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East African Journal of Education and Social Sciences
EAJESS March-April 2026, Vol. 7, No. 2, pp. 88-97.
ISSN: 2714-2132 (Online), 2714-2183 (Print). Published by G-Card
DOI: https://doi.org/10.46606/eajess2026v07i02.0494.

Changes in Malaria Burden and Preventive Intervention Coverage in Liberia: An Interrupted Time Series Analysis

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Abstract
Malaria remains a major public health challenge in Liberia despite continued efforts to control the disease. This study examined changes in malaria burden and preventive intervention coverage from January 2021 to December 2025, focusing on the period following January 2023. Monthly county-level surveillance data were obtained from Liberia's Health Management Information System and analyzed using a longitudinal ecological

design. Annual trends were summarized descriptively, followed by interrupted time series regression to assess changes after January 2023. A multivariable linear mixed-effects model examined the independent associations between preventive intervention coverage and malaria burden. Confirmed malaria cases fell from 742,092 in 2021 to 542,070 in 2023, before rising to 759,957 in 2025. Immediately after January 2023, malaria test positivity (β_2 = 3.67, p = 0.038), severe malaria (β_2 = 4.52, p < 0.001) and malaria-related deaths (β_2 = 2.87, p = 0.041) increased significantly. IPTp3 (β_2 = −9.10, p = 0.021) and IPTp3+ (β_2 = −7.72, p = 0.034) also declined immediately while LLIN coverage showed a significant decline in the post-interruption trend (β_3 = −4.12, p = 0.041). In the adjusted model, higher IPTp3 (β = −0.063, p = 0.001) and LLIN coverage (β = −0.052, p = 0.002) were associated with lower malaria burden. The study concludes that routine surveillance can help track malaria trends and program performance. Sustaining preventive interventions and using surveillance evidence in program planning may strengthen malaria control in Liberia.

Keywords: Malaria burden; malaria prevention; interrupted time series; mixed-effects modelling; routine surveillance; Liberia.

How to cite: Gbawoquiya, G. M., Kpoeh, E., Mabande, L., Washington, T., Korvayan, J. A. , Kollie, M., Kpehe, A. and Swaray, C. (2025). Changes in Malaria Burden and Preventive Intervention Coverage in Liberia: An Interrupted Time Series Analysis**.** East African Journal of Education and Social Sciences 7(2), 88-97.
DOI: https://doi.org/10.46606/eajess2026v07i02.0494.

Introduction

Malaria remains one of the leading causes of morbidity and mortality, with the greatest burden occurring in sub-Saharan Africa. According to the World Health Organization, an estimated 263 million malaria cases and 597,000 malaria-related deaths were reported globally in 2023, of which approximately 94% of cases and 95% of deaths occurred in the WHO African Region. Although substantial progress has been made over the past two decades through expanded access to effective malaria prevention, diagnosis and treatment, progress has recently slowed because of persistent health-system challenges, inadequate financing, climate variability, insecticide and drug resistance and disruptions to essential health services (WHO, 2024).

Liberia remains a high-transmission country where malaria continues to be a leading cause of outpatient visits, hospital admissions and mortality, particularly among children under five years of age and pregnant women. In response, the National Malaria Control Program has prioritized the scale-up of proven interventions, including long-lasting insecticidal nets (LLINs), intermittent preventive treatment during pregnancy (IPTp), prompt parasitological diagnosis using malaria rapid diagnostic tests and microscopy, effective treatment with artemisinin-based combination therapy and strengthened surveillance systems (Ministry of Health Liberia, 2022; WHO, 2023a). These interventions have received substantial support from the Global Fund and the United States President's Malaria Initiative, contributing to improved malaria prevention and case management. Despite these efforts, sustaining high intervention coverage and ensuring their effective utilization remain ongoing challenges, particularly in resource-constrained settings (Global Fund to Fight AIDS, Tuberculosis and Malaria, 2023; WHO, 2024).

Routine malaria surveillance systems are essential for monitoring disease trends, evaluating program performance and informing evidence-based public health decision-making. In Liberia, the national Health Management Information System (HMIS) compiles monthly malaria surveillance reports submitted by health facilities across all fifteen counties. These routinely collected data provide an opportunity to assess temporal changes in malaria burden and preventive intervention coverage at the national level while supporting ongoing monitoring and evaluation of malaria control efforts (WHO, 2023b; Ministry of Health Liberia, 2023).

Interrupted time series (ITS) analysis has been widely used to evaluate changes in disease trends and assess the population-level effects of public health interventions using routinely collected surveillance data (Wagner et al., 2002; Bernal et al., 2017). During and after the COVID-19 pandemic, ITS methods have been increasingly applied to investigate disruptions in malaria prevention and treatment services across several malaria-endemic countries, demonstrating that program implementation, health-system performance and contextual factors can influence malaria transmission dynamics (Hogan et al., 2020; Sherrard-Smith et al., 2020). However, despite the availability of routine national malaria surveillance data in Liberia, there is limited published evidence using interrupted time series and multivariable mixed-effects modelling to evaluate long-term national trends in malaria burden alongside changes in preventive intervention coverage. Most available reports focus primarily on annual program performance and descriptive summaries without formally assessing temporal level changes, trend changes or county-level variation using longitudinal analytical approaches.

This study addressed this gap by examining changes in malaria burden and coverage of key malaria preventive interventions in Liberia, using national routine surveillance data collected between January 2021 and December 2025.

Methodology

This section describes the study design, study setting, data source, study variables, data management procedures, statistical analyses and ethical considerations employed.

Design

This study employed the longitudinal ecological study design, using routinely collected secondary malaria surveillance data obtained from the Liberia National Health Management Information System (HMIS). Monthly county-level observations collected between January 2021 and December 2025 were analyzed to examine temporal changes in malaria burden and preventive intervention coverage. Interrupted Time Series (ITS) regression was applied to evaluate changes in malaria indicators before and after January 2023, which served as the interruption point for the analysis. To further examine factors associated with malaria burden, multivariable linear mixed-effects regression models were fitted to assess the independent effects of the post-January 2023 period and malaria preventive intervention coverage while accounting for county-level variation through random effects.

Study Setting

The study was conducted in Liberia, a malaria-endemic country in West Africa that is administratively divided into fifteen counties, where malaria remains one of the leading causes of outpatient visits, hospital admissions and mortality, particularly among children under five years of age and pregnant women (Ministry of Health Liberia, 2022; WHO, 2024).

Data Source and Study Population

The study utilized routinely collected secondary malaria surveillance data obtained from the Liberia National Health Management Information System (HMIS), which is managed by the Ministry of Health. The dataset comprised monthly county-level surveillance records from all 15 counties spanning the period from January 2021 to December 2025. HMIS compiles routinely reported malaria surveillance data submitted by public and private health facilities across Liberia as part of the national disease surveillance system (Ministry of Health Liberia, 2023).

Variables extracted for this study included confirmed malaria cases, malaria test positivity rate, severe malaria cases, malaria-related deaths, intermittent preventive treatment during pregnancy (IPTp3 and IPTp3+) coverage and long-lasting insecticidal net (LLIN) coverage. As the analysis included all available monthly county-level surveillance records during the study period, no sampling procedure was required.

Data Management

Before statistical analysis, dataset was examined for completeness, internal consistency, duplicate observations and missing values. Variables were screened for implausible values and checked for consistency across monthly reporting periods to ensure data quality. Records with missing values for variables included in a specific analysis were excluded from that analysis. As the proportion of missing data was minimal, no imputation procedures were undertaken. Following data cleaning, the final dataset was imported into R version 4.5.1 for statistical analysis.

Statistical Analysis

Descriptive statistics summarized annual patterns in malaria burden and preventive intervention coverage from 2021 to 2025. Interrupted time series (ITS) regression was then used to examine changes occurring after January 2023**,** which was defined as the interruption point. The ITS model was specified as

$$Y_t = \beta_0 + \beta_1 Time_t + \beta_2 Post_t + \beta_3 PostTime_t + \varepsilon_t$$

, where Y_t is the malaria outcome in month t; $Time_t$ represents the number of months from the start of the study period; $Post_t$ is coded 0 before January 2023 and 1 from January 2023 onward, and $PostTime_t$ represents the number of months elapsed after the interruption. The coefficient β_0 represents the baseline level, β_1 the pre-January 2023 trend, β2 the immediate change in level following January 2023 and β3 the change in trend after the interruption. The term ε_t represents the random error.

The null hypotheses were $H0{:}\beta_2$ =0, indicating no immediate change after January 2023, and $H0{:}\,\beta_3$ =0, indicating no change in the post-interruption trend. Statistical significance was assessed using two-sided tests at the 5% level (p < 0.05). Autocorrelation was assessed using the Durbin–Watson statistic.

A linear mixed-effects regression model with county-specific random intercepts was fitted to examine the independent relationship between malaria burden and preventive intervention coverage. The random intercept accounted for repeated monthly observations within counties and differences between counties. The model was specified as:

$$Y_{it} = \beta_0 + \beta_1 Time_t + \beta_2 Post_t + \beta_3 IPTp3_{it} + \beta_4 LLIN_{it} + \mu_i + \varepsilon_{it}$$

, where Y_{it} represents malaria burden in county i during month t; $Time_t$ is calendar month; $Post_t$ indicates the period beginning in January 2023; IPTp3it represents IPTp3 coverage in county i during month t and $LLIN_{it}$ represents $LLIN$ coverage. The term μ_i denotes the county-specific random intercept while ϵit represents the residual error.

Because this was a linear mixed-effects model, the coefficients were interpreted on the outcome scale rather than exponentiated. Each coefficient represents the expected change in malaria burden for a one-unit increase in the corresponding predictor, with the other variables held constant. Model adequacy was evaluated using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), log-likelihood values and residual diagnostic plots. Autocorrelation in the interrupted time series models was assessed using the Durbin–Watson statistic to evaluate the independence of residuals. All statistical analyses were performed using R version 4.5.1.

Descriptive statistics summarized annual trends in malaria burden and preventive intervention coverage. Interrupted Time Series (ITS) regression was subsequently applied to evaluate changes in malaria burden and preventive intervention coverage before and after January 2023, which served as the interruption point. The ITS models estimated the baseline level at the beginning of the study period (β_0), the pre-interruption trend (β_1), the immediate level change following January 2023 (β_2) and the change in trend during the post-interruption period (β_3). Statistical inference was based on hypothesis testing of the interruption parameters, where the null hypotheses assumed no immediate level change (H_0: $\beta_2 = 0$) and no change in the post-interruption trend (H_0: $\beta_3 = 0$). Statistical significance was evaluated using two-sided tests at the 5% significance level (p < 0.05).

To identify factors independently associated with malaria burden, multivariable linear mixed-effect regression models with county-specific random intercepts were fitted to account for the correlation among repeated monthly observations within counties. The models estimated the independent effects of time, the post-January 2023 period, IPTp3 coverage and LLIN coverage on malaria burden while controlling for unobserved county-level heterogeneity. The statistical significance of regression coefficients was assessed using Wald tests with a two-sided significance level of 5%.

Model adequacy was evaluated using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), log-likelihood values and residual diagnostic plots. Autocorrelation in the interrupted time series models was assessed using the Durbin–Watson statistic to evaluate the independence of residuals.

Ethical Consideration

The study was conducted in collaboration with the National Malaria Control Program and the routine malaria surveillance data used for analysis were provided by the Director of the National Malaria Control Program. The analysis was based on anonymized secondary data extracted from the national Health Management Information System (HMIS), with no personal identifiers included in the dataset. Data was kept confidential and used solely for the purposes of this study.

Results and Discussion

This section presents the study findings. The results are organized around four research questions that examined temporal trends in malaria burden and preventive intervention coverage, changes following January 2023 and association between malaria preventive intervention coverage and malaria burden. The findings are presented sequentially using descriptive statistics, interrupted time series regression and multivariable mixed-effects regression analyses.

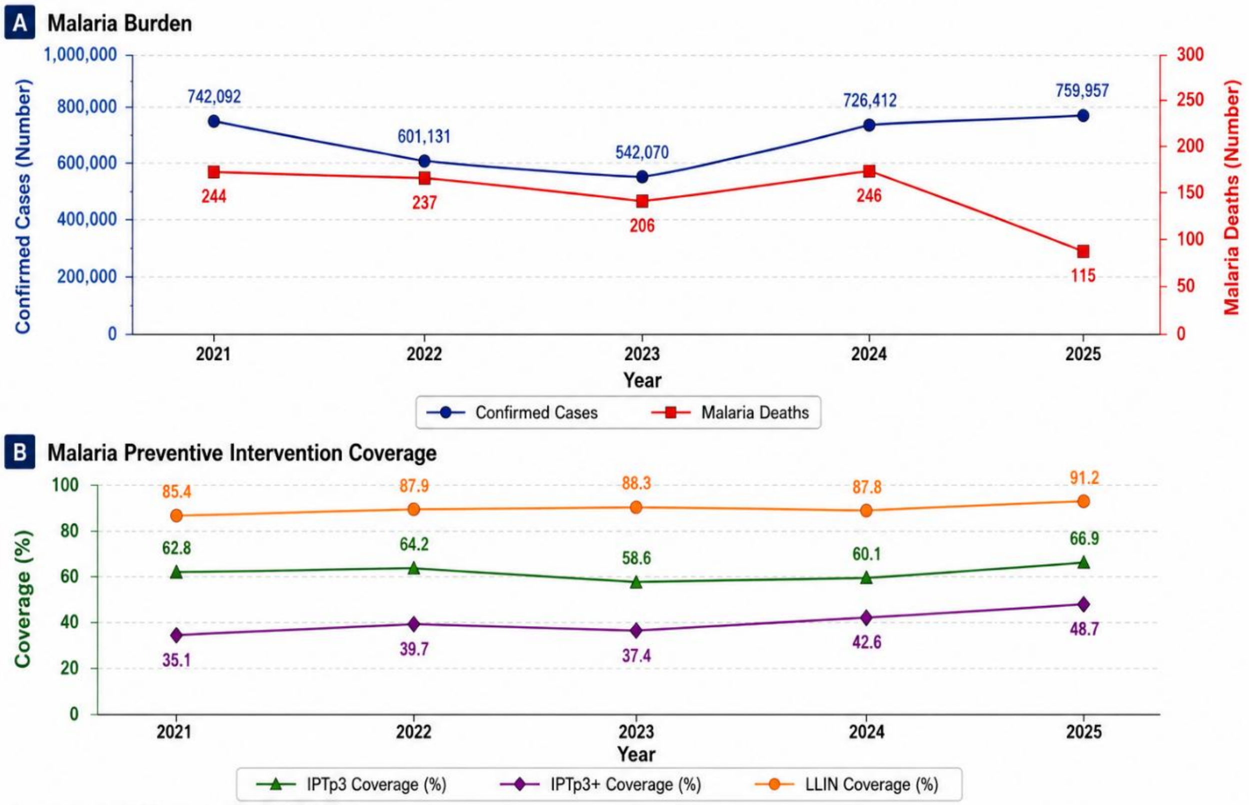
Research Question 1: What are the annual trends in malaria burden and preventive intervention coverage in Liberia between 2021 and 2025?

Descriptive statistical analysis was conducted to examine annual trends in malaria burden and preventive intervention coverage in Liberia between 2021 and 2025. Table 1 summarizes the corresponding annual estimates for confirmed malaria cases, malaria-related deaths, IPTp3 coverage, IPTp3+ coverage and LLIN coverage while Figure 1 presents a graphical overview of these trends.

Table 1: Annual Trends in Malaria Burden and Preventive Intervention Coverage in Liberia (2021–2025)

Year	Confirmed Cases	Malaria Deaths	IPTp3 Coverage (%)	IPTp3+ Coverage (%)	LLIN Coverage (%)
2021	742,092	244	62.8	35.1	85.4
2022	601,131	237	64.2	39.7	87.9
2023	542,070	206	58.6	37.4	88.3
2024	726,412	246	60.1	42.6	87.8
2025	759,957	115	66.9	48.7	91.2

Figure 1. Annual Trends in Malaria Burden and Malaria Preventive Intervention Coverage in Liberia, 2021–2025



Source: Liberia HMIS Malaria Database (2021–2025)
IPTp3 = Intermittent preventive treatment during pregnancy (at least three doses); IPTp3+ = Intermittent preventive treatment during pregnancy (at least three or more doses); LLIN = Long-lasting insecticidal nets.

Figure 1 shows that confirmed malaria cases declined from 742,092 in 2021 to 542,070 in 2023 before increasing to 726,412 in 2024 and 759,957 in 2025. Malaria-related deaths followed a similar pattern, decreasing from 244 deaths in 2021 to 206 in 2023, increasing slightly in 2024, and declining to 115 in 2025.

In contrast, preventive intervention coverage showed a different temporal pattern. Although IPTp3 and IPTp3+ coverage fluctuated during the study period, both indicators improved by 2025. LLIN coverage remained consistently high, increasing from 85.4% in 2021 to 91.2% in 2025 with only minor year-to-year variation.

These findings indicate that malaria burden and preventive intervention coverage did not follow the same temporal pattern. While coverage of key malaria prevention interventions generally improved throughout the study period, malaria burden declined during the first three years before increasing again in 2024 and 2025. This descriptive analysis provides the basis for the interrupted time series analyses presented in the subsequent sections, which assess whether the changes observed after January 2023 were statistically significant.

The decline in confirmed malaria cases and malaria-related deaths between 2021 and 2023, followed by a subsequent increase in malaria cases, is consistent with reports from other malaria-endemic settings, where temporal changes in malaria transmission have been influenced by climatic variability, vector ecology, health-system performance, healthcare-seeking behavior and implementation of malaria control programs (WHO, 2024; Bhatt et al., 2015; Snow et al., 2017).

Although IPTp3, IPTp3+ and LLIN coverage improved over the study period, the increase in malaria burden despite generally high intervention coverage suggests that program coverage alone may not be sufficient to sustain reductions in malaria transmission. The effectiveness of malaria prevention interventions depends not only on achieving high coverage but also on consistent utilization, timely replacement of long-lasting insecticidal nets, quality of service delivery and local environmental and epidemiological conditions (Bhatt et al., 2015; Snow et al., 2017; WHO, 2024). These findings highlight the importance of continuous surveillance to monitor changes in malaria transmission, evaluate program performance and support timely public health action.

Research Question 2: Was the malaria burden change significant following January 2023 in Liberia?

Interrupted time series (ITS) regression assessed changes in malaria burden following January 2023, which served as the interruption point. The analysis examined temporal changes in confirmed malaria cases, malaria test positivity, severe malaria and malaria-related deaths before and after January 2023. Figure 2 illustrates the ITS model for confirmed malaria cases while Table 2 presents the corresponding regression estimates for malaria burden indicators.

Table 2: Interrupted Time Series Results for Malaria Burden Outcomes, January 2021–December 2025

Outcome	β_0	β_1	β_2	β_3	p (β_2)	p (β_3)
Test Positivity (%)	64.23	-6.00	3.67	4.86	0.038	0.001
Severe Malaria (%)	7.73	-0.28	4.52	-1.45	<0.001	0.181
Malaria Deaths (rate)	16.73	-0.47	2.87	-2.57	0.041	0.112

Note: β_0 represents the baseline level at the start of the series; β_1 represents the pre-2023 trend; β_2 represents the immediate level change at the beginning of 2023; and β_3 represents the change in trend after 2023.

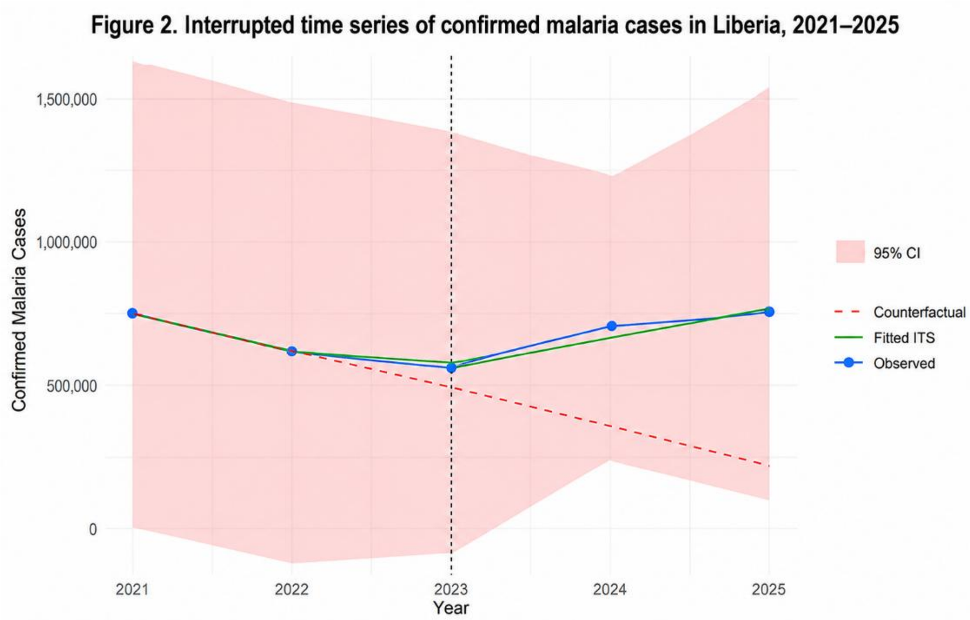


Figure 2 shows that confirmed malaria cases followed a gradual downward trajectory before January 2023, indicating a decline in malaria burden during the pre-interruption period. After January 2023, this declining trend was reversed and confirmed malaria cases increased progressively throughout 2024 and 2025. The divergence between the observed and counterfactual trends indicates a change in the temporal pattern of malaria burden following the interruption point. The close agreement between the observed data and the fitted ITS model demonstrates that the model adequately captured the temporal trend while the shaded 95% confidence interval indicates reasonable precision in the model estimates.

The graphical findings are consistent with the ITS regression results presented in Table 2. Malaria test positivity increased immediately following January 2023 (β_2 = 3.67, p = 0.038) and continued to increase during the post-interruption period (β_3 = 4.86, p = 0.001). Severe malaria also showed a significant immediate increase (β_2 = 4.52, $p < 0.001$), although the subsequent trend was not statistically significant (β_3 = –1.45, p = 0.181). Similarly, malaria-related deaths increased immediately after January 2023 (β_2 = 2.87, p = 0.041), but no significant post-interruption trend was observed (β_3 = –2.57, p = 0.112). These findings indicate that malaria burden changed following January 2023, although the magnitude and persistence of the changes differed across malaria burden indicators.

The interruption in January 2023 marked a shift in the temporal pattern of malaria burden. The continued increase in malaria test positivity suggests increased malaria transmission, improved case detection or both. In contrast, the absence of sustained increases in severe malaria and malaria-related deaths indicates that although malaria occurrence increased, disease severity and mortality did not increase at the same rate. This pattern may reflect improvements in early diagnosis, prompt treatment, case management or the continued implementation of malaria prevention strategies, although these factors were not directly examined in the present study.

These findings are consistent with reports from other malaria-endemic countries, where temporal changes in malaria burden have been associated with program implementation, climatic variability, vector ecology, healthcare utilization and health-system performance (Hogan et al., 2020; Sherrard-Smith et al., 2020; WHO, 2024). Similar fluctuations in malaria transmission have been documented across sub-Saharan Africa following disruptions to routine malaria prevention and treatment services (Hogan et al., 2020; Sherrard-Smith et al., 2020). These patterns highlight the interaction between program implementation, environmental conditions and health-system resilience.

Interrupted time series analysis is widely recognized as a robust quasi-experimental approach for evaluating temporal changes using routinely collected surveillance data (Wagner et al., 2002; Bernal et al., 2017). Accordingly, the observed changes should be interpreted as statistically significant temporal shifts associated with the period after January 2023 rather than as evidence of causality. The findings also demonstrate the value of routine malaria surveillance data for detecting changes in malaria burden, evaluating program performance and informing evidence-based malaria control policies.

Research Question 3: Did malaria preventive intervention coverage change significantly following January 2023 in Liberia?

Interrupted time series (ITS) regression assessed changes in malaria preventive intervention coverage following January 2023, which served as the interruption point. The analysis evaluated temporal changes in intermittent preventive treatment during pregnancy (IPTp3), IPTp3+ and long-lasting insecticidal net (LLIN) coverage before and after January 2023. Table 3 presents the interrupted time series regression estimates, including the baseline level (β_0), pre-interruption trend (β_1), immediate level change (β_2) and post-interruption trend change (β_3) for IPTp3, IPTp3+, and LLIN coverage.

Table 3. Interrupted Time Series Results for Malaria Service Coverage Indicators, Jan 2021–Dec 2025

Indicator	β_0	β_1	β_2	β_3	p (β_2)	p (β_3)
IPTp3 (%)	62.93	-1.38	-9.10	4.95	0.021	0.110
IPTp3+ (%)	38.47	1.79	**-7.72**	3.24	0.034	0.190
LLIN (%)	88.91	0.83	-3.36	-4.12	0.082	0.041

Note: Estimates were obtained from interrupted time series models fitted to monthly observations from January 2021 through December 2025. β_0 represents the baseline level at the start of the series; β_1 the pre-2023 trend; β_2 the immediate level change at the beginning of 2023; and β_3 the change in trend after January 2023.

Table 3 shows that IPTp3 coverage declined significantly immediately after January 2023 (β_2 = −9.10, p = 0.021). The post-interruption trend was positive (β_3 = 4.95) but this increase was not statistically significant (p = 0.110). IPTp3+ coverage showed a similar pattern, with a significant immediate decline ($\beta_2 = -7.72$, p = 0.034) followed by a positive but non-significant trend ($\beta_3 = 3.24$, p = 0.190). LLIN coverage did not show a statistically significant immediate level change ($\beta_2 = -3.36$, p = 0.082) but its post-interruption trend declined significantly ($\beta_3 = -4.12$, p = 0.041).

These patterns are consistent with evidence from malaria-endemic countries showing that malaria prevention coverage can be affected by program implementation, commodity availability, financing and health-system constraints (Hogan et al., 2020; Sherrard-Smith et al., 2020; WHO, 2024). The World Malaria Report also highlights persistent gaps in access to malaria prevention tools, particularly in settings facing health-system and financing constraints (WHO, 2024).

The positive IPTp3 and IPTp3+ coefficients may indicate some improvement in antenatal malaria prevention services after the initial decline, although the available evidence does not support concluding that coverage had significantly recovered. The significant downward trend in LLIN coverage is more concerning because sustained access to insecticide-treated nets is an important component of malaria prevention. WHO (2024) reports continued gaps in ITN coverage in sub-Saharan Africa and identifies inadequate financing, health-system weaknesses and other operational challenges as barriers to maintaining access to malaria prevention tools.

Research Question 4: Which malaria preventive interventions were independently associated with malaria burden in Liberia?

Multivariable linear mixed-effects regression models were fitted to identify malaria preventive interventions independently associated with malaria burden while accounting for repeated monthly observations within counties and unmeasured county-level heterogeneity through county-specific random intercepts. The model simultaneously evaluated the effects of time, the post-January 2023 period, IPTp3 coverage and LLIN coverage on malaria burden. Table 4 presents the adjusted regression coefficients, 95% confidence intervals (CIs) and corresponding p-values from the final mixed-effects model.

Table 4: Multivariable Mixed-Effects Model for Malaria Burden in Liberia

Variable	β	SE	95% CI	p-value
Time	-0.130	0.051	-0.229 to -0.030	0.011
Period beginning in 2023	0.215	0.072	0.074 to 0.356	0.003
IPTp3 Coverage (%)	-0.063	0.019	-0.101 to -0.025	0.001
LLIN Coverage (%)	-0.052	0.017	-0.085 to -0.019	0.002

Table 4 shows that time remained significantly associated with malaria burden (β = –0.130, 95% CI: –0.229 to –0.030, p = 0.011), indicating a significant temporal change in malaria burden during the study period independent of the measured intervention variables. The period beginning in January 2023 also remained significantly associated with malaria burden (β = 0.215, 95% CI: 0.074 to 0.356, p = 0.003), demonstrating that the temporal changes observed after the interruption persisted following adjustment for preventive intervention coverage. Among the malaria prevention interventions, higher IPTp3 coverage was independently associated with lower malaria burden (β = –0.063, 95% CI: –0.101 to –0.025, p = 0.001). Similarly, higher LLIN coverage was associated with reduced malaria burden (β = –0.052, 95% CI: –0.085 to –0.019, p = 0.002). These findings indicate that both IPTp3 and LLIN coverage remained significant independent predictors of malaria burden after adjustment for temporal trends and county-level variation.

The inverse association between IPTp3 coverage and malaria burden is consistent with World Health Organization recommendations identifying intermittent preventive treatment during pregnancy as a key intervention for preventing malaria infection, maternal anaemia, placental malaria, low birth weight and other adverse pregnancy outcomes in malaria-endemic settings (WHO, 2024). Previous studies conducted across sub-Saharan Africa (Kayentao et al., 2013; Accrombessi et al., 2020) have similarly shown that increasing IPTp coverage is associated with reduced malaria-related morbidity and improved maternal and neonatal health outcomes. These findings reinforce the importance of maintaining high antenatal care attendance, ensuring an uninterrupted supply of sulfadoxine-pyrimethamine, and strengthening adherence to national malaria prevention guidelines.

The inverse association between LLIN coverage and malaria burden is consistent with evidence demonstrating the effectiveness of insecticide-treated nets in reducing human-vector contact and interrupting malaria transmission (WHO, 2024). Large-scale studies conducted across Africa have consistently shown that widespread LLIN coverage is associated with substantial reductions in malaria incidences, parasite prevalence and malaria-related mortality, particularly when combined with other malaria control interventions (Bhatt et al., 2015; WHO, 2024). However, sustained program effectiveness depends not only on achieving high coverage but also on consistent household utilization, timely replacement of worn nets and continued community engagement to promote appropriate use (WHO, 2017; WHO, 2024).

A key strength of this study is the use of multivariable mixed-effects regression, which accounted for repeated monthly observations within counties while controlling for unmeasured county-level heterogeneity. Nevertheless, because the analysis was based on routinely collected ecological surveillance data, the observed associations should be interpreted as population-level associations rather than evidence of individual-level causality.

These findings support continued investment in IPTp and LLIN interventions within Liberia's National Malaria Control Program. Sustaining antenatal malaria prevention services, routine and mass LLIN distribution, strengthened surveillance systems and regular program evaluation will be important for maintaining progress toward malaria control and elimination. Incorporating mixed-effects regression and interrupted time series analysis into routine program evaluation can further strengthen evidence-based decision-making and support more targeted malaria control strategies.

Conclusions and Recommendations

This study contributes to the understanding of malaria epidemiology in Liberia by demonstrating the value of routine national surveillance data for assessing temporal changes in malaria burden and preventive intervention coverage. The study highlights the importance of longitudinal surveillance for monitoring malaria trends, evaluating program performance and supporting evidence-informed malaria control policies.

The study further demonstrates that continuous monitoring of malaria burden and preventive intervention coverage is essential for detecting changes in disease patterns and identifying periods requiring intensified public health action. The findings reinforce the importance of sustaining evidence-based malaria prevention interventions while illustrating the usefulness of interrupted time series and multivariable mixed-effects regression for evaluating routine surveillance data and supporting program decision-making.

Routine malaria surveillance systems should therefore be strengthened to improve the timely detection of changes in malaria transmission and program performance. National malaria control program should continue to prioritize the sustained implementation of evidence-based preventive interventions, particularly intermittent preventive treatment during pregnancy and long-lasting insecticidal nets, through effective program monitoring and uninterrupted service delivery. Future research should investigate environmental, climatic, entomological, socioeconomic and health-system factors that influence malaria transmission and program effectiveness to strengthen the evidence base for malaria control policies and interventions in Liberia.

References

Accrombessi, M., Yovo, E., Fievet, N., Hounkonnou, C. P. A., Mama, A., Sossou, D., Vianou, B., Massougbodji, A., Briand, V., Cot, M., & Cottrell, G. (2020). Suboptimal intermittent preventive treatment in pregnancy (IPTp) is associated with an increased risk of submicroscopic Plasmodium falciparum infection in pregnant women: A prospective cohort study in Benin. Clinical Infectious Diseases, 73(11), e3759–e3767. https://doi.org/10.1093/cid/ciaa1355.

Bernal, J. L., Cummins, S., & Gasparrini, A. (2017). Interrupted time series regression for the evaluation of public health interventions: A tutorial. International Journal of Epidemiology, 46(1), 348–355. https://doi.org/10.1093/ije/dyw098.

Bhatt, S., Weiss, D. J., Cameron, E., Bisanzio, D., Mappin, B., Dalrymple, U., Battle, K. E., Moyes, C. L., Henry, A., Eckhoff, P. A., Wenger, E. A., Briët, O., Penny, M. A., Smith, T. A., Bennett, A., Yukich, J., Eisele, T. P., Griffin, J. T., Fergus, C. A. and Gething, P. W. (2015). The effect of malaria control on Plasmodium falciparum in Africa between 2000 and

2015. Nature, 526(7572), 207–211. https://doi.org/10.1038/nature15535.

Global Fund to Fight AIDS, Tuberculosis and Malaria (2023). Results report 2023. https://www.theglobalfund.org/media/13263/corporate_2023resultsreport_report_en.pdf.

Hogan, A. B., Jewell, B. L., Sherrard-Smith, E., Vesga, J. F., Watson, O. J., Whittaker, C., Hamlet, A., Smith, J. A., Winskill, P., Verity, R., Baguelin, M., Lees, J. A., Whittles, L. K., Ainslie, K. E. C., Bhatt, S., Boonyasiri, A., Brazeau, N. F., Cattarino, L., Cooper, L. V., ... Hallett, T. B. (2020). Potential impact of the COVID-19 pandemic on HIV, tuberculosis, and malaria in low-income and middle-income countries: A modelling study. The Lancet Global Health, 8(9), e1132–e1141. https://doi.org/10.1016/S2214-109X(20)30288-6.

Kayentao, K., Garner, P., van Eijk, A. M., Naidoo, I., Roper, C., Mulokozi, A., MacArthur, J. R., Luntamo, M., Ashorn, P., Doumbo, O. K., & ter Kuile, F. O. (2013). Intermittent preventive therapy for malaria during pregnancy using 2 vs 3 or more doses of sulfadoxine-pyrimethamine and risk of low birth weight in Africa: Systematic review and meta-analysis. JAMA, 309(6), 594–604. https://doi.org/10.1001/jama.2012.216231.

Ministry of Health Liberi. (2022). National malaria strategic plan 2021–2025. Ministry of Health, Republic of Liberia.

Ministry of Health Liberia. (2023). Health management information system (HMIS) annual report. Ministry of Health, Republic of Liberia.

Sherrard-Smith, E., Hogan, A. B., Hamlet, A., Watson, O. J., Whittaker, C., Winskill, P., Ali, F., Mohammad, A. B., Uhomoibhi, P., Maikore, I., Ogbulafor, N., Nikau, J., Kont, M. D., Challenger, J. D., Verity, R., Lambert, B., Cairns, M., Rao, B., Baguelin, M., ... Churcher, T. S. (2020). The potential public health consequences of COVID-19 on malaria in Africa. Nature Medicine, 26(9), 1411–1416. https://doi.org/10.1038/s41591-020-1025-y.

Snow, R. W., Sartorius, B., Kyalo, D., Maina, J., Amratia, P., Mundia, C. W., Bejon, P., & Noor, A. M. (2017). The prevalence of Plasmodium falciparum in sub-Saharan Africa since 1900. Nature, 550(7677), 515–518. https://doi.org/10.1038/nature24059

Wagner, A. K., Soumerai, S. B., Zhang, F., & Ross-Degnan, D. (2002). Segmented regression analysis of interrupted time series studies in medication use research. Journal of Clinical Pharmacy and Therapeutics, 27(4), 299–309. https://doi.org/10.1046/j.1365-2710.2002.00430.x.

WHO (2017). Achieving and maintaining universal coverage with long-lasting insecticidal nets for malaria control. Global Malaria Program. https://www.who.int/publications/i/item/WHO-HTM-GMP-2017.20.

WHO (2023a). Liberia malaria country profile. https://www.who.int/publications/m/item/malaria-2023-lbr-country-profile.

WHO (2023b). World malaria report 2023. https://www.who.int/publications/i/item/9789240086173.

WHO (2024). World malaria report 2024. https://www.who.int/publications/i/item/9789240104440.