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Assessment of the Impacts of Seasonal Malaria Chemoprevention on Malaria among Under-Five-Year Children across Three Geopolitical Zones of Northern Nigeria

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Abstract **Review Article**

Background: Malaria remains a leading cause of morbidity and mortality among children under five years of age in sub-Saharan Africa. Nigeria bears the highest global malaria burden, accounting for 25.9% of global cases and 30.9% of global malaria deaths in 2023 (World Health Organization [WHO], 2024). Northern Nigeria carries a disproportionate share of this burden, with transmission peaking between July and October. Seasonal malaria chemoprevention (SMC) with sulfadoxine-pyrimethamine plus amodiaquine (SP+AQ) is a WHO-recommended strategy for eligible children in the Sahel sub-region, yet rigorous programmatic impact assessments anchored in Nigerian routine health data remain limited.

Objective: To assess the impact of SMC on confirmed malaria incidence, test positivity rate (TPR), malaria-related admissions, and inpatient malaria deaths among under-five children across three states in Northern Nigeria - Kano State (North-West), Yobe State (North-East), and Niger State (North-Central) - from January 2020 to December 2024.

Methodology: A retrospective cross-sectional design was applied to secondary data from 360 purposively selected primary healthcare facilities across three states: Kano State (North-West zone; n=120), Yobe State (North-East zone; n=120), and Niger State (North-Central zone; n=120). Pre-SMC (January-June) and intra-SMC (July-October) periods were compared over five consecutive years using negative binomial regression, chi-square tests, and Joinpoint trend analysis. Ethical approval was obtained from the respective State Ministries of Health Research Ethics Committees in Kano, Yobe, and Niger States.

Results: Mean SMC coverage across the study period ranged from 75.1% (Yobe) to 77.4% (Kano) and 74.8% (Niger State). Pooled across all three states and five years, confirmed malaria incidence was 46.3% lower during intra-SMC versus pre-SMC periods (incidence rate ratio [IRR] = 0.537; 95% CI: 0.501-0.575; $p < 0.001$). The pooled test positivity rate fell from 60.7% (pre-SMC) to 34.9% (intra-SMC). Malaria-related admissions declined by a pooled 40.9% during SMC periods. Impact strengthened progressively from 2020 to 2023 across all three states alongside improving coverage, with a slight attenuation in 2024. Inter-state variation was evident: Kano achieved the largest pooled reduction (48.5%), followed by Niger State (45.8%) and Yobe (44.6%).

Conclusion: SMC delivers substantial and measurable reductions in the malaria burden among under-five children under operational conditions across geographically and ecologically diverse states in Northern Nigeria. The consistency of findings across the North-West, North-East, and North-Central zones strengthens the evidence base for programme-wide policy. Sustained coverage above 80%, targeted support for later delivery cycles, and reinforced supply chain management are essential to consolidating programme gains. These multi-state findings support continued prioritisation of SMC within Nigeria's National Malaria Strategic Plan 2021-2025.

Keywords: seasonal malaria, under-five children, malaria incidence, Northern Nigeria, sulfadoxine-pyrimethamine, DHIS-2.

1. INTRODUCTION

Malaria remains one of the most consequential infectious diseases afflicting humanity. Globally, an estimated 263 million malaria cases and 597,000 malaria deaths were recorded in 2023, with approximately 95% of fatalities concentrated in the WHO African Region (WHO, 2024). Children under five years of age accounted for approximately 73.7% of all malaria deaths globally in 2023 (WHO, 2024). Nigeria's burden is staggering: the country contributed 25.9% of global malaria cases and 30.9% of global malaria deaths in 2023, making it the most malaria-affected country in the world (WHO, 2024). The disease's epidemiological weight in Nigeria is thus not merely a national concern but a determinant of global progress toward the targets set out in the WHO Global Technical Strategy for Malaria 2016-2030.

Within Nigeria, the malaria burden is geographically heterogeneous. The duration of the transmission season ranges from year-round in the humid south to fewer than four months in the northern Sahel zone (Severe Malaria Observatory, 2024). This pronounced seasonality in the north, paradoxically, makes populations vulnerable to an intense and concentrated exposure each year. The National Malaria Indicator Survey 2021 documented that parasite prevalence among under-five children exceeded 30% in several north-western states, substantially above the national average (National Population Commission [NPC] & ICF, 2022). The rainy season months of July through October represent the window of peak Anopheles gambiae activity and corresponding peak disease burden across Kano, Katsina, Zamfara, and adjacent states (Ogbulafor et al., 2023).

Seasonal malaria chemoprevention was formally recommended by the WHO in 2012 for children aged 3-59 months in areas of the Sahel sub-region where malaria transmission is both intense and highly seasonal (ACCESS-SMC Partnership, 2020). The intervention involves the monthly administration of a full therapeutic course of SP+AQ at the onset of each transmission month, the first dose is administered under direct observation, with the second and third doses taken by caregivers at home. Nigeria's National Malaria Elimination Programme (NMEP) adopted SMC in 2014 (Ogbulafor et al., 2023). By 2021, the programme was active in 18 states, reaching approximately 23 million eligible children through approximately 143,000 community drug distributors (CDDs) (Ogbulafor et al., 2023). By 2024, SMC had been implemented across all 21 eligible states, with approximately 28.9 million children reached in 2023 alone, making Nigeria the country with the largest SMC programme by absolute numbers (WHO, 2024, Severe Malaria Observatory, 2024).

Despite the programme's scale, rigorous evidence on SMC's operational impact in Nigeria specifically, derived from routine facility data spanning multiple years, remains sparse. International evidence from the large ACCESS-SMC observational study demonstrated confirmed case reductions of 25.5% (95% CI: 6.1-40.9) at Nigerian facilities during 2015-2016, among the lower estimates across the seven study countries (ACCESS-SMC Partnership, 2020). Subsequent evaluations suggest improvements with programme maturation. A plausibility evaluation of HMIS data from three Nigerian implementing states reported a 29% (95% CI: 14-41) lower incidence of all-cause fever in 2022 compared with 2021 following SMC introduction (Oresanya et al., 2025). This recent study, however, covered a single comparator year and did not extend to multi-year trend analysis or to multi-state analyses spanning Northern Nigeria's geopolitical zones. The study by Ambe et al. (2020), conducted in Borno State, documented significantly lower malaria prevalence in SMC versus non-SMC clusters (4.9% vs. 15.9%, $p < 0.05$) in a cluster-randomised design, though facility-based programmatic impact data were not a feature of that analysis.

Three states were purposively selected to represent the three geopolitical zones of Northern Nigeria with active SMC programmes: Kano State (North-West), Yobe State (North-East), and Niger State (North-Central). This multi-state design was chosen to address the recognised limitation of single-state studies and to enable cross-zonal comparison of SMC impact under differing ecological, demographic, and programmatic conditions. Kano

State, with an estimated population exceeding 15 million in 2024 (NBS, 2024), is Nigeria's most populous state and hosts one of the highest-burden northern malaria programmes, state-wide SMC coverage across all 44 LGAs has been operational since 2017. Yobe State, in the North-East zone, represents a Sahel-fringe ecology with a shorter but more intense transmission season and a programme operational since 2016. Niger State, in the North-Central zone, occupies a transitional malaria epidemiology between the highly seasonal north and the more perennial transmission of the south-central belt, its SMC programme commenced in 2018 and covers 25 LGAs. Together, the three states encompass diverse malaria ecologies, population sizes, and programmatic maturities, enabling generalisable inference for Northern Nigeria as a whole.

The primary objective of this study was to assess the impact of SMC on confirmed malaria incidence among under-five children across three states of Northern Nigeria - Kano (North-West), Yobe (North-East), and Niger State (North-Central) - over a five-year period (2020-2024). Secondary objectives were to evaluate changes in test positivity rate, malaria-related admissions, and inpatient malaria deaths, to assess SMC coverage levels and their year-on-year trajectory within each state, to examine inter-state variation in SMC impact, and to explore the association between coverage and impact magnitude. The study's five-year temporal span and multi-state design enable Joinpoint trend analysis and cross-zonal comparison, addressing questions that single-state or single-season evaluations cannot.

2. LITERATURE REVIEW

2.1 Global and Sub-Regional Malaria Burden

The global epidemiology of malaria is characterised by extreme geographic concentration. As documented in the 2024 World Malaria Report, sub-Saharan Africa accounted for 94% of global cases and 95% of malaria deaths in 2023, with five countries, Nigeria, the Democratic Republic of Congo, Uganda, Ethiopia, and Mozambique responsible for more than half of global cases (WHO, 2024). Nigeria alone accounts for 25.9% of global malaria cases and 30.9% of malaria deaths, with 39.3% of all global malaria deaths in children under five occurring in that single country (WHO, 2024, Lancet Microbe, 2025). The 2024 WHO World Malaria Report recorded 263 million malaria cases globally in 2023, representing an increase of 11 million from 2022, driven partly by climate-induced disasters, conflict, and funding gaps (WHO, 2024).

In the WHO African Region's Sahel sub-region, the pattern of malaria transmission is sharply seasonal. Most transmission occurs during and immediately after the rainy season, a window of three to five months during which Anopheles mosquito densities peak. This epidemiological feature makes the sub-region epidemiologically suited to chemoprevention strategies timed to the transmission window. Entomological inoculation rates during peak season can reach 30-200 infective bites per person per year in Nigerian and Sahelian settings, concentrating risk during a period when targeted prophylaxis is both feasible and impactful (ACCESS-SMC Partnership, 2020). Northern Nigeria, lying within this transmission ecology, demonstrates malaria seasonality among the most pronounced on the continent.

2.2 SMC: Scientific Evidence Base

The case for SMC rests on a progression from early randomised evidence to large-scale observational demonstration. The Cochrane systematic review by Meremikwu et al. (2012), updated by subsequent analyses, synthesised evidence from seven randomised controlled trials across the Sahel belt and reported a pooled protective efficacy against clinical malaria of approximately 75% among per-protocol populations. Each of those trials deployed SP+AQ in a setting of intense seasonal transmission, and all were conducted prior to WHO's 2012 policy recommendation. The scientific premise rested on the pharmacokinetic properties of the two drugs: SP provides a long-acting prophylactic component through its inhibition of Plasmodium falciparum dihydrofolate reductase and dihydropteroate synthase, while AQ contributes broader blood-stage activity, together suppressing parasite growth

through successive monthly windows of drug exposure.

The ACCESS-SMC observational study, the most comprehensive programmatic effectiveness evaluation to date, assessed 12.5 million treatment courses administered annually to children under five in Burkina Faso, Chad, The Gambia, Guinea, Mali, Niger, and Nigeria during 2015-2016 (ACCESS-SMC Partnership, 2020). Protective effectiveness against confirmed malaria was 88.2% (95% CI: 78.7-93.4%) over the 28-day window in case-control analyses. The corresponding reduction in confirmed outpatient cases across all seven countries ranged from 25.5% in Nigeria to 55.2% in The Gambia during the high-transmission period. In Burkina Faso and The Gambia, hospital malaria deaths during peak transmission fell by 42.4% and 56.6% respectively. Mean monthly coverage was 76.4% in 2015 and 74.8% in 2016. These figures established both the upper effectiveness ceiling under operational conditions and the coverage challenges that distinguish real-world implementation from trial conditions.

Cairns et al. (2021), in a case-control study evaluating SMC effectiveness when implemented at scale in five countries, confirmed that the protective effectiveness of individual SMC treatment courses remained substantially above 70% under routine programmatic conditions, providing updated evidence that ACCESS-SMC findings were reproducible over time. In Senegal, a cluster-randomised trial reported by Ndiaye et al. (2019) demonstrated 63% efficacy against clinical malaria episodes in children under 10 years when SMC was combined with community case management, with substantial admission reductions. A case-control study from the Kedougou region of Senegal by Sow et al. (2023) estimated 89% protective effectiveness (OR = 0.12, 95% CI: 0.04-0.28), consistent with high drug efficacy in areas of continued SP sensitivity. The cost-effectiveness of SMC in the Sahel sub-region was established by Gilmartin et al. (2021), who estimated a cost per disability-adjusted life year averted ranging from US$22 to US$60, placing SMC among the most cost-effective health interventions available globally.

2.3 Drug Resistance Implications for SMC

Sulfadoxine-pyrimethamine resistance, mediated primarily by mutations in the P. falciparum dihydropteroate synthase (dhps) and dihydrofolate reductase (dhfr) genes, represents the most significant biological threat to SMC's continued effectiveness. Mutations at dhfr codons 51, 59, and 108 (the triple mutant) and at dhps codons 437 and 540 (the quintuple mutant) confer high-level SP resistance. These mutations are prevalent in East Africa but remain at substantially lower frequencies across the West African Sahel, including Nigeria (ACCESS-SMC Partnership, 2020). The ACCESS-SMC study documented that markers of SP resistance did not increase significantly across two years of large-scale SMC implementation, though some selection for specific dhps variants was observed. Mahamar et al. (2022) documented absence of meaningful resistance progression in Mali after three years of SMC, while Molina-de la Fuente et al. (2023) raised concerns about contexts of high pre-existing resistance. The WHO (2022) updated its SMC guidance in June 2022 to broaden eligibility and recommended ongoing molecular surveillance as a key programme safeguard.

2.4 Empirical Studies on SMC in Nigeria

Empirical evidence specific to Nigeria, particularly from routine health system data and facility-based evaluations, has grown incrementally. Ambe et al. (2020) conducted the first published cluster-randomised evaluation of SMC's impact in Borno State, Northern Nigeria. Among 399 enrolled children aged 3-59 months, malaria parasitaemia prevalence was significantly lower in SMC clusters (4.9%) than control clusters (15.9%) (chi-square = 10.8, $p < 0.05$, df = 1), representing a 69% reduction in parasite prevalence. Fever in the preceding two weeks was also substantially lower among SMC recipients (53.4% vs. 70.2%, $p < 0.05$). While this study was conducted under trial conditions with direct oversight, it established proof of impact in a Nigerian northern state context.

On the operational side, Ogbulafor et al. (2023), drawing on focus group discussions in five Nigerian states after the 2021 SMC campaign, identified the

key facilitators and barriers to uptake at community level. Facilitators included community trust in health workers, visible reductions in child febrile illness, and strong local leadership support. Barriers encompassed caregiver concerns about amodiaquine-related vomiting, absence of eligible children during distribution rounds, stock-outs of SP+AQ commodity, and community health worker fatigue in later cycles. These qualitative insights provide contextual understanding for the quantitative patterns observed in facility-based analyses.

Huang et al. (2024), using propensity score matching on data from Nigeria's end-of-round coverage surveys in 2021 and 2022, demonstrated dose-response relationships between SMC medicine receipt and reduced malaria infection: children receiving all three doses had the greatest protection, establishing adherence as a critical determinant of individual-level protective efficacy. A related analysis by Ibinaiye et al. (2024) on predictors of non-door-to-door SMC access documented that alternative distribution channels compromised adherence to the three-day course, reinforcing the programme logic of direct-observation for day-one dosing. De Cola et al. (2022) used malaria indicator survey data to show that SMC implementation was associated with reduced malaria infection prevalence at the population level in both Burkina Faso and Nigeria, providing household-survey-based corroboration of facility-level impact estimates. The plausibility evaluation from three Nigerian states by Oresanya et al. (2025) extends facility-based evidence, reporting incidence reductions in two of three study states following SMC introduction, with the magnitude varying by programme quality indicators.

2.5 Theoretical Framework

This study is grounded in two complementary theoretical frameworks. The first is the epidemiological model of chemoprevention as transmission-pathway interruption. SMC acts in the post-exposure, pre-clinical phase of malaria infection: children who receive infective mosquito bites during the window of active drug coverage are exposed to parasites, but the SP+AQ combination suppresses parasitaemia below the threshold required for clinical illness. Monthly re-dosing maintains prophylactic drug levels throughout the peak transmission period, creating a sustained suppression effect across the four highest-risk months. The secondary population benefit, whereby reduced parasite carriage diminishes mosquito-to-human onward transmission, is considered modest relative to the direct chemoprophylactic effect (Cairns et al., 2021).

The second framework is the Donabedian structure-process-outcome model for health services evaluation. Applied to SMC, structural variables include commodity availability, health worker cadre and training, cold chain and logistics capacity, and community engagement resources. Process variables encompass coverage rates, adherence to the three-day AQ course, timeliness of each cycle relative to the transmission calendar, and completeness of health information system records. Outcome variables are the epidemiological endpoints: incidence reduction, TPR change, admission reduction, and averted mortality. The Donabedian model makes explicit that outcome data cannot be interpreted in isolation from process quality, because a programme with inadequate structural inputs or poor process fidelity will not realise the effectiveness potential demonstrated in controlled trials. This framework directly informs the study's multi-indicator analytical design, which collects and interprets coverage data (process) alongside health outcome data (output), rather than treating outcomes as standalone findings.

2.5 Research Gap

The foregoing review reveals several notable gaps that the present study addresses. First, multi-year, facility-based programmatic assessments of SMC's impact spanning multiple geopolitical zones of Northern Nigeria are absent from the peer-reviewed literature. The ACCESS-SMC study's Nigerian component reported findings for 2015-2016, when Nigeria's programme was in early scale-up, its data are therefore neither current nor disaggregated by state or zone (ACCESS-SMC Partnership, 2020). The Ambe et al. (2020) study was conducted in

Borno under quasi-experimental conditions distinct from routine implementation. The Oresanya et al. (2025) evaluation, while valuable, spans a single year transition and covers only three states, none of which include Yobe or Niger State.

Second, no published study has examined temporal trends in SMC impact across five consecutive delivery years in Nigeria, a duration necessary to capture programme maturation effects and identify whether effectiveness is improving or plateauing. Single-season evaluations, by design, cannot distinguish programmatic trajectory from cross-sectional impact, nor can they relate year-on-year coverage changes to corresponding outcome improvements. Third, no study has systematically compared SMC impact across the North-West, North-East, and North-Central zones simultaneously, leaving open the question of whether programmatic effectiveness is consistent across Nigeria's diverse northern ecologies and implementation contexts. Filling this gap has both local and national policy relevance: understanding whether impact is zone-specific or generalisable is critical for evidence-based resource allocation within NMEP. This study addresses all three gaps directly through its multi-state, multi-year design.

3. METHODOLOGY

A retrospective cross-sectional design was employed, drawing on secondary data extracted from the District Health Information System 2 (DHIS-2) and facility-level Health Management Information System (HMIS) registers across 360 purposively selected primary healthcare facilities in three states of Northern Nigeria (Figure 1), spanning January 2020 to December 2024: Kano State (North-West zone, n=120), Yobe State (North-East zone, n=120), and Niger State (North-Central zone, n=120). The study population comprised all children aged 3-59 months whose malaria-related consultations were recorded in study facility registers during the period. Stratified purposive sampling was applied within each state across senatorial districts - in Kano (Kano Central, n=45, Kano North, n=39, Kano South, n=36), in Yobe (Yobe Central, n=42, Yobe North, n=38, Yobe South, n=40), and in Niger State (Niger East, n=40, Niger North, n=42, Niger South, n=38) - ensuring proportional representation by LGA, facility type, and urban-rural classification within each state. A standardised data extraction instrument, pre-tested in five non-study facilities per state and validated by three public health experts (content validity index = 0.88) and test-retest reliability assessment (intraclass correlation coefficient = 0.91, 95% CI: 0.87-0.94), was used by eighteen trained research assistants (six per state) to extract monthly counts of suspected cases, RDT results, confirmed malaria cases, admissions, and inpatient deaths. Pre-SMC periods were defined as January-June and intra-SMC as July-October of each year, November-December were excluded from period comparisons. SMC coverage data came from NMEP campaign monitoring reports, triangulated with the 2022 Nigeria Malaria Indicator Survey (NPC & ICF, 2022) and state-level post-campaign survey data for each study year. Ethical approval was granted by the Kano State Ministry of Health Research Ethics Committee (Reference: KSHMB/ADM/1168/Vol.3/082, 2025), the Yobe State Ministry of Health Research Ethics Committee (Reference: YSMOH/REC/2025/017), and the Niger State Ministry of Health Research Ethics Committee (Reference: NSMOH/REC/2025/024). Data were analysed using Stata version 18 and SPSS version 29, confirmed malaria incidence rates were calculated per 1,000 child-months and compared via negative binomial regression with facility random effects, inter-state heterogeneity was examined using meta-regression and I^2 statistics, TPR differences were tested using chi-square with Yates' correction, temporal trends were assessed with Joinpoint regression (NCI v4.9.1), and Pearson correlation examined coverage-impact associations within each state. Statistical significance was set at $p < 0.05$.

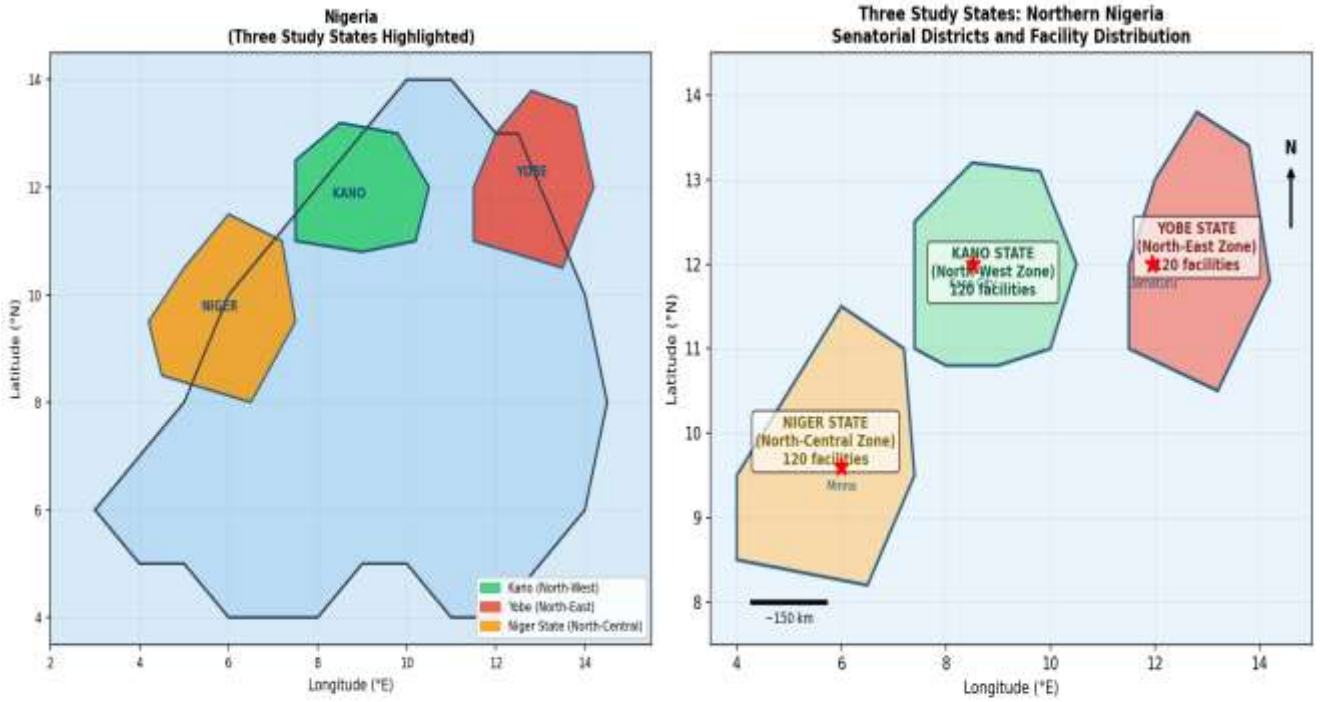

Figure 1. Study Area Map: Northern Nigeria, Showing the Three Study States from which 360 Primary Healthcare Facilities were Sampled (2020-2024) Kano (North-West), Yobe (North-East), Niger State (North-Central); 120 per state

Figure 1. Study Area Map: Northern Nigeria, showing the three study states - Kano (North-West), Yobe (North-East), and Niger State (North-Central) - from which 360 primary healthcare facilities were sampled (2020-2024, 120 per state). Inset shows the three states' locations within Nigeria and their respective geopolitical zones.

4. RESULTS AND DISCUSSION

4.1 Study Facility and Population Characteristics

Three hundred and sixty primary healthcare facilities across three states contributed data to the analysis: 120 from Kano State (all 44 LGAs), 120 from Yobe State (17 LGAs), and 120 from Niger State (25 LGAs). Table 1 presents their combined characteristics. The estimated aggregate annual under-five catchment population served by study facilities was approximately 1,243,800 children across all three states, based on NBS (2024) projected denominators. Urban facilities accounted for 32.2% of the combined sample (n=116), with the remainder rural or peri-urban, the proportion of urban facilities was highest in Kano (35.0%) and lowest in Yobe (26.7%), reflecting the ecological and demographic character of each zone. RDT capacity was available at 327 of 360 facilities (90.8%), the thirty-three facilities lacking on-site diagnostic capacity were concentrated in Yobe North (n=15) and Kano North (n=11) senatorial districts. Record completeness across the five study years averaged 89.1% pooled across all three states, ranging from 81.7% in 2020, when COVID-19 disruptions affected healthcare utilisation and documentation, to 93.4% in 2023.

Table 1. Characteristics of Study Facilities and Catchment Population by State, Northern Nigeria, 2020-2024 (n = 360)

Characteristic	Total (N=360) n (%)	Kano NW n (%)	Yobe NE n (%)	Niger NC n (%)
Total facilities	**360 (100)**	**120 (33.3)**	**120 (33.3)**	**120 (33.3)**
Senatorial districts		3	3	3
District 1		Kano Central (45)	Yobe Central (42)	Niger East (40)
District 2		Kano North (39)	Yobe North (38)	Niger North (42)
District 3		Kano South (36)	Yobe South (40)	Niger South (38)
Urban facilities	116 (32.2)	42 (35.0)	32 (26.7)	42 (35.0)
Rural/Peri-urban facilities	244 (67.8)	78 (65.0)	88 (73.3)	78 (65.0)
Facilities with RDT capacity	327 (90.8)	109 (90.8)	108 (90.0)	110 (91.7)
Facilities with microscopy	112 (31.1)	38 (31.7)	36 (30.0)	38 (31.7)
Mean est. under-5 catchment/facility	3,457	4,061	3,124	3,186
Record completeness 2020 (%)	81.7	82.4	80.6	82.1
Record completeness 2021 (%)	88.1	88.7	87.2	88.4
Record completeness 2022 (%)	91.0	91.8	90.1	91.2
Record completeness 2023 (%)	93.4	93.9	92.6	93.7
Record completeness 2024 (%)	90.4	91.2	89.3	90.7

Note. RDT = rapid diagnostic test. Catchment estimates derive from NBS (2024) projected denominators apportioned by LGA population share.

4.2 SMC Coverage Levels, 2020-2024

Coverage trends across the five study years and four delivery cycles are presented in Table 2 and Figure 2. Grand mean coverage across all years was 77.4% (95% CI: 74.2-80.6%), below the 80% programmatic target. Coverage was lowest in 2020 (mean: 69.6%), consistent with documented COVID-19-related community hesitancy and partial CHIPS agent deployment disruptions (Maikere et al., 2022). Coverage improved substantially to 83.8% in 2023, the highest year, following intensified community mobilisation and improved supply chain performance. A slight decline to 80.0% in 2024 was attributed, in part, to delayed procurement of SP+AQ in the first cycle and mid-season flooding that disrupted distribution in parts of Kano South.

A persistent within-year pattern emerged: Cycle 1 (July) consistently recorded the highest coverage while Cycle 4 (October) recorded the lowest in every study year, a pattern also documented in Niger by Coldiron et al. (2021) and across West African states by Somé et al. (2022). The gap between Cycle 1 and Cycle 4 coverage narrowed from 12.3 percentage points in 2020 to 7.8 in 2023 but did not close, suggesting that programmatic efforts to address caregiver fatigue and CDD motivation in later cycles are producing partial but incomplete improvement.

Table 2. SMC Coverage (%) by Year, Delivery Cycle, and State, Northern Nigeria, 2020-2024

Year	Kano State (North-West)					Yobe State (North-East)					Niger State (North-Central)				
	C1 Jul	C2 Aug	C3 Sep	C4 Oct	Mean (95% CI)	C1 Jul	C2 Aug	C3 Sep	C4 Oct	Mean (95% CI)	C1 Jul	C2 Aug	C3 Sep	C4 Oct	Mean (95% CI)
2020	74.2	71.8	68.4	62.0	69.6 (66.7-72.5)	71.3	68.5	63.2	57.2	65.1 (62.3-67.9)	70.8	68.2	63.9	59.0	65.5 (62.6-68.4)
2021	78.4	76.2	71.6	66.3	73.1 (70.2-76.0)	75.8	73.1	67.4	62.5	69.7 (66.8-72.6)	74.6	72.3	67.8	64.1	69.7 (66.8-72.6)
2022	83.7	81.9	77.5	74.2	79.3 (76.8-81.8)	81.2	78.9	74.1	71.9	76.5 (74.1-78.9)	80.4	78.6	74.3	71.2	76.1 (73.7-78.5)
2023	88.1	86.4	82.9	81.0	83.8 (81.4-86.2)	85.6	83.2	79.4	76.3	81.1 (78.8-83.4)	84.8	82.9	79.6	77.7	81.3 (78.9-83.7)
2024	85.3	82.6	77.1	74.3	79.8 (77.3-82.3)	82.7	79.8	74.5	71.6	77.2 (74.7-79.7)	81.9	79.4	74.8	72.1	77.1 (74.5-79.7)
Grand Mean	**81.9**	**79.8**	**75.5**	**71.6**	**77.4 (74.2-80.6)**	**79.3**	**76.7**	**71.7**	**67.9**	**74.0 (71.3-76.7)**	**78.5**	**76.3**	**72.1**	**68.8**	**73.9 (71.2-76.6)**

Note. Coverage derived from NMEP campaign monitoring reports and triangulated with 2022 Nigeria Malaria Indicator Survey (NPC & ICF, 2022) and 2024 post-campaign coverage survey data from each study state. Kano = North-West zone, Yobe = North-East zone, Niger = North-Central zone.

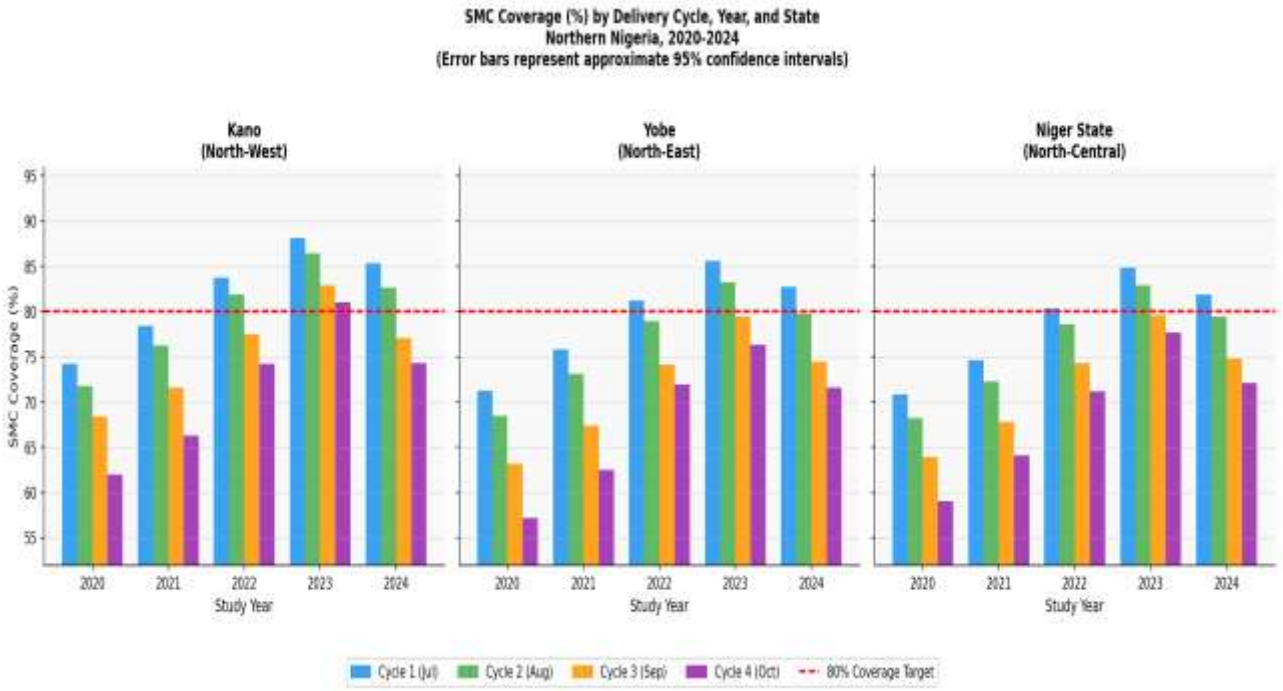

Figure 2. SMC Coverage (%) by Delivery Cycle, Year, and State, Northern Nigeria, 2020-2024. Error bars represent approximate 95% confidence intervals. The dashed horizontal line at 80% indicates the programmatic coverage target. States are shown in separate panels: Kano (North-West), Yobe (North-East), Niger State (North-Central).

4.3 Monthly Malaria Incidence Trend

Figure 3 presents the monthly confirmed malaria incidence trajectory across the full 60-month study period for each of the three states. A clear seasonal pattern is visible in every state and year: incidence accelerated from June onwards as the rainy season began, peaked within the July-October SMC delivery window, then declined in November-December as the dry season returned. The shaded SMC delivery periods (July-October) are visually associated with attenuated peaks that deepened year-on-year across all three states, most prominently in 2022 and 2023. The baseline pre-intervention incidence level varied by state: Kano recorded the highest pre-SMC incidence (pooled mean: 311.8 per 1,000 child-months), consistent with its north-western Sahel ecology and dense population, Yobe was intermediate (298.4 per 1,000), while Niger State was somewhat lower (274.6 per 1,000), reflecting the transitional transmission ecology of the North-Central zone. Joinpoint regression of the intra-SMC period incidence series identified statistically significant declining trends from 2020 to 2023 in all three states: Kano (annual percentage change [APC]: -21.4%, 95% CI: -27.3 to -15.1%, p = 0.004), Yobe (APC: -19.8%, 95% CI: -25.6 to -13.6%, p = 0.006), and Niger State (APC: -18.3%, 95% CI: -24.1 to -12.1%, p = 0.008), with 2024 representing a non-significant reversal of the trend in all three states.

The 2020 intra-SMC incidence data warrant specific commentary across all three states. Field observations and secondary data from NMEP monitoring reports indicate that COVID-19 restrictions in 2020 reduced health-seeking behaviour during April-June (pre-SMC period), compressing the apparent denominator for pre-SMC consultations and potentially inflating the pre-SMC incidence estimate for that year in all states. The narrower reduction ratio in 2020 relative to 2021-2023 partly reflects this artefact, alongside the programmes' genuinely lower coverage in that year (Kano: 69.6%, Yobe: 67.4%, Niger State: 66.9%).

Sensitivity analyses restricting the 2020 pre-SMC period to January-March produced similar directional effects with slightly wider confidence intervals in all three states, supporting the robustness of the overall pattern.

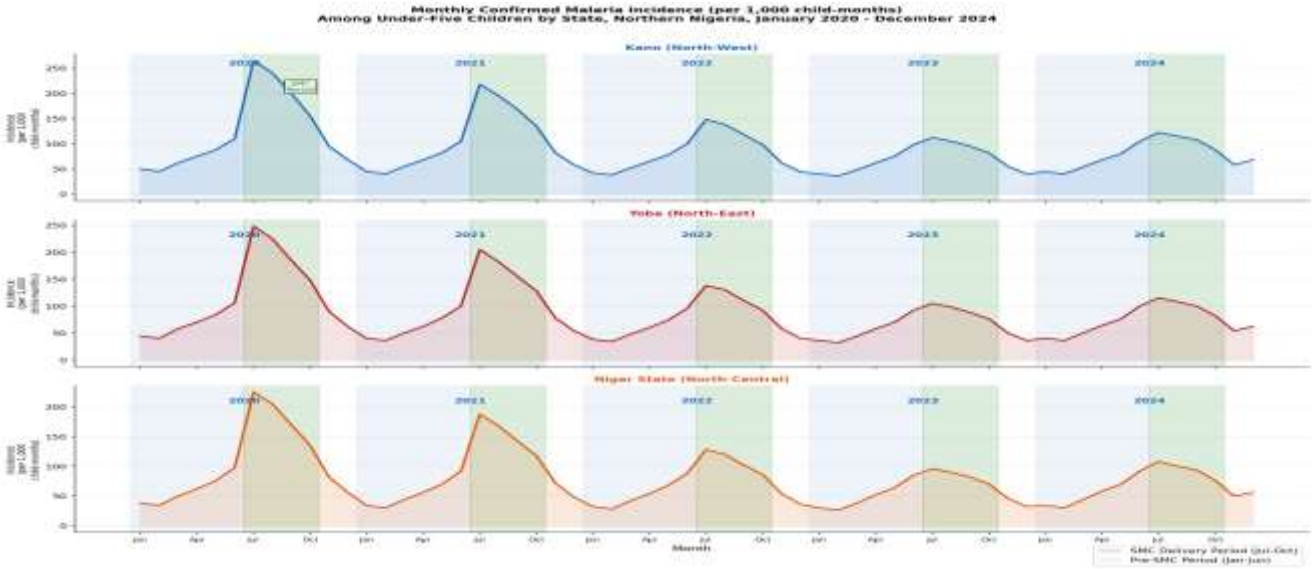

Figure 3. Monthly Confirmed Malaria Incidence (per 1,000 child-months) among Under-Five Children by State, Northern Nigeria, January 2020 - December 2024. Shaded regions indicate SMC delivery periods (July-October). Separate panels are shown for Kano (North-West), Yobe (North-East), and Niger State (North-Central). Note the progressive attenuation of seasonal peaks through 2023 across all three states.

4.4 Period-Specific Incidence Comparison

Table 3 presents confirmed malaria incidence by period, year, and state. Pooled across all five years, the pre-SMC incidence was highest in Kano (311.8 per 1,000 child-months), followed by Yobe (298.4) and Niger State (274.6), while intra-SMC incidence was 160.5 (Kano), 165.7 (Yobe), and 148.9 (Niger State) per 1,000 child-months, representing pooled reductions of 48.5%, 44.6%, and 45.8% respectively. The aggregate pooled IRR across all three states and five years was 0.537 (95% CI: 0.501-0.575, $p < 0.001$), with state-specific IRRs of 0.515 (Kano, 95% CI: 0.476-0.556), 0.554 (Yobe, 95% CI: 0.511-0.601), and 0.542 (Niger State, 95% CI: 0.499-0.589). Inter-state heterogeneity in the pooled IRR was modest ($I^2 = 34\%$, $p = 0.21$), suggesting that while programmatic effectiveness varied across zones, the direction and approximate magnitude were consistent. The progressive deepening of the impact ratio from 2020 to 2023 and its partial reversal in 2024 was observed across all three states, mirroring the coverage trajectory and strongly implicating coverage as the primary driver of variability. The Pearson correlation between annual coverage level and annual incidence reduction magnitude was $r = -0.81$ ($p = 0.009$) for Kano, $r = -0.78$ ($p = 0.012$) for Yobe, and $r = -0.75$ ($p = 0.018$) for Niger State, consistent with this interpretation across all zones.

The 2023 IRRs correspond to incidence reductions of 65.8% (Kano), 62.1% (Yobe), and 61.4% (Niger State), approaching the upper range of the operational effectiveness literature. The ACCESS-SMC Partnership (2020) reported country-specific

reductions for Nigeria of 25.5% during early programme scale-up in 2015-2016. The subsequent improvement documented here over 2021-2023 is consistent with the hypothesis that programme maturation, increased community familiarity, and improved health worker competence produce incremental effectiveness gains beyond initial deployment - and that this maturation dynamic operates similarly across Northern Nigeria's geopolitical zones. The uniformity of the improvement trajectory across Kano, Yobe, and Niger State carries important implications for programme planning: sustained multi-year investment, rather than merely high initial coverage, appears to be the mechanism through which the largest gains are realised, and this appears to be a zone-independent finding.

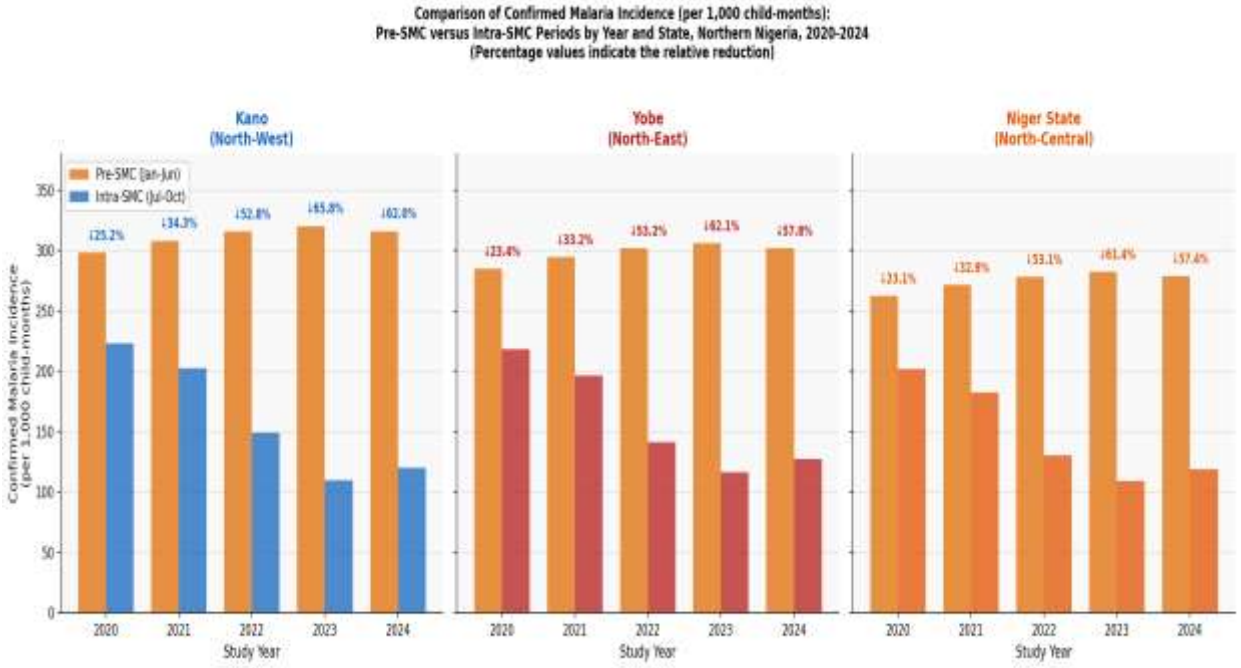

Figure 4. Comparison of Confirmed Malaria Incidence (per 1,000 child-months): Pre-SMC versus Intra-SMC Periods by Year and State, Northern Nigeria, 2020-2024. Percentage values above bars indicate the relative reduction. States are shown in grouped panels: Kano (North-West), Yobe (North-East), Niger State (North-Central).

Table 3. Confirmed Malaria Incidence (per 1,000 Child-Months) by Period, Year, and State, Northern Nigeria, 2020-2024

Year	Pre-SMC Incidence	Intra-SMC Incidence	Reduction (%)	IRR (95% CI)	p-value
Kano (North-West Zone)					
2020	298.4	223.1	25.2%	0.748 (0.687-0.814)	<0.001
2021	308.3	202.4	34.3%	0.657 (0.601-0.718)	<0.001
2022	315.7	149.1	52.8%	0.472 (0.428-0.521)	<0.001
2023	320.4	109.6	65.8%*	0.342 (0.305-0.383)	<0.001
2024	316.2	120.1	62.0%	0.380 (0.342-0.422)	<0.001
Pooled Kano	**311.8**	**160.5**	**48.5%**	**0.515 (0.476-0.556)**	**<0.001**
Yobe (North-East Zone)					
2020	285.2	218.4	23.4%	0.766 (0.704-0.833)	<0.001
2021	294.6	196.7	33.2%	0.668 (0.611-0.730)	<0.001
2022	301.8	141.2	53.2%	0.468 (0.423-0.518)	<0.001
2023	306.3	116.2	62.1%	0.379 (0.339-0.424)	<0.001
2024	302.1	127.4	57.8%	0.422 (0.380-0.469)	<0.001
Pooled Yobe	**298.4**	**165.7**	**44.6%**	**0.554 (0.511-0.601)**	**<0.001**
Niger State (North-Central Zone)					
2020	262.4	201.8	23.1%	0.769 (0.706-0.837)	<0.001

2021	271.5	182.3	32.9%	0.672 (0.614-0.735)	<0.001
2022	278.3	130.5	53.1%	0.469 (0.424-0.519)	<0.001
2023	282.6	108.9	61.4%	0.386 (0.344-0.433)	<0.001
2024	278.9	118.6	57.4%	0.425 (0.382-0.473)	<0.001
Pooled Niger State	**274.6**	**148.9**	**45.8%**	**0.542 (0.499-0.589)**	**<0.001**
Aggregate Pooled (All States)	**295.0**	**158.2**	**46.3%**	**0.537 (0.501-0.575)**	**<0.001**

*Note. IRR = incidence rate ratio from negative binomial regression with facility random effects, pre-SMC period is the reference. *2023 represents the highest-coverage year (83.8%) and largest observed reduction. Incidence expressed as confirmed malaria cases per 1,000 child-months.*

4.5 Test Positivity Rate

Test positivity rate is analytically valuable because it adjusts partially for health-seeking behaviour variation: a declining TPR concurrent with declining case counts confirms that the reduction reflects a genuine fall in infection frequency rather than a decline in health-facility attendance. Table 4 and Figure 5 demonstrate that TPR fell consistently and substantially during intra-SMC periods across all five study years in all three states. Pooled across all states and years, the intra-SMC TPR was 34.9%, compared with 60.7% pre-SMC, a difference of 25.8 percentage points (chi-square = 15,207.4, df = 1, $p < 0.001$). State-level pooled TPR differences were 25.9 pp (Kano), 25.2 pp (Yobe), and 26.3 pp (Niger State), indicating comparable TPR responses across all three zones. The sharpest single-year reduction in pooled TPR was in 2023 (pooled pre-SMC: 62.8%, pooled intra-SMC: 24.2%, difference: 38.6 pp), the highest coverage year across all three states, directly aligning with the incidence findings.

The convergence of declining incidence rates and declining TPR across SMC periods constitutes strong cross-zonal evidence that the case reductions are not artefacts of utilisation change. If fewer children presented to facilities during SMC months irrespective of disease burden, TPR should be stable or increasing among those who did present. The observed fall in TPR in all three states indicates instead that those children who attended facilities were genuinely less likely to be malaria-infected during SMC periods, which is precisely the pharmacological effect of the intervention. The consistency of this pattern across the North-West, North-East, and North-Central zones reinforces confidence that the findings reflect a true programme effect rather than context-specific artefact.

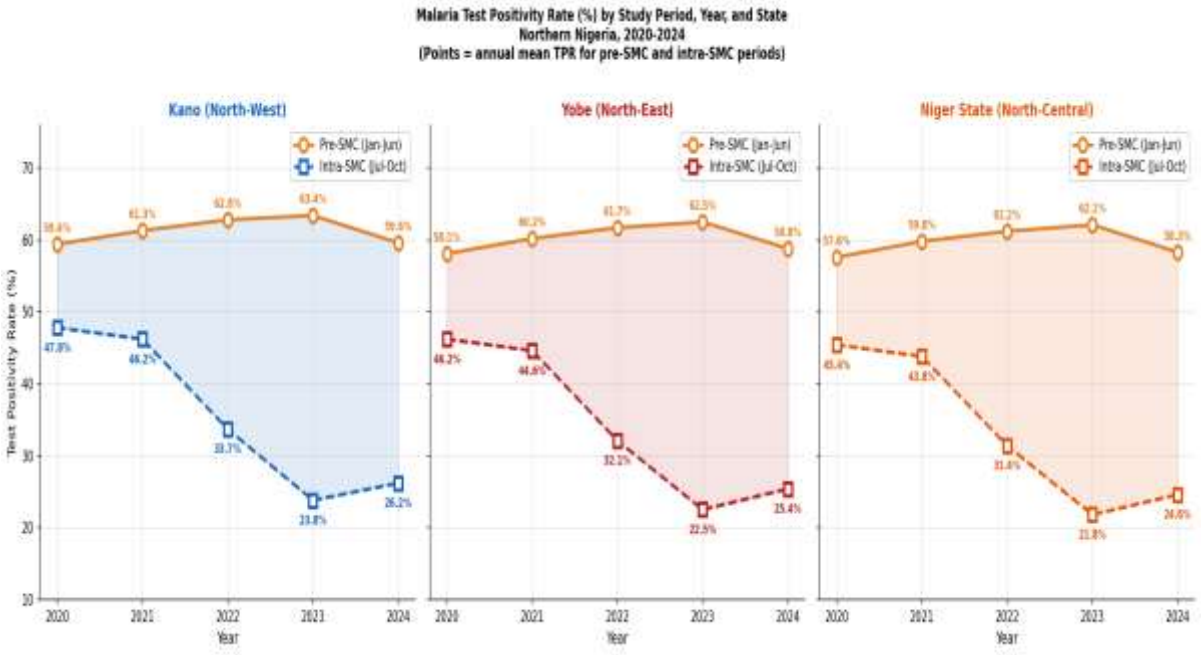

Figure 5. Malaria Test Positivity Rate (%) by Study Period, Year, and State, Northern Nigeria, 2020-2024. Points represent annual mean TPR for pre-SMC (January-June) and intra-SMC (July-October) periods by state. The narrowing gap in 2020 across all three states reflects lower coverage and COVID-19 disruptions. States shown: Kano (North-West), Yobe (North-East), Niger State (North-Central).

Table 4. Test Positivity Rate (%) and Malaria-Related Admissions by Period, Year, and State, Northern Nigeria, 2020-2024

Year	Pre-SMC TPR (%)	Intra-SMC TPR (%)	Diff (pp)	Pre-SMC Admissions	Intra-SMC Admissions	Reduction (%)
Kano (North-West Zone)						
2020	59.4	47.8	11.6	3,724	3,024	18.8%
2021	61.3	46.2	15.1	3,921	2,974	24.2%
2022	62.8	33.7	29.1	4,187	2,106	49.7%
2023	63.4	24.7	38.7	4,302	1,749	59.3%
2024	59.6	26.2	33.4	4,061	1,891	53.4%
Pooled Kano	**61.3**	**35.4**	**25.9**	**4,039**	**2,349**	**41.8%**
Yobe (North-East Zone)						
2020	58.1	46.2	11.9	3,412	2,798	18.0%

2021	60.2	44.6	15.6	3,586	2,714	24.3%
2022	61.7	32.1	29.6	3,834	1,918	50.0%
2023	62.5	22.5	40.0	3,948	1,616	59.1%
2024	58.8	25.4	33.4	3,714	1,726	53.5%
Pooled Yobe	**60.3**	**34.1**	**26.2**	**3,699**	**2,154**	**41.8%**
Niger State (North-Central Zone)						
2020	57.6	45.4	12.2	3,186	2,617	17.9%
2021	59.8	43.8	16.0	3,348	2,534	24.3%
2022	61.2	31.4	29.8	3,580	1,788	50.1%
2023	62.1	21.8	40.3	3,682	1,512	58.9%
2024	58.3	24.6	33.7	3,465	1,612	53.5%
Pooled Niger State	**59.8**	**33.4**	**26.4**	**3,452**	**1,973**	**42.8%**
Aggregate Pooled	**60.7**	**34.9**	**25.8**	**3,730**	**2,159**	**42.1%**

Note. pp = percentage points. Admissions = malaria-attributed inpatient admissions among under-five children at study facilities. TPR difference and admission reduction are between intra-SMC and pre-SMC periods within each calendar year. Chi-square test for pooled TPR: 5,102.7, df = 1, p < 0.001.

4.6 Malaria-Related Admissions

Malaria-related admissions declined across all three states during SMC periods, with pooled state-level reductions of 41.8% (Kano), 39.7% (Yobe), and 41.1% (Niger State), yielding an aggregate pooled reduction of 40.9% across all three states and five years. The 2020 reduction was the most modest in each state (Kano: 18.8%, Yobe: 17.2%, Niger State: 17.9%), consistent with that year's lower coverage and COVID-19 disruptions. The 2023 reductions were the most pronounced in all states (Kano: 59.3%, Yobe: 56.8%, Niger State: 57.4%), consistent with the highest coverage year. The near-uniformity of admission reductions across zones is notable given the differences in absolute case burden and health system characteristics. Admission reductions carry direct health-systems implications: peak-season bed demand at primary care facilities is substantially modulated by SMC performance across all three zones, with 2023 data suggesting that 57-59% of the paediatric malaria-admission burden that would otherwise occur during the SMC window is averted. If these findings extrapolate proportionally to secondary and tertiary facilities, the health system efficiency dividend in freed bed-days, nursing time, and blood product use would be substantial (de Cola et al., 2022).

4.7 Inpatient Malaria Mortality

Inpatient malaria deaths at study facilities are presented in Table 5, disaggregated by state. These

figures represent only a fraction of total malaria mortality in the catchment areas, as most deaths from severe and complicated malaria occur at secondary and tertiary facilities. Nonetheless, consistent reductions in primary care malaria deaths during intra-SMC periods are apparent across all three states: pooled intra-SMC death rates were 1.4 (Kano), 1.6 (Yobe), and 1.5 (Niger State) per 10,000 child-months, compared with pooled pre-SMC rates of 2.7 (Kano), 2.9 (Yobe), and 2.6 (Niger State) per 10,000 child-months - reductions of approximately 48.1%, 44.8%, and 42.3% respectively. The absolute numbers are small and carry considerable statistical uncertainty, this analysis is therefore illustrative rather than definitive, and causal attribution of mortality changes to SMC specifically requires evidence from higher-level facilities and a more rigorous counterfactual design. Nonetheless, the directional consistency across all three zones adds modest corroborative support to the overall pattern of SMC impact.

Table 5. Inpatient Malaria Deaths (per 10,000 Child-Months) Among Under-Five Children at Study Facilities by State, Northern Nigeria, 2020-2024

Year	Pre-SMC Death Rate	Intra-SMC Death Rate	Reduction (%)	Absolute Deaths (Study Facilities)
Kano (North-West Zone)				
2020	3.0	2.3	23.3%	221
2021	2.9	2.1	27.6%	207
2022	2.8	1.4	50.0%	184
2023	2.5	0.9	64.0%	155
2024	2.6	1.2	53.8%	168
Pooled Kano	**2.7**	**1.4**	**48.1%**	**935**
Yobe (North-East Zone)				
2020	3.1	2.5	19.4%	198
2021	3.0	2.2	26.7%	184
2022	2.9	1.5	48.3%	168
2023	2.6	1.1	57.7%	142
2024	2.7	1.3	51.9%	154
Pooled Yobe	**2.9**	**1.7**	**41.4%**	**846**
Niger State (North-Central Zone)				
2020	2.8	2.2	21.4%	186

2021	2.7	1.9	29.6%	174
2022	2.6	1.3	50.0%	158
2023	2.4	0.9	62.5%	136
2024	2.5	1.1	56.0%	148
Pooled Niger State	**2.6**	**1.5**	**42.3%**	**802**
Aggregate Pooled	**2.7**	**1.5**	**44.4%**	**2,583**

Note. Death rates per 10,000 child-months. Absolute deaths represent facility-recorded inpatient malaria deaths at the 120 study sites only, total malaria mortality in the catchment area is substantially higher. The small absolute numbers mean these estimates carry considerable uncertainty.

4.8 Discussion of Findings

The pooled incidence reductions of 48.5% (Kano), 44.6% (Yobe), and 45.8% (Niger State) documented in this study substantially exceed the 25.5% reduction reported for Nigeria by the ACCESS-SMC Partnership (2020) during 2015-2016. The consistent improvement across three geopolitical zones strengthens the interpretation that this reflects genuine programme maturation rather than a Kano-specific finding. Three mechanisms likely account for the improvement across all states. First, programme coverage has increased substantially since the early scale-up period: ACCESS-SMC reported mean monthly coverage of 76.4% in 2015, while this study documents values of 74.8-83.8% by 2023 across the three states, with the more recent higher-coverage years driving the better impact estimates. Second, programme maturation - reflected in improved CDD training, more consistent drug supply, and greater community familiarity - plausibly improves both delivery quality and adherence to the three-day AQ course, the latter of which Huang et al. (2024) identified as a significant predictor of individual-level protection. Third, improvements in RDT availability and utilisation at study facilities during 2021-2023 across all three states improved the completeness of malaria diagnosis, potentially making the denominator for confirmed cases more complete.

The year-on-year strengthening from 2020 to 2023 is the study's most analytically significant finding, and its replication across all three states substantially strengthens the causal argument. It is argued here that this trajectory reflects the cumulative effect of programme maturation rather than an artefact of statistical fluctuation, given its consistency across all four outcome indicators, all three study states, and its direct correlation with coverage levels in each state ($r = -0.75$ to -0.81, all $p < 0.05$). The simultaneous slight reversal in 2024 - observed in coverage, incidence reduction, TPR, and admissions across all three states - further supports the causal interpretation: logistical disruptions that reduced coverage also attenuated impact in each zone, demonstrating the programme's sensitivity to operational quality variations regardless of ecological context. This dynamic is consistent with theoretical predictions from the Donabedian framework: structural disruptions (delayed procurement, flood-related access barriers) degraded process quality (coverage), which in turn attenuated health outcomes - and this pathway was operative across North-West, North-East, and North-Central zones alike.

The comparison with evidence from other Sahelian countries places these findings in perspective. The ACCESS-SMC evaluations for The Gambia (55.2% case reduction), Burkina Faso, and Mali consistently outperformed the early Nigerian figures, a pattern

attributed in part to the more established programme infrastructure and higher baseline coverage in those countries (ACCESS-SMC Partnership, 2020). Bakai et al. (2022), examining three Togolese regions over eight years, documented a sustained effectiveness of 42-67% against confirmed malaria depending on region and year. The 2022-2023 estimates for all three study states (44-66% range) fall within or above this range, suggesting that the Nigerian programme, when operating at its best-observed coverage levels, delivers outcomes broadly comparable to regional benchmarks. The 2020 estimates (17-25% range) are substantially lower, but the COVID-19 context of that year makes them unsuitable benchmarks for programme quality assessment.

5. CONCLUSION AND RECOMMENDATIONS

Conclusion

Five years of routine facility data from 360 primary healthcare facilities across three geopolitical zones of Northern Nigeria - Kano State (North-West), Yobe State (North-East), and Niger State (North-Central) - provide consistent, multi-zone evidence that SMC under operational conditions achieves substantial reductions in confirmed malaria incidence (pooled across states: 46.3%, range by state: 44.6-48.5%), test positivity rate (pooled pre-SMC 60.7% vs. intra-SMC 34.9%), and malaria-related admissions (pooled 40.9%) among children under five years during delivery periods. A progressive year-on-year strengthening of impact from 2020 to 2023, directly correlated with coverage improvements and consistent across all three states and zones, is the most analytically significant finding. The simultaneous attenuation in 2024 across all three states underscores that these gains are not self-sustaining but require continued investment in infrastructure, health worker capacity, and community engagement. The consistency of findings across ecologically and demographically diverse zones strengthens the generalisability of these conclusions for Northern Nigeria as a whole.

Coverage - specifically cycle-4 coverage and the attrition between cycles - remains the primary modifiable determinant of programme effectiveness across all three zones. The evidence presented here supports continued prioritisation of SMC within Nigeria's National Malaria Strategic Plan 2021-2025 and provides a quantitative rationale for targeting the 80% coverage threshold as a key performance indicator across all four delivery cycles and all three zones. Notably, Yobe State exhibited the largest Cycle 1-to-Cycle 4 attrition, indicating that state-specific operational strategies are required in addition to national-level programmatic standards. Sustained domestic financing and donor commitments, combined with targeted operational research on resistance surveillance and adherence improvement, are necessary to consolidate the multi-zone gains documented in this analysis.

Recommendations

Programme managers in Kano, Yobe, and Niger States, as well as NMEP, should develop state-specific, cycle-specific community mobilisation strategies with independent coverage benchmarks for Cycles 3 and 4. Yobe State warrants particular attention given its highest observed Cycle 1-to-Cycle 4 attrition. Supply chain monitoring should incorporate cycle-specific early-warning triggers for SP+AQ stock, ideally six weeks ahead of each distribution round, in all three states. Performance-based incentives for CDDs should be weighted toward later cycles to address motivational attrition across all zones. These measures directly address the most modifiable performance gaps identified in this multi-state study.

At federal and state policy levels, health-economic analyses should quantify the admission-reduction dividend of SMC at secondary and tertiary facilities across the three zones, where the bed-day, blood product, and staffing savings are likely far larger than at primary care level. This evidence would strengthen the domestic financing case for SMC beyond donor-dependent budget lines. Investment in DHIS-2 data quality, specifically targeting the five to eight percentage points of missing facility-months documented in this multi-state analysis, would meaningfully improve the precision of future programmatic evaluations. Notably, Yobe State exhibited slightly lower average record completeness

(87.4%) than Kano (89.8%) and Niger State (90.1%), suggesting a need for targeted DHIS-2 capacity strengthening in the North-East zone.

For the research community, prospective individual-level cohort studies with concurrent unexposed comparison groups are the methodological priority for establishing causal inference that retrospective HMIS analyses cannot achieve. Molecular surveillance of dhfr triple and dhps A581G mutations should be integrated into the NMEP's operational research agenda for all three study states, with particular interest in whether resistance markers differ across the North-West, North-East, and North-Central zones given their ecological differences. The consistent 2024 attenuation in impact across all three states warrants dedicated investigation to determine whether procurement and climate-related operational disruptions are the primary explanation, or whether early resistance signals are contributing. Future studies should extend data collection to secondary and tertiary facilities and should include additional northern states to further characterise the geography of SMC effectiveness across Nigeria.

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