

Multilevel Determinants of Insecticide-Treated Net Use in A Post-Malaria Elimination Setting: Analysis of the 2016 Timor-Leste Demographic and Health Survey

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ABSTRACT

Background: Although malaria has been eliminated in Timor-Leste, mosquito-borne diseases such as dengue remain a major public health concern. Insecticide-treated nets (ITNs) continue to be an important preventive measure; however, evidence on the determinants of ITN utilization in the post-malaria elimination era remains limited. This study aimed to examine individual and contextual factors associated with ITN utilization among adults in Timor-Leste.

Subjects and Method: This study used secondary data from the 2016 Timor-Leste Demographic and Health Survey (TLDHS). A total of 17,229 respondents aged 15 years and older were included in the analysis. The dependent variable was ITN utilization. Independent variables included sex, age, education, marital status, media exposure, household wealth index, and place of residence. Multilevel logistic regression was applied to assess both individual- and contextual-level determinants, accounting for clustering at the municipality and community (cluster) levels.

Results: Women were more likely to use ITNs than men (AOR=1.36; 95% CI=1.26 to 1.48; $p<0.001$). Married respondents had higher odds of ITN utilization than unmarried respondents (AOR=2.41; 95% CI=2.17 to 2.67; $p<0.001$). Respondents with primary and secondary education were more likely to use ITNs than those with no formal education. Media exposure was positively associated with ITN use (AOR=1.10; 95% CI=1.01 to 1.21; $p=0.028$). Rural residents were more likely to use ITNs than urban residents (AOR=1.38; 95% CI=1.08 to 1.77; $p=0.009$). Compared with the poorest households, respondents from poorer, middle-income, and richer households had significantly higher odds of ITN utilization. Multilevel analysis revealed significant contextual variation, with 4.9% and 26.7% of the variance attributable to municipality- and cluster-level differences, respectively.

Conclusion: ITN utilization in Timor-Leste is influenced by both individual and contextual factors. Marital status, sex, education, media exposure, household wealth, and place of residence were significant determinants of ITN use. Community-level variation highlights the importance of combining individual-focused interventions with community-based strategies to sustain mosquito-borne disease prevention in the post-malaria elimination era.

Keywords: insecticide-treated net, mosquito-borne disease, multilevel analysis, vector control

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BACKGROUND

Mosquito-borne diseases remain a major public health challenge worldwide. The World Health Organization (WHO) estimates that vector-borne diseases account for more than 17% of all infectious diseases and cause over 700,000 deaths annually. Among these diseases, malaria and arboviral infections such as dengue and chikungunya contribute substantially to global morbidity and mortality, particularly in tropical and subtropical regions (WHO, 2024). Dengue alone is estimated to cause approximately 390 million infections annually, with around 96 million cases presenting clinically significant symptoms (WHO, 2019). Although global malaria incidence and mortality have declined considerably over the past two decades, mosquito-borne diseases continue to impose a substantial burden on health systems, especially in low- and middle-income countries (Newby et al., 2016; Fikadu and Ashenafi, 2023).

The burden of mosquito-borne diseases remains particularly high in South-east Asia. The region accounts for the majority of global dengue cases and continues to experience recurrent outbreaks driven by rapid urbanization, climate variability, population growth, and increased human mobility (WHO, 2024). At the same time, malaria remains endemic in several countries, although notable progress toward elimination has been achieved in recent years (Li et al., 2025). These epidemiological transitions highlight the importance of maintaining sustainable vector-control interventions capable of preventing multiple mosquito-borne diseases rather than focusing on a single disease entity.

Timor-Leste represents an important example of this transition. The country recently achieved malaria elimination certification from the World Health Organization after successfully interrupting local malaria transmission through sustained surveillance, vector-control measures, and public health interventions (WHO, 2025). However, the elimination of malaria does not imply the disappearance of mosquito-borne disease threats. Dengue remains endemic throughout the country and continues to cause periodic outbreaks, particularly during the rainy season. National surveillance data reported 1,451 dengue cases and 10 deaths in 2020, followed by 901 cases and 11 deaths in 2021. In 2022, 1,286 dengue cases were reported, with more than 60% occurring among children under 14 years of age (WHO, 2022). Furthermore, Timor-Leste experienced its first documented chikungunya outbreak in 2024, emphasizing the continued vulnerability of the population to mosquito-borne diseases (Machado et al., 2024).

Insecticide-treated nets (ITNs) remain one of the most effective and cost-effective vector-control interventions available. Historically, ITNs were developed primarily to prevent malaria transmission by reducing human contact with nocturnal *Anopheles* mosquitoes. However, WHO recognizes ITNs as an important component of Integrated Vector Management (IVM), a strategy that seeks to reduce human-vector contact and strengthen prevention of mosquito-borne diseases more broadly (WHO, 2012). Consistent use of ITNs has been shown to substantially reduce malaria transmission and remains an important preventive measure for populations living in areas vulnerable to

mosquito-borne diseases (Lindsay et al., 2021).

Despite extensive distribution programs, ownership of ITNs does not necessarily translate into consistent utilization. Previous studies have identified several factors associated with ITN use, including age, sex, education, marital status, household wealth, place of residence, media exposure, household size, and access to sufficient numbers of ITNs (Terefe et al., 2023; Merga et al., 2024; Kuetché et al., 2023). Evidence from Ethiopia, Cameroon, and East Africa indicates that socio-demographic and household characteristics substantially influence whether individuals actually sleep under an ITN, even when the household possesses one (Yirsaw et al., 2021; Terefe et al., 2023; Kuetché et al., 2023). These findings suggest that behavioral and contextual determinants play a critical role in the effectiveness of vector-control interventions.

The Social Ecological Theory provides a useful framework for understanding ITN utilization because health-related behaviors are shaped by interactions between individual characteristics and the broader social and environmental context (Bronfenbrenner, 1977; Golden et al., 2015). In the context of ITN use, factors such as age, sex, education, and marital status may interact with household resources, access to information, place of residence, and geographic conditions to influence utilization patterns (Lover et al., 2011; Bandzuh et al., 2022). This perspective highlights that effective vector-control interventions require consideration of both individual-level and contextual-level determinants and provides a conceptual basis for applying multilevel analysis to investigate ITN utilization.

In Timor-Leste, approximately 64% of households owned at least one ITN accord-

ing to the 2016 Timor-Leste Demographic and Health Survey (TLDHS). Nevertheless, ownership was not evenly translated into utilization. Furthermore, approximately one-third of households lacked sufficient ITNs to provide adequate protection for all household members (TLDHS, 2016). Understanding factors associated with ITN utilization is therefore essential for sustaining vector-control efforts and reducing the risk of mosquito-borne diseases. While previous studies have investigated determinants of ITN use in various settings, evidence from Timor-Leste remains limited, particularly studies using nationally representative data and accounting for contextual geographic variation. Furthermore, little evidence is available regarding municipality-level variation in ITN utilization using nationally representative data.

Therefore, this study aimed to examine individual and contextual determinants of insecticide-treated net use among individuals aged 15 years and above in Timor-Leste using data from the 2016 Timor-Leste Demographic and Health Survey. By applying a multilevel analytical approach, this study sought to assess both individual-level factors and geographic variation in ITN utilization, thereby providing evidence to inform future vector-control policies and health promotion strategies.

SUBJECTS AND METHOD

1. Study Design

This study analyzed data from the 2016 Timor-Leste Demographic and Health Survey (TLDHS). The TLDHS is a nationally representative cross-sectional survey conducted by the General Directorate of Statistics of Timor-Leste in collaboration with the Ministry of Health and ICF International. The survey applied a stratified

two-stage cluster sampling design to collect demographic, socioeconomic, and health-related information from households throughout the country. Data processing was from March to May 2026.

2. Population and Sample

The source population consisted of all individuals included in the 2016 TLDHS household survey. This study included respondents aged 15 years and above who had complete information on insecticide-treated net (ITN) utilization and study variables.

Data from the Person Recode (PR), Individual Recode (IR), Male Recode (MR), and Household Recode (HR) datasets were merged to obtain information on individual characteristics, household conditions, and media exposure. A total of 61,496 individuals were initially identified in the PR dataset. After restricting the sample to respondents aged ≥ 15 years and excluding observations with incomplete information, 17,229 respondents were included in the final analysis.

3. Study Variables

The dependent variable was insecticide-treated net (ITN) utilization, defined as sleeping under an ITN on the night preceding the survey.

Independent variables included sex (male, female), age group (15–24, 25–34, 35–44, and ≥ 45 years), educational attainment (no education, primary, secondary/higher), marital status (never married, married, widowed/divorced), household wealth index (poorest, poorer, middle, richer, and richest), place of residence (urban and rural), and media exposure (yes and no).

The contextual variable was municipality. Thirteen municipalities were included as higher-level contextual units: Aileu, Ainaro, Baucau, Bobonaro, Covalima,

Dili, Ermera, Lautem, Liquiçá, Manatuto, Manufahi, Oecusse, and Viqueque.

4. Operational Definition of Variables

ITN utilization was measured using the TLDHS variable indicating whether a respondent slept under an insecticide-treated net on the night preceding the survey. The outcome variable was categorized as used ITN or did not use ITN.

Sex was categorized as male or female.

Age was categorized into four groups: 15–24, 25–34, 35–44, and ≥ 45 years.

Educational attainment was categorized as no education, primary, and secondary or higher.

Marital status was categorized as never married, married, and widowed/divorced.

Household wealth index was categorized into poorest, poorer, middle, richer, and richest according to the DHS wealth index classification.

Place of residence was categorized as urban or rural.

Media exposure was defined as exposure to at least one source of mass media, including radio, television, or printed media, and was categorized as yes or no.

Geographic region was a derived variable created by grouping the 13 municipalities of Timor-Leste into four geographic regions: Northern Coast, Southern Coast, Inland, and Enclave. This variable was included as a fixed-effect covariate in the analysis.

Municipality was defined as the respondent's administrative area of residence. The 13 municipalities (Aileu, Ainaro, Baucau, Bobonaro, Covalima, Dili, Ermera, Lautem, Liquiçá, Manatuto, Manufahi, Oecusse, and Viqueque) were treated as higher-level contextual units (random effects) in the multilevel logistic regression analysis.

5. Study Instrument

Data were obtained from standardized TLDHS 2016 questionnaires administered

using Computer-Assisted Personal Interviewing (CAPI). The survey collected information on demographic characteristics, household socioeconomic conditions, health-related behaviors, and malaria prevention practices, including ownership and utilization of insecticide-treated nets.

6. Data analysis

Data analysis was conducted using Stata version 17. Sampling weights, clustering, and stratification were incorporated to account for the complex survey design of the TLDHS.

Descriptive statistics were used to summarize respondents' characteristics. Bivariate associations between independent variables and ITN utilization were assessed using the Chi-square test and crude odds ratios (ORs).

To examine contextual influences on ITN utilization, multilevel logistic regression analysis was performed. Individual-level variables and geographic region were entered as fixed-effect covariates, whereas municipality was specified as a higher-level random-effect contextual factor. A caterpillar plot was generated to visualize municipality-level random effects and geographic variation in ITN utilization.

7. Research Ethics

This study used anonymized secondary data obtained from the Demographic and Health Surveys (DHS) Program. Permission

to access and analyze the dataset was granted by the DHS Program with approval authorization was on September 23, 2025. Ethical approval for the original survey was obtained by the relevant ethics committees in Timor-Leste. All respondents provided informed consent before participation, and no personally identifiable information was included in the dataset. Ethical approval from Universitas Sebelas Maret was released on February 05, 2026 with number: 22/UN27.06.11/KEP/EC/2026.

RESULTS

1. Sample Characteristics

A total of 17,229 respondents aged 15 years and above were included in this study (Table 1). Women accounted for 73.45% of respondents. The largest age group was 15–24 years (39.71%). More than half of respondents had secondary education (51.10%). Most respondents were married (59.29%), and approximately two-thirds reported exposure to mass media (66.60%). Regarding socioeconomic characteristics, 68.97% of respondents resided in rural areas. The Northern Coast region accounted for the largest proportion of respondents (57.48%). Overall, 51.04% of respondents reported sleeping under an insecticide-treated net (ITN) on the night preceding the survey.

Table 1. Characteristics of Respondents (n=17,229)

Category	n	%
Sex		
Male	4,622	26.55
Female	12,607	73.45
Age in Group		
15-24	6,922	39.71
25-34	4,757	28.28
35-44	3,424	19.78
45-54	1,901	10.94
55+	225	1.29

Category	n	%
Education		
No education	3,337	20.04
Primary	3,113	18.25
Secondary	9,158	51.10
Higher	1,621	10.61
Marital Status		
Never Married	6,562	37.58
Married	10,137	59.29
Widow/Divorced	530	3.13
Media Access		
No	5,654	33.40
Yes	11,575	66.60
Wealth Index		
Poorest	2,828	16.93
Poorer	3,280	19.27
Middle	3,499	19.89
Richer	4,053	21.46
Richest	3,569	22.44
Residence		
Urban	5,834	31.03
Rural	11,395	68.97
Municipality		
North coast	8,461	57.48
South coast	5,044	22.74
Inland	2,718	13.84
Enclave	1,006	5.94
ITN Use		
No	8,059	48.96
Yes	9,170	51.04

2. Bivariate Analysis

Bivariate analysis demonstrated significant associations between ITN utilization and several respondent characteristics, including sex, educational attainment, marital status, media exposure, household

wealth index, place of residence, and geographic region ($p < 0.05$). These variables were subsequently included in the multivariable analysis to identify independent determinants of ITN utilization.

Table 2. Bivariate analysis of factors related to insecticide-treated net use in a post-malaria elimination setting

Variables	Use of ITN		OR	95% CI		p
	No	Yes		Lower Limit	Upper Limit	
Sex						
Male	2,414(29.41)	2,208(23.80)	Ref.			
Female	5,645(70.59)	6,962(76.20)	1.33	1.21	1.45	<0.001
Age Group						
15-24	3,628 (44.61)	3,294 (35.01)	Ref.			

Variables	Use of ITN		OR	95% CI		p
	No	Yes		Lower Limit	Upper Limit	
25-34	1,979 (25.20)	2,778 (31.24)	1.57	1.41	1.75	<0.001
35-44	1,454 (18.00)	1,970 (21.49)	1.52	1.37	1.68	
45-54	882 (10.75)	1,019 (11.12)	1.31	1.15	1.50	
55+	116 (1.44)	109 (1.14)	1.00	0.72	1.40	
Education						
No education	1,683 (20.45)	1,654 (19.63)	Ref.			<0.001
Primary	1,342 (16.59)	1,771(19.84)	1.24	1.06	1.45	
Secondary	4,129 (50.03)	5,029 (52.13)	1.08	0.93	1.26	
Higher	905 (12.92)	716 (8.40)	0.67	0.55	0.83	
Marital Status						
Never Married	3,734 (46.03)	2,828(29.47)	Ref.			<0.001
Married	4,069 (50.82)	6,068(67.42)	2.07	1.89	2.26	
Widow/	256 (3.16)	274 (3.11)	1.53	1.23	1.92	
Divorced						
Media Access						
No	2,724 (33.03)	2,930(33.76)	Ref.			0.570
Yes	5,335 (66.97)	6,240(66.24)	0.96	0.86	1.08	
Wealth Index						
Poorest	1,499 (18.58)	1,329 (15.35)	Ref.			<0.001
Poorer	1,415 (17.04)	1,865 (21.42)	1.52	1.29	1.79	
Middle	1,404 (16.62)	2,095 (23.03)	1.67	1.39	2.02	
Richer	1,632 (18.77)	2,421 (24.04)	1.54	1.26	1.90	
Richest	2,109 (28.99)	1,460 (16.16)	0.67	0.53	0.84	
Residence						
Urban	3,231 (38.47)	2,603(23.89)	Ref.			<0.001
Rural	4,828 (61.53)	6,567(76.11)	1.99	1.66	2.38	
Municipality						
North Coast	4,188 (61.02)	4,273(54.08)	Ref.			<0.001
South Coast	2,081 (19.14)	2,963(26.19)	1.54	1.24	1.91	
Inland	1,402 (14.90)	1,316(12.83)	0.97	0.76	1.23	
Enclave	388 (4.94)	618(6.89)	1.57	1.19	2.08	

3. Multilevel Logistic Regression Analysis

Multilevel logistic regression analysis confirmed that both individual-level and contextual-level factors influenced ITN utilization (Table 3). In the final model, after accounting for municipality- and cluster-level variation, women remained more likely to use ITNs than men (aOR= 1.36; 95% CI=1.26 to 1.48; $p<0.001$).

Marital status emerged as the strongest individual-level determinant of ITN utilization. Married respondents had significantly higher odds of ITN use than unmarried respondents (aOR=2.41; 95%

CI= 2.17 to 2.67; $p<0.001$), while widowed respondents were also more likely to use ITNs (aOR=1.65; 95% CI=1.32 to 2.06; $p<0.001$).

Educational attainment was positively associated with ITN utilization. Respondents with primary education (aOR= 1.20; 95% CI= 1.07 to 1.36; $p= 0.002$) and secondary education (aOR= 1.36; 95% CI= 1.22 to 1.52; $p<0.001$) were more likely to use ITNs than those with no formal education. However, higher education was not significantly associated with ITN utilization after adjustment for other covariates. Age also remained an important predictor, with

respondents aged 45–54 years (aOR= 0.85; 95% CI=0.73 to 0.99; $p=0.039$) and ≥ 55 years (aOR= 0.69; 95% CI=0.50 to 0.96; $p=0.030$) demonstrating lower odds of ITN utilization compared with those aged 15–24 years.

Media exposure was significantly associated with ITN use. Respondents exposed to radio, television, or newspapers/ magazines were more likely to use ITNs than those without media exposure (aOR= 1.10; 95% CI=1.01 to 1.21; $p=0.028$). Place of residence also remained a significant predictor, with rural residents exhibiting higher odds of ITN utilization than

urban residents (aOR=1.38; 95% CI=1.08 to 1.77; $p=0.009$).

Household wealth showed a non-linear relationship with ITN utilization. Compared with the poorest households, respondents from poorer (aOR=1.44; 95% CI=1.27 to 1.63; $p<0.001$), middle-income (aOR= 1.38; 95% CI=1.21 to 1.58; $p<0.001$), and richer households (aOR=1.58; 95% CI= 1.37 to 1.82; $p<0.001$) had significantly higher odds of ITN use. In contrast, the richest households did not differ significantly from the poorest group (aOR=0.85; 95% CI=0.72 to 1.01; $p=0.070$).

Table 3. Multilevel logistic regression of factors related to insecticide-treated net use in a post-malaria elimination setting

Variables	Model 1 aOR(95%CI)	Model 2 aOR(95%CI)	Model 3 aOR(95%CI)
Sex			
Male	Ref.	Ref.	Ref.
Female	1.34(1.24-1.46)	1.36(1.25-1.48)	1.36(1.26-1.48)
Age Group			
15-24	Ref.	Ref.	Ref.
25-34	1.09(0.98-1.21)	1.09(0.98-1.21)	1.09(0.98-1.21)
35-44	0.89(0.79-1.01)	0.91(0.80-1.03)	0.91(0.80-1.03)
45-54	0.83(0.72-0.96)	0.85(0.73-0.99)	0.85(0.73-0.99)
55+	0.67(0.48-0.93)	0.69(0.50-0.96)	0.69(0.50-0.96)
Education			
No Education	Ref.	Ref.	Ref.
Primary	1.23(1.09-1.38)	1.20(1.07-1.36)	1.20(1.07-1.36)
Secondary	1.34(1.20-1.50)	1.36(1.21-1.52)	1.36(1.22-1.52)
Higher	0.94(0.82-1.22)	1.15(0.98-1.36)	1.16(0.99-1.36)
Marital Status			
Never Married	Ref.	Ref.	Ref.
Married	2.42(2.18-2.68)	2.41(2.18-2.68)	2.41(2.17-2.67)
Widow/ Divorced	1.66(1.33-2.07)	1.65(1.32-2.06)	1.65(1.32-2.06)
Media Access			
No	Ref.	Ref.	Ref.
Yes	1.11(1.01-1.21)	1.10(1.00-1.20)	1.10(1.01-1.21)
Wealth Index			
Poorest		Ref.	Ref.
Poorer		1.43(1.26-1.63)	1.44(1.27-1.63)
Middle		1.37(1.20-1.56)	1.38(1.21-1.58)
Richer		1.54(1.33-1.77)	1.58(1.37-1.82)
Richest		0.82(0.70-0.97)	0.85(0.72-1.01)

Variables	Model 1 aOR(95%CI)	Model 2 aOR(95%CI)	Model 3 aOR(95%CI)
Residence			
Urban			Ref.
Rural			1.38(1.08-1.77)

Note: Model I adjusted for individual-Level variables; Model II adjusted for Household-Level variables; Model III the full model adjusted for the Community-Level variables.

The multilevel model further demonstrated substantial contextual variation in ITN utilization (Table 5). Approximately 4.9% of the total variation in ITN use was attributable to differences between municipalities, while 26.7% was attributable to differences between clusters. The median

odds ratio (MOR) was 1.57 at the municipality level and 2.57 at the cluster level, indicating that community-level factors exerted a greater influence on ITN utilization than broader administrative differences between municipalities.

Table 4. Model Parameter

Parameter	Baseline model	Model 1	Model 2	Model 3
Variance (Municipality)	0.26	0.26	0.24	0.22
Variance (Cluster)	0.98	1.02	0.99	0.98
MOR(Municipality)	1.63	1.62	1.60	1.57
MOR(Cluster)	2.57	2.63	2.59	2.57
ICC (Municipality)	5.8%	5.6%	5.3%	4.9%
ICC (Cluster)	27.4%	28.0%	27.3%	26.7%
AIC	20,980.35	20,377.7	20,233.73	20,229.06
BIC	21,003.61	20,486.26	20,373.31	20,376.39
Log likelihood	-10,487.175	-10,174.849	-10,098.867	-10,095.53
LR test	N/A	<0.001	<0.001	<0.001
N observation	17,229	17,229	17,229	17,229
Cluster	455	455	455	455
N of municipality	13	13	13	13

4. Geographic Variation in ITN Utilization

The caterpillar plot (Figure 1) revealed substantial variation in ITN utilization across municipalities. Covalima, Lautem, and Manatuto exhibited positive municipality-level effects, indicating a higher likelihood of ITN use than expected after accounting for individual characteristics. In contrast, Ainaro, Dili, and Ermera showed negative municipality-level effects, suggesting lower ITN utilization relative to the overall average.

The spatial distribution map showed considerable geographic disparities in both

ITN utilization and dengue burden (Figure 2). Dili recorded the highest proportion of non-use of ITNs (31.28%) and the largest number of dengue cases (212 cases). Elevated dengue burdens were also observed in Baucau (18 cases) and Bobonaro (9 cases). Conversely, several municipalities with relatively high ITN utilization, including Lautem, Aileu, and Covalima, reported few or no dengue cases. These findings suggest that geographic variation in ITN utilization may contribute to differences in dengue burden across municipalities.

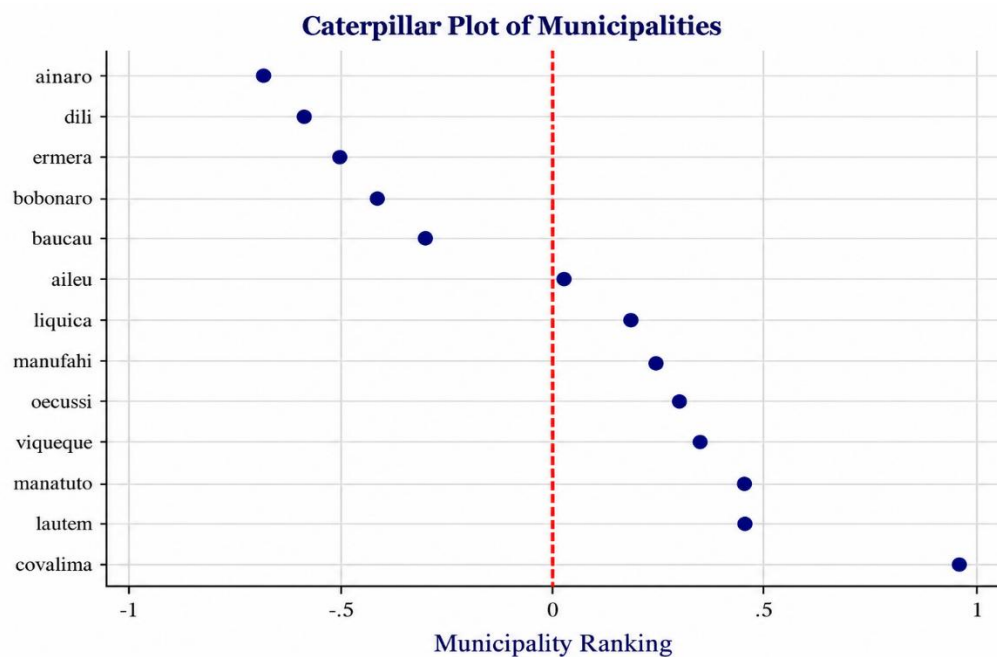


Figure 1. Municipality Caterpillar Plot

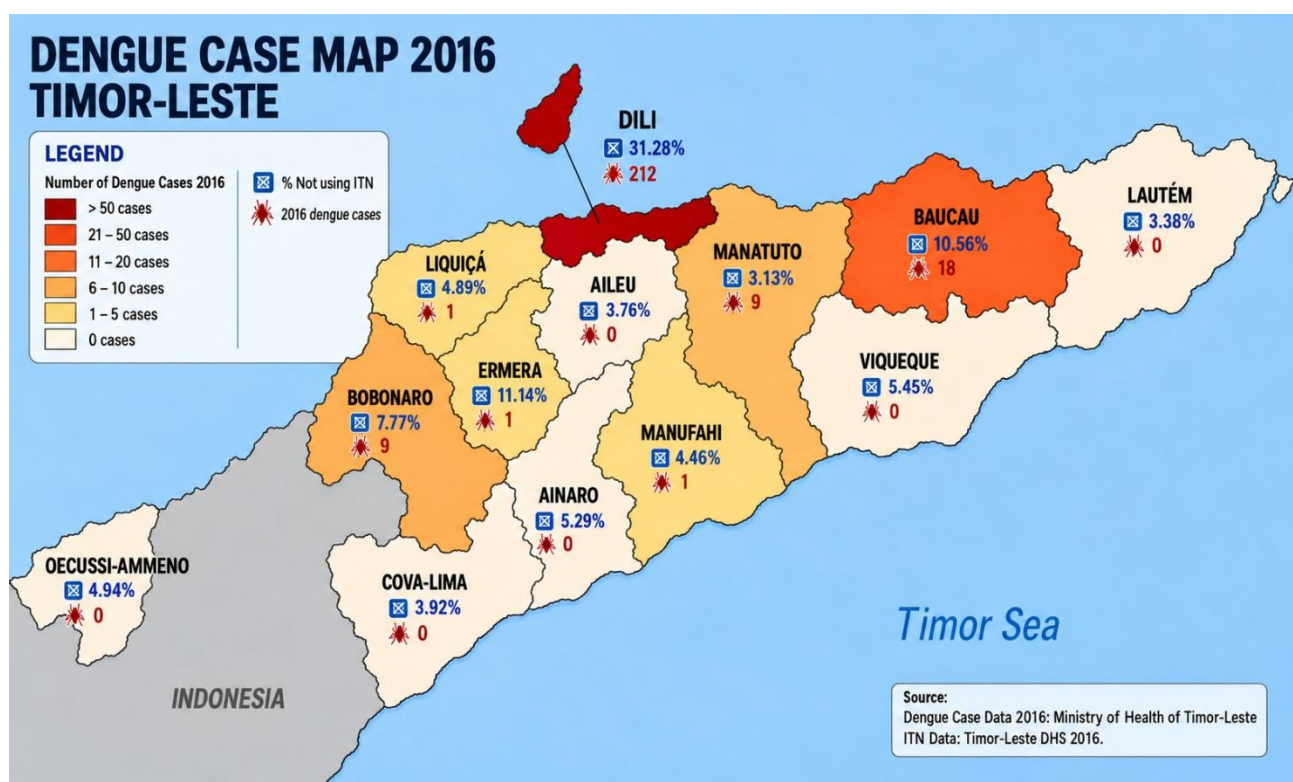


Figure 2. Geographic Distribution of Non-use of ITNs and Dengue Cases in Timor-Leste, 2016

DISCUSSION

This study investigated individual and contextual determinants of insecticide-treated net (ITN) utilization among indi-

viduals aged 15 years and above in Timor-Leste using nationally representative survey data and a multilevel analytical approach.

Approximately half of respondents reported sleeping under an ITN on the night preceding the survey. The findings demonstrate that ITN utilization is influenced by a combination of demographic, socioeconomic, behavioral, and contextual factors. In particular, marital status, place of residence, household wealth, and municipality-level characteristics emerged as important determinants of ITN use. These findings support the Social Ecological Theory, which suggests that health behaviors are shaped through interactions between individual characteristics and broader environmental and social contexts (Bronfenbrenner, 1977; Golden et al., 2015). The observed variation across municipalities further indicates that preventive behaviors are influenced not only by individual decision-making but also by contextual conditions within communities. The present study identified both individual-level and contextual-level determinants of ITN utilization. The most important findings were the strong influence of marital status, the higher utilization observed among rural residents, socioeconomic differences in ITN use, and significant municipality-level variation after adjustment for individual characteristics.

Marital status was the strongest determinant of ITN utilization in the present study. Married respondents were substantially more likely to use ITNs than unmarried respondents, while widowed or divorced individuals also demonstrated significantly higher utilization. Similar findings have been reported in Ethiopia and Cameroon, where married individuals showed greater adherence to malaria prevention measures compared with unmarried populations (Terefe et al., 2023; Kuetché et al., 2023). Marriage may increase perceived responsibility for household health and encourage preventive behaviors through family-based decision-

making. Married individuals are also more likely to sleep with partners or children, creating stronger motivation to protect household members from mosquito bites. This finding suggests that family structure remains an important determinant of preventive health behavior and should be considered when designing health promotion interventions.

The study also identified a substantial urban-rural disparity in ITN utilization. Respondents residing in rural areas were significantly more likely to use ITNs than those living in urban areas. Although urban populations generally have greater access to health services and health information, similar patterns have been observed in Cambodia and several African countries, where rural populations reported higher utilization of mosquito nets despite lower socioeconomic development. One explanation is that rural communities often experience greater exposure to mosquito breeding sites associated with agricultural activities, forests, and poorly controlled environmental conditions. Consequently, perceived risk of mosquito-borne diseases may be higher among rural residents, leading to more consistent use of preventive measures. In contrast, urban residents may rely on alternative methods such as insecticide sprays, electric mosquito repellents, screened housing, or improved living conditions. The Social Ecological Theory provides a useful explanation for this pattern because environmental context influences how individuals perceive disease risk and adopt preventive behaviors (Bronfenbrenner, 1977; Lover et al., 2011).

Educational attainment and media exposure were positively associated with ITN utilization. Respondents with primary and secondary education were more likely to use ITNs than individuals without formal education, while exposure to mass media

increased the likelihood of utilization. These findings are consistent with previous studies indicating that education improves health literacy, enhances understanding of disease prevention, and promotes adoption of protective behaviors (Merga et al., 2024; Terefe et al., 2023). Similarly, access to information through radio, television, and printed media may strengthen awareness regarding mosquito-borne diseases and reinforce public health messages. The positive influence of media exposure highlights the continuing importance of communication strategies in promoting vector-control interventions, particularly in settings where dengue and other mosquito-borne diseases remain endemic.

An interesting socioeconomic pattern emerged from the analysis. Respondents from poorer, middle-income, and richer households were more likely to use ITNs than those in the poorest households, whereas utilization declined among the richest households. Similar observations have been reported in several low- and middle-income countries. Kuetché et al. (2023) reported that ITN utilization generally increased with household wealth, while other studies found that wealthier households often substitute mosquito nets with alternative prevention methods such as improved housing, window screens, air conditioning, and commercial repellents. These findings suggest that economic resources may influence preventive behavior through multiple pathways. While increased household wealth can improve access to health-protective resources, it may also reduce dependence on ITNs as the primary method of mosquito control. Therefore, socioeconomic status should not be interpreted solely as a measure of access but also as a determinant of behavioral preference and risk perception.

One of the most important findings of this study is the persistence of contextual variation after adjustment for individual-level characteristics. The multilevel analysis demonstrated that municipality-level factors continued to influence ITN utilization even after controlling for demographic and socioeconomic variables. This finding is consistent with the Social Ecological Theory, which proposes that health behaviors are affected by environmental, social, and policy-level influences beyond individual characteristics (Golden et al., 2015). Municipality-level variation may reflect differences in local vector-control programs, community norms, access to health promotion activities, environmental conditions, and historical disease burden. Previous studies have shown that contextual factors can substantially influence the uptake of preventive interventions, even among individuals with similar socioeconomic characteristics (Bandzuh et al., 2022).

The caterpillar plot provided further evidence of geographic heterogeneity in ITN utilization. Municipalities such as Covalima, Lautem, and Manatuto showed higher-than-expected utilization, whereas Ainaro, Dili, and Ermera exhibited lower-than-expected utilization after adjustment for individual-level factors. These findings suggest that local contextual conditions either facilitate or constrain adoption of preventive behaviors. Such variation may be related to differences in community engagement, local health promotion efforts, accessibility of mosquito-net distribution programs, or perceived disease risk. The existence of substantial municipality-level variation indicates that a uniform national strategy may not be sufficient to address disparities in ITN utilization across Timor-Leste.

The spatial distribution of ITN utilization and dengue burden revealed addi-

tional insights into geographic inequalities. Dili recorded both the highest proportion of individuals not using ITNs (31.28%) and the highest number of dengue cases (212 cases). Elevated dengue burdens were also observed in Baucau and Bobonaro, municipalities located along the Northern Coast region. In contrast, municipalities such as Lautem, Aileu, and Covalima reported relatively lower proportions of non-use and fewer dengue cases. Although the cross-sectional design does not permit causal inference, these patterns suggest that areas characterized by lower ITN utilization may face greater vulnerability to mosquito-borne diseases. The concentration of dengue cases in urbanized municipalities may also reflect higher population density, increased human mobility, and environmental conditions favorable for *Aedes* mosquito breeding. These findings reinforce the importance of geographically targeted vector-control strategies rather than relying exclusively on nationwide interventions.

This study has several strengths. First, it utilized nationally representative TLDHS data, providing findings that are generalizable to the Timor-Leste population. Second, the large sample size increased statistical precision and allowed examination of multiple determinants simultaneously. Third, the use of multilevel logistic regression enabled assessment of both individual-level and contextual-level influences on ITN utilization, which has rarely been explored in Timor-Leste. Finally, the integration of geographic visualization through municipality-level mapping and caterpillar plots provided additional evidence regarding spatial variation in preventive behavior.

Several limitations should also be acknowledged. Because the DHS survey was conducted in 2016, utilization patterns may not fully reflect current ITN practices

following malaria elimination certification in 2025. The cross-sectional design prevents causal interpretation of observed associations. ITN utilization was self-reported and may therefore be subject to recall bias or social desirability bias. In addition, some contextual factors potentially relevant to ITN utilization, including housing quality, local vector-control programs, environmental conditions, and community-level socioeconomic indicators, were not available in the TLDHS dataset. Future studies should incorporate these factors to improve understanding of geographic variation in ITN utilization.

In conclusion, ITN utilization in Timor-Leste is influenced by both individual and contextual determinants. Marital status, educational attainment, media exposure, household wealth, place of residence, and municipality-level characteristics significantly affected utilization patterns. Persistent geographic disparities observed across municipalities indicate that vector-control interventions should be tailored to local contexts rather than relying solely on nationwide approaches. Strengthening health promotion activities, particularly in urban areas and municipalities with lower-than-expected ITN utilization, may improve uptake of preventive measures and contribute to sustained control of mosquito-borne diseases in Timor-Leste.

AUTHOR CONTRIBUTION

JDS conceived and designed the study, acquired and managed the dataset, performed data cleaning and statistical analyses, interpreted the findings, prepared the tables and figures, and drafted the manuscript. VW contributed to the study design, supervised the statistical analyses, critically reviewed the methodology, and revised the manuscript for important intellectual content. NHH contributed to

the conceptualization of the study, interpretation of the findings, and critical revision of the manuscript. AEP contributed to the interpretation of the results, provided critical scientific input, and substantially revised the manuscript. RPF contributed to the interpretation of the findings, critically reviewed the manuscript, and provided important intellectual contributions to improve the quality of the article. All authors read and approved the final manuscript and agreed to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that the study was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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