malaria Indicator Survey and environmental and urbanization indicators. The dataset for the study contains 3,593 women aged 15–49 years from households with at least one ITN across all 15 counties and Greater Monrovia out of the 4,513 women who participated in the 2022 MIS. A multilevel logistic regression is used to analyze hierarchical clustering effects and estimate the individual- and county-level determinants of ITN use and random intercepts for each county as follows: a null model, an individual-level model, a contextual/environmental model, and a full model combining all predictors. Model performance is measured with intraclass correlation coefficients and marginal/conditional R^2. ITN use was significantly clustered by county (null-model ICC = 0.05), indicating considerable geographic heterogeneity. At the individual level, correct malaria knowledge (OR ≈ 1.98, 95% CI: 1.45–2.69) and pregnancy status (OR = 1.36, 95% CI: 1.03–1.79) were the most robust positive predictors of ITN use, and higher wealth, larger household size, and subordinate intra-household (daughter/other relative) status were associated with lower probability of use. Contextual and environmental predictors suggested that, compared to people living in counties of low elevation (<100 m), residence at mid-range elevations (≈101–400 m) was a strong negative factor for ITN use (ORs ≈ 0.51–0.69), independent of individual characteristics. These core effects were preserved in the full model (marginal R^2 = 0.135; conditional R^2 = 0.151), which reduced but did not eliminate county-level variance (ICC = 0.02), showing that unmeasured structural-related factors that influence ITN uptake, such as the quality of the program's implementation, robustness of the supply chain, mass ITN distribution, and local norms, continue to influence ITN implementation. These findings suggest that the use of ITNs among Liberia's reproductive-age women shows a multilevel relationship between individual knowledge about risk and maternal health status; intra-household power and resources allocated; and the ecological setting (especially elevation) and county-level health system differences. These findings suggest that simply increasing ITN coverage is not enough; targeted behavior change communication, pregnancy-focused interventions, intra-household equity strategies, and program strengthening for mid-elevation and underperforming areas in the counties are required to address the ownership–use gap and promote malaria control in Liberia.

1. Introduction

Malaria represents a critical public health challenge in Sub-Saharan Africa, accounting for approximately 250 million cases and over 600,000 deaths annually, with women of reproductive age (15-49 years) and their children under age five constituting disproportionately vulnerable populations (World Health Organization, 2023). Liberia, classified as a malaria-endemic country with high transmission intensity, faces a substantial malaria disease burden despite efforts to expand prevention and treatment coverage (Ministry of Health Liberia, 2022). National surveillance data indicate

that malaria incidence declined from 281 per 1,000 population in 2016 to 177 per 1,000 in 2021; however, this remaining burden far exceeds the national target of 95 per 1,000 by 2025, signaling the need for intensified and more effective control strategies (Liberia Ministry of Health National Malaria Control Program, 2021-2025).

Insecticide-treated nets (ITNs) represent one of the most effective and cost-efficient malaria prevention tools available (Roll Back Malaria Partnership, 2023). ITNs provide dual protection through mechanical barrier and chemical insecticidal properties, reducing malaria transmission at both individual and community levels through mass population effects (Pooled analysis by WHO, 2023). When household ITN ownership reaches saturation (at least one net per two people) and consistent use is achieved, community-level protection extends to even non-users, creating herd immunity effects that suppress mosquito population and parasite transmission (Keating, Masanja, & Khatib, 2010; Curtis, Maxwell, Lemnge, et al., 2003). Despite the documented efficacy of ITNs, a critical gap exists between ownership and utilization in Liberia and across Sub-Saharan Africa.

The 2022 Liberia Demographic and Health Survey indicated that 55% of Liberians had access to at least one ITN in their household, yet actual utilization rates remain substantially lower (Ghana Health Supply Chain, 2024). This ownership-use gap, where individuals possess ITNs but do not consistently use them, represents a significant missed opportunity for malaria control and underscores the importance of understanding determinants of ITN adoption and sustained use. Women of reproductive age are a particularly critical population for malaria prevention given their vulnerability during pregnancy, when malaria infection dramatically increases risk of severe anemia, placental patriotization, premature delivery, low birthweight, and maternal mortality (Desai et al., 2007; Cot & Ategbo, 1992). Additionally, as primary household decision-makers and caregivers, reproductive age women's health behaviors cascade throughout household units, influencing children's prevention practices and family-level malaria vulnerability.

In this context, the study focuses on women of reproductive age (15–49 years) who participated in the Liberia Malaria Indicator Survey 2022, using both regional and global literature, while treating the terms “mosquito bed net” and “insecticide-treated net (ITN)” interchangeably, to address persistent evidence gaps specific to Liberia. Liberia covers low-lying coastal plains and forested highlands up to roughly 500 meters, with heavy rain and a high temperature year-round for Anopheles propagation and persistence of malaria (Githeko et al., 2000; Snow & Marsh, 2002). Seasonal peak of the vector population and clinical cases is strongly driven during the wet season observed from May to October, whereas the dry season observed from November to April lowers but does not stop transmission (Ministry of Health (MoH) & Liberia Institute of Statistics and Geo-Information Services (LISGIS, 2023; World Health Organization (WHO, 2023). This ecological situation coincides with a health system still in recovery from 14 years of civil war (1989–2003) that ravaged infrastructure, forced health workers to relocate, and widened rural–urban inequalities in care access (World Bank, 2025; National Malaria Control Program (NMCP, 2023).

Despite proven efficacy of ITNs for malaria prevention and substantial investment in procurement and distribution programs in Liberia, utilization remains suboptimal, particularly among reproductive-age women. Understanding the constellation of individual, household, and contextual factors determining ITN use is essential for designing targeted interventions to close the ownership-use gap and accelerate progress toward malaria elimination goals. Current evidence base for Liberia lacks a comprehensive analysis integrating cognitive mechanisms, behavioral practices, and multilevel contextual factors shaping ITN use among reproductive age women.

The primary research question of this study is, “?” Our study suggests that several factors inter-relate and contribute to ITN utilization in the people. Acknowledging the complexity of malaria prevention, this study uses multilevel regression modelling and utilizes nationally representative data from the 2022 Liberia Malaria Indicator Survey to explore individual, household, and environmental correlates of use of insecticide-treated net (ITN) among women of reproductive age. The analysis aims to examine the reasons why ITNs are still underutilized in Liberia, by disentangling the interrelated factors, which are associated with almost universal intentions of ownership and continued large-scale distribution efforts (MIS, 2022; Krezanoski et al., 2019; Snow & Marsh, 2002). The specific

objectives are: (1) to explore the sociodemographic determinants of individual ITN use; (2) to examine regional and county-based differences in ITN utilization; and (3) to develop policy recommendations for malaria control and prevention in Liberia.

This study is justified and significant for several reasons. First, it can contribute to fill a significant gap in knowledge by examining climate and environment contributors along with socioeconomic and behavioral factors to ITN use (something that is yet to be fully explored in the data). Second, it adds theoretically by triangulating concurrent behavioral and contextual frameworks, the Health Belief Model (Rosenstock, 1974), Theory of Planned Behavior (Ajzen, 1991), and the Social Ecological Model (Bronfenbrenner, 1994), to elucidate the role of ITN utilization among women of reproductive age. Third, it provides methodological progress by using MIS data at multilevel levels of regression analysis, separating effects at individual versus context (and controlling for the clustering at county level). From a policy perspective this study responds to an urgent call for enhanced malaria prevention in Liberia - women of reproductive age are often central to household health decision-making and the promotion of ITN use among them is associated with the potential of significant gains in child survival and maternal health. Findings are anticipated to inform interventions for individual counties, strengthen communication on behavior change, contribute to climate-adapted malaria control strategies and contribute to evidence in support of the implementation of Liberia's national malaria strategic plan and malaria elimination at a global level.

This study adopts an interdisciplinary framework that integrates ecological, climatic, and epidemiological perspectives to guide a more effective malaria response for vulnerable populations (Omeye Francis I., 2024). The model links individual, environmental/climatic, and contextual (situational) predictors to malaria knowledge and, ultimately, insecticide-treated net (ITN) utilization, drawing conceptually on the Health Belief Model and Theory of Planned Behavior, which stress the importance of knowledge, attitudes, and perceived control in driving protective behavior (Ajzen, 1991; Janz & Becker, 1984).

It also aligns with the Social Ecological Model by situating individual behavior within broader environmental and policy contexts (Bronfenbrenner, 1994), and incorporates evidence that elevation, temperature, and precipitation shape vector ecology and malaria transmission intensity, particularly in lowland, high-rainfall areas (Snow & Marsh, 2002; Githeko et al., 2000). The framework specifies three clusters of predictors that influence ITN use through malaria knowledge as a mediator. At the individual level, factors such as women's education, wealth status, age, pregnancy status, household size, exposure to malaria (personal/household history), relationship to the household head, and the presence of children under five shape access to, interpretation of, and responses to malaria information, thereby affecting malaria knowledge and downstream ITN behavior. Contextual predictors: region, urban–rural residence, county-level malaria prevalence, and rural–urban-specific prevalence, capture community and health-system conditions that structure risk, service availability, ITN supply, campaign intensity, and social norms around net use, which in turn condition both malaria knowledge and ITN uptake. Environmental and climatic predictors, including elevation, temperature, and precipitation, capture underlying ecological risk, transmission intensity, and seasonality, influencing both objective vulnerability and the salience of malaria messages, and thus reinforcing motivation and knowledge related to ITN use (Snow & Marsh, 2002; Githeko et al., 2000).

Within this pathway, malaria knowledge is the central mediating mechanism: it encompasses awareness of malaria transmission, prevention strategies, and ITN benefits, and is shaped jointly by individual, contextual, and environmental factors. Enhanced knowledge is posited to improve risk perception, self-efficacy, and perceived benefits, leading to higher ITN utilization among women of reproductive age.

2. Methods

This study employs a secondary data analysis of cross-sectional survey data from the Liberia Malaria Indicator Survey (MIS) 2022. The MIS is a nationally representative, population-based survey conducted by Liberia's Ministry of Health in partnership with the Demographic and Health Surveys (DHS) Program and funding from the U.S. President's Malaria Initiative (PMI). The survey collects comprehensive data on malaria prevention practices, treatment-seeking behaviors, knowledge and attitudes, and malaria parasitemia burden across the country's 15 counties. The analysis uses the R programming language with lme4 as the key package for analysis. Three nested multilevel logistic regression models are used to examine the determinants of insecticide-treated net (ITN) use. The Null Model serves as the baseline, Model 1 includes individual-level sociodemographic predictors, Model 2 adds environmental and climatic predictors, and the Full Model incorporates all predictors simultaneously. By comparing

fixed effects, random effects, and model fit statistics, the study evaluates how well each set of predictors performs and assesses the relative importance of individual- versus contextual-level factors.

2.1 Data Source: Liberia MIS 2022

Survey Characteristics: Time Period: October-December 2022. Sample Size: 4,513 women ages 15-49 years from 4,338 households. Geographic Coverage: All 15 counties of Liberia (Bomi, Bong, Gbarpolu, Grand Bassa, Grand Cape Mount, Grand Gedeh, Lofa, Margibi, Maryland, Montserrado, Nimba, Rivercess, Sinoe, and River Gee). Sampling Strategy: Stratified two-stage cluster sampling, with enumeration areas (clusters) selected in the first stage and households selected in the second stage. Data Collection: Female household members and eligible women within households were interviewed using standardized questionnaires; a subset (522 children) underwent blood testing for malaria parasitemia. The survey achieved >85% household response rate and >90% individual interview completion rate. Questionnaires were pilot-tested and administered by trained enumerators in standardized protocols. Questions on ITN ownership and use were derived from standard DHS ITN modules validated across multiple African countries and in multiple languages (English and Liberian languages), supporting internal validity. Primary Study Population: Women ages 15-49 years (reproductive age) interviewed in MIS 2022 who provided complete data on ITN use status and key predictor variables.

Rationale for Using MIS 2022: The most recent comprehensive national dataset, including ITN use measures, demographic variables, and spatial identifiers (county codes), permits multilevel analysis. Secondary analysis of this data addresses current evidence gaps with minimal additional data-collection burden while ensuring ethical compliance with the original survey protocols.

2.2 Variable Measurement

Outcome Variable:

- ITN (Insecticide-Treated Net) use: Binary variable coded as 0 = No and 1 = Yes, based on whether the respondent slept under a mosquito net the night before the 2022 LMIS survey.

Level 1: Individual-Level Predictors

- Education: Recoded into three levels: 0 = No education, 1 = Primary/Secondary, 2 = Higher.
- Wealth status: Recoded into three categories: 1 = Poor (poorest + poor), 2 = Middle, 3 = Rich (richer + richest).
- Age: Categorized into seven groups (15–19, 20–24, …, 45–49).
- Pregnancy status: Binary variable: 1 = No/unsure, 2 = Yes.
- Knowledge of malaria: Binary variable: 0 = No, 1 = Yes.
- Exposure to malaria messages: Binary: 0 = No, 1 = Yes; prior studies link exposure to higher ITN use.
- Household size: Three levels: 0–4, 5–9, 10+.
- Presence of children under 5: Three groups: 0–1, 2–3, 4+.
- Relationship to household head: Recoded into four groups: 1 = Head, 2 = Wife, 3 = Daughter, 4 = Others.

Level 2: Contextual-Level Predictors

- Region: Six regions in Liberia: Greater Monrovia, Northwestern, South Central, North Central, Southeastern A, Southeastern B.
- Residence type: Urban or rural, reflecting structural and service-access differences.
- Elevation (meters): Represents ecological differences affecting vector distribution.
- Temperature and precipitation: Capture climate factors influencing mosquito abundance and seasonality.
- County-level malaria prevalence: Under-five malaria prevalence by county, highlighting how local malaria risk and norms affect ITN use.

ITN use (Yes/No) is modeled as the outcome variable, predicted by various individual (education, wealth, pregnancy, awareness) and contextual (region, environment, malaria prevalence) factors.

3. Results

3.1 Multilevel Regression

Three nested multilevel logistic regression models assess determinants of insecticide-treated net (ITN) usage. A Null Model: baseline Model, Model 1 accounts for individual-level sociodemographic predictors, environmental and climatic predictors in Model 2, and a fully adjusted model with all predictors (Full Model). Comparison of fixed effects, random effects, and model fit statistics helps us gauge the performance of predictors and the relative role of individual- or contextual-level variables.

Table 2: Combine Multilevel Logistic Regression Models of ITN Use

Predictor	Null Model OR (95% CI)	Model 1: Individual OR (95% CI)	Model 2: Contextual OR (95% CI)	Full Model OR (95% CI)
(Intercept)	1.750***	1.00 (0.62-1.65)	2.147 (0.747-6.174)	1.53 (0.47-5.02)
INDIVIDUAL PREDICTORS				
Education: Some education		1.10 (0.92-1.31)		1.11 (0.93-1.33)
Education: Higher education		0.90 (0.65-1.49)		1.02 (0.67-1.54)
Wealth: Middle		0.80** (0.64-0.92)		0.76** (0.63-0.92)
Wealth: Rich		0.50*** (0.39-0.72)		0.53*** (0.39-0.73)
Age: 20-24		1.00 (0.83-1.32)		1.06 (0.84-1.34)
Age: 25-29		1.10 (0.83-1.39)		1.08 (0.83-1.39)
Age: 30-34		1.30 (0.97-1.76)		1.30 (0.97-1.75)
Age: 35-39		1.40* (1.02-1.84)		1.41* (1.05-1.90)
Age: 40-44		1.20 (0.86-1.65)		1.17 (0.84-1.63)
Age: 45-49		1.50* (1.08-2.21)		1.57* (1.09-2.25)
Age: 50+		1.50 (0.74-3.14)		1.57 (0.75-3.27)
Pregnancy: Yes		1.40* (1.04-1.81)		1.36* (1.03-1.79)
Malaria knowledge: Yes		1.90*** (1.41-2.59)		1.98*** (1.45-2.69)
Household size: 5-9		0.80** (0.62-0.91)		0.76** (0.63-0.93)
Household size: 10+		0.50*** (0.40-0.72)		0.55*** (0.41-0.73)
Exposure to malaria messaging: Yes		1.10 (0.92-1.24)		1.08 (0.93-1.26)
Children under 5: 2-3		1.40*** (1.19-1.71)		1.39*** (1.17-1.68)
Children under 5: 4+		1.20 (0.90-1.61)		1.17 (0.87-1.57)
Relationship to head: Wife		1.10 (0.89-1.39)		1.12 (0.89-1.40)
Relationship to head: Daughter		0.50*** (0.41-0.71)		0.54*** (0.41-0.71)
Relationship to head: Others		0.60*** (0.43-0.73)		0.55*** (0.42-0.72)

CONTEXTUAL PREDICTORS				
Residence: Urban		1.30** (1.07-1.56)	1.06 (0.89-1.26)	1.31** (1.08-1.58)
Region: North Central			6.07 (0.53-69.85)	4.51 (0.36-57.07)
Region: North Western			2.76 (0.53-14.40)	1.88 (0.34-10.49)
Region: South Central			1.10 (0.39-3.13)	0.78 (0.26-2.30)
Region: South Eastern (A)			4.17 (0.48-35.89)	2.91 (0.31-27.23)
Region: South Eastern (B)			3.89 (0.46-32.99)	2.62 (0.26-24.18)
Temperature: Low			1.66 (0.81-3.39)	1.76 (0.84-3.71)
Precipitation: Wet			0.85 (0.55-1.31)	0.88 (0.56-1.39)
Elevation: 101-200m			0.69* (0.53-0.92)	0.64** (0.478-0.86)
Elevation: 201-300m			0.55*** (0.41-0.74)	0.510*** (0.38-0.69)
Elevation: 301-400m			0.67* (0.48-0.94)	0.526*** (0.37-0.75)
Elevation: 401-500m			1.26 (0.91-1.74)	1.117 (0.79-1.57)
Elevation: 501-600m			1.17 (0.86-1.59)	0.943 (0.68-1.31)
Children <5 malaria prevalence/county (%)			0.96 (0.88-1.04)	0.961 (0.88-1.05)
Urbanization level per county			1.00 (0.99-1.02)	1.01 (0.99-1.02)
RANDOM EFFECTS				
σ^2	3.29	3.29	3.29	3.29
τ_{00} County	0.17	0.18	0.06	0.06
ICC	0.05	0.05	0.02	0.02
N County	16	16	16	16
Observations	3593	3593	3593	3593
Marginal R^2 / Conditional R^2	0.000 / 0.050	0.092 / 0.140	0.043 / 0.059	0.135 / 0.151
Note: *p<0.05 **p<0.01 ***p<0.001				

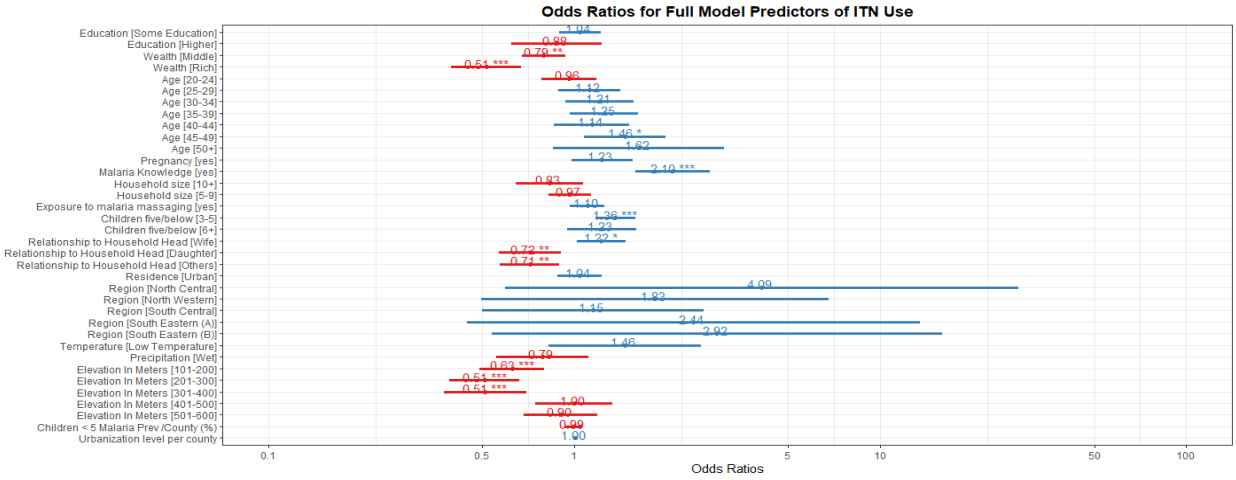
Data Sources: MIS, 2022

The results show that ITN use among Liberian women is shaped by both individual characteristics and county-level context. The null model reveals substantial between-county variation (τ_{00} = 0.17, ICC = 0.05), confirming spatial clustering and justifying a multilevel approach. In Model 1 (individual predictors), malaria knowledge and pregnancy status are the strongest drivers: women with good malaria knowledge are nearly twice as likely to use ITNs (OR = 1.98), and pregnant women have 36% higher odds (OR = 1.36). Older age (35–49) is moderately associated with higher use, while higher wealth, larger households, and being a daughter or "other" relative (vs. head) are linked to lower ITN use. County-level variance remains large, indicating that geography and unmeasured contextual factors matter beyond individual traits. Model 2 (contextual and environmental predictors) highlights elevation as a key ecological factor: women living at 101–400 m have significantly lower odds of using ITNs compared with those at 401–600 m, suggesting mid-altitude areas face particular barriers, possibly due to perceived risk, access, or program reach, while county-level differences persist even after adjusting for environment. The Full Model (individual + contextual + environmental) has the highest explanatory power (marginal R^2 = 0.135, conditional R^2 = 0.151). Core individual effects, such as malaria knowledge, pregnancy, wealth, household size, and relationship to household head, remain stable, and mid-elevation areas continue to show lower ITN uptake. County-level variation declines but does

not disappear (τ_{00} = 0.06, ICC = 0.02), pointing to unmeasured county-level factors such as health system performance, supply chains, and local norms.

Across all models, county-level random effects stay substantial, indicating persistent structural differences in program delivery, community mobilization, and local context. Individual behavioral factors (especially malaria knowledge and pregnancy) consistently predict higher ITN use, while environmental factors like elevation independently reduce uptake. The findings underscore the need for targeted, county-specific strategies that combine awareness and pregnancy-focused messaging, intra-household equity in net access, and customized support for mid-elevation and low-performing counties.

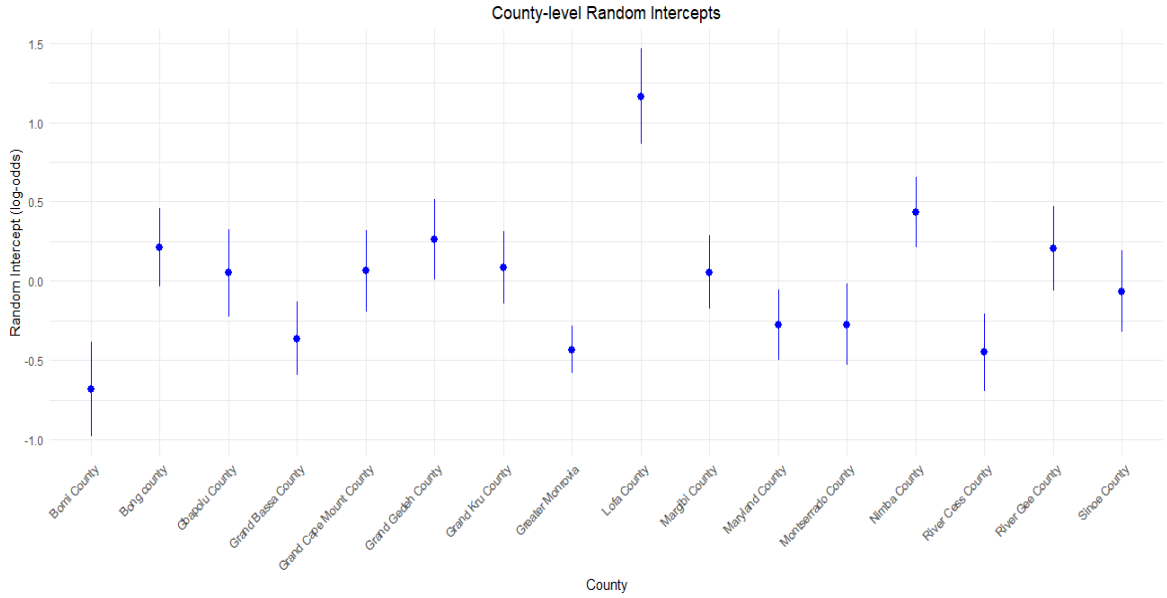
Figure 8: Odds Ratios Full Model



Data Sources: MIS, 2022

Figure 8 shows adjusted odds ratios from the full multilevel model, highlighting which factors remain significantly linked to ITN use among Liberian women after accounting for other variables. At the individual level, correct malaria knowledge is the strongest positive predictor (OR ≈ 2.10), and pregnancy is also positively associated, reflecting targeted protective behavior for pregnant women. Older women (35–39 and 45–49 years) show slightly higher odds of use, while larger households (5–9 or ≥10 members) and women who are daughters or "other" relatives of the household head have lower odds than wives or heads, indicating that intra-household power and competition for nets matter. Socioeconomic and regional context also shape ITN use: women in middle- and especially rich-households have lower odds of using ITNs than poor women, pointing to a wealth–use paradox where higher-income groups use available nets less. Compared with Greater Monrovia, women in North Central, South Central, and South Eastern (A and B) regions show higher odds of use, revealing big regional differences even after adjusting for individual and environmental factors. Environmentally, a clear elevation gradient emerges: women living at 101–400 m have significantly lower odds of ITN use than those at 401–600 m, while temperature, precipitation, and county-level urbanization show weak or null effects in the full model. Overall, ITN use is driven by knowledge and maternal status, intra-household status and crowding, regional program context, and elevation-linked ecological conditions, rather than urban–rural residence alone.

Figure 9: County-Level Random Intercept



Data Sources: MIS, 2022

Figure 9 shows the county-specific random intercepts of the multilevel logistic regression outcome for insecticide-treated net (ITN) use measured using log-odds. Positive intercepts reflect counties in which women had higher baseline odds of ITN use than the national level after adjusting for all measured individual, household, and environmental covariates, while negative intercepts represent counties in which systematically adjusted odds are lower. Lofa, Nimba, and Grand Gedeh have particularly positive random effects, indicating particularly promising contextual or programmatic conditions for ITN use. In contrast, Bomi, River Cess, Montserrado, and Maryland show inverse intercepts, suggesting that underlying structural or normative impediments to use are not captured by the covariates we have observed.

4. Discussion

ITN use among Liberian reproductive-age women is shaped by interdependent individual, household, ecological, and health-system factors in a fragile, post-conflict environment with year-round malaria transmission. The large between-county variance in the null model ($\tau_{00} = 0.17$, ICC = 0.05) indicates spatial clustering of ITN use, confirming that women in the same county share similar behavioral and structural conditions and justifying the use of multilevel modelling to disentangle these stratified influences. At the individual level, malaria knowledge and pregnancy status emerge as the strongest positive predictors. Women with correct malaria knowledge are almost twice as likely to sleep under an ITN (OR ≈ 1.98, 95% CI [1.45, 2.69]), and pregnant women have 36% higher odds of ITN use than non-pregnant women (OR = 1.36, 95% CI [1.03, 1.79]). Older women (35–39 and 45–49 years) are also more likely to use ITNs than younger women, whereas women in wealthier households, larger households, and subordinate household positions (daughters or "other" relatives, rather than heads or wives) show lower odds of use, even in households with at least one net. These patterns indicate that, beyond physical access, intra-household power dynamics, age-graded authority, and competition for limited nets determine who is actually protected.

Contextual and environmental factors add another explanatory layer, revealing a key ecological gradient in ITN use. Women living at mid-range elevations (101–400 m) have significantly lower odds of ITN use than those at lower or higher elevations (ORs ≈ 0.51–0.69), suggesting that these zones may experience more heterogeneous or seasonal transmission, weaker perceived risk, or poorer program penetration, all of which can reduce motivation to use nets. The full model, combining individual, contextual, and environmental predictors, explains a modest but meaningful

share of variability (marginal $R^2 = 0.135$, conditional $R^2 = 0.151$), while preserving the strength of core effects: malaria knowledge and pregnancy status remain strongly positive, whereas higher income, larger household size, non-head relationship status, and mid-range elevation continue to correlate with lower use. County-level variance declines but remains significant ($\tau_{00} = 0.06$, ICC = 0.02), indicating that unmeasured county-specific factors such as ITN supply-chain consistency, frontline health-worker performance, local governance, and social norms around net sharing and prioritization still drive residual differences in uptake.

These findings are consistent with, yet also distinct from, the broader literature. The strong independent positive effect of malaria knowledge aligns with multi-country studies showing that accurate understanding of malaria etiology and ITN benefits correlates with higher net use, although general education alone is often insufficient to change behavior (Apo et al., 2015; Kanyangarara et al., 2018). Similarly, the high ITN use among pregnant women is consistent with evidence that prioritizing this group in household and health programs reduces maternal anemia, low birth weight, and perinatal mortality (Gamble et al., 2006; Steketee & Campbell, 2010; Ter Kuile et al., 2003). In contrast, the negative relationship between wealth and ITN use contradicts many African studies where higher-income groups show greater ITN use, possibly because they have better access to alternative prevention and information (Babalola et al., 2016; Ayanore et al., 2019). In Liberia, lower ITN use among wealthier women despite some ownership may reflect alternative prevention methods, housing features that alter indoor exposure, and discomfort or heat concerns that discourage nightly net use (Atieli et al., 2011; Krezanoski et al., 2019).

The pronounced negative effect of mid-range elevation underscores the ecological dimension of malaria risk, echoing work showing that transmission varies with elevation, temperature, and rainfall (Githeko et al., 2000; Snow & Marsh, 2002). Women in mid-elevation areas appear systematically less likely to deploy nets, likely because transmission is more seasonal and focal than in lowland coastal zones, leading to lower perceived risk and weaker community norms of routine ITN use. The persistence of county-level variance after adjusting for individual and environmental predictors parallels regional evidence from East and Southern Africa indicating that 10–20% of ITN-use variability occurs at the community level (Azanaw & Worede, 2025). This highlights the importance of sub-national program quality, community involvement, and local leadership in translating net availability into actual protection.

The study shows that ITN use is highest among poor, rural women, wives and heads of household, and residents of counties such as Lofa and Nimba and higher-elevation zones (501–600 m), while non-use concentrates among urban and wealthier women, daughters and "other" relatives, residents of Greater Monrovia and some coastal counties, and women in mid-elevation areas. These patterns align with literature on intra-household decision-making, net scarcity in large households, discomfort, and differential risk perception, which shape ITN use in hierarchical settings where some members are prioritized over others (Baume & Marin, 2007; Babalola et al., 2016; Krezanoski et al., 2019).

Overall, the chapter answers the study's central question "What are the antecedents of ITN use among women of reproductive age in Liberia?" by demonstrating that ITN use is governed by a multilevel mechanism in which individual risk assessment and maternal status, household power and resource distribution, ecological setting (especially elevation), and county-level system performance jointly determine whether women sleep under a net. The contribution is threefold: first, it offers a nationally representative multilevel analysis in a country where quantitative evidence on ITN determinants has been limited, clarifying mechanisms behind Liberia's large ownership–use gap. Second, it integrates contextual and environmental data with national survey microdata, drawing attention to an ecologically structured behavior gap at mid-elevations that prior work has largely overlooked. Third, it captures the residual contribution of county-level variance despite full adjustment, reinforcing that ITN use is not merely an individual choice but is deeply embedded in Liberia's geographic and institutional landscape. The findings thus both concur with and extend existing studies, providing comprehensive insight into malaria prevention through ITN use among women and methodologically by applying a rich, nationally representative dataset within a multilevel framework.

4.1 Limitations

This study has several limitations. First, it is a cross-sectional analysis, so it can identify associations but cannot establish causality between predictors and ITN use. Second, ITN adoption is based on self-reported data, which may be influenced by social desirability bias, as respondents may overstate net use to appear compliant with health recommendations. The analysis focuses only on reproductive-aged women aged 15–49 who participated in the 2022 Malaria Indicator Survey. Although the data are nationally representative for this group, the findings do not extend to other age groups or population segments, so ITN adoption patterns among children, older adults, or men cannot be inferred. Finally, while the study includes many important variables, several potentially relevant factors were not

examined, such as detailed housing quality, specific cultural beliefs about malaria, or more granular aspects of net condition and durability, all of which could influence ITN adoption but remain unmeasured in this analysis.

5. Conclusion and Recommendations

The study concludes that ITN use among Liberian reproductive-age women is not just about owning a net, but about how personal knowledge, pregnancy status, socioeconomic position, household power, environmental conditions, and county-level program performance interact. Even where malaria knowledge and pregnancy encourage ITN use, higher wealth, larger households, and being a daughter or "other" relative reduce the likelihood of use, reinforcing inequities in protection. Lower ITN use in mid-elevation areas and persistent between-county differences highlight the role of unmeasured structural and normative factors in a setting where malaria remains the leading cause of illness and death despite widespread net ownership.

For Policy, the Study Recommends:

1. Targeted risk communication that addresses misconceptions and seasonal and geographic variation, especially for adolescents, young women, non-head female relatives, and wealthier urban populations with low ITN use.
2. Strengthening antenatal ITN supply and promoting equitable intra-household net allocation, plus mid-elevation-specific strategies combining outreach, micro-planning, and indoor residual spraying.
3. Improving county-level systems, including supply chains, mass distribution, supervision, and data-driven management, while linking ITN efforts with poverty and housing programs to ensure adequate, comfortable net coverage in hot, humid settings

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For future research, the chapter calls for:

1. Longitudinal and mixed-methods studies on seasonal and life-stage changes in ITN use, local risk perceptions, comfort, intra-household bargaining, and men's roles in net allocation and replacement.
2. County-level implementation research on supply chains, community-health-worker coverage, oversight, and integration with other malaria interventions, plus climate-sensitive modeling of how temperature and rainfall shifts affect transmission and ITN needs across elevation bands.
3. Equity-focused evaluations of new technologies such as dual-active long-lasting insecticidal nets and malaria vaccines to see how they interact with existing ITN-use patterns among high-risk and structurally marginalized women, and how geography, social stratification, and health-system capacity shape real-world malaria-prevention outcomes in Liberia.

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