INTERNATIONAL JOURNAL OF MEDICAL SCIENCE AND DENTAL HEALTH
(ISSN: 2454-4191)
www.ijmsdh.org (2026)

Received: 17 March 2026
Revised: 24 March 2026
Accepted: 25 March 2026
Published: 27 March 2026

Page No - 66-77
DOI - 10.55640/ijmsdh-12-03-08

Article Citation: OKEREKE, P. U., ADENIYI, D. A.., ADEDEJI, M. T.., AKINOLA, S. O.., OKEREKE, W. O.., OZIOMA, C. F.., OKOLI, O. G.., Chibueze, C. O.., OGAMBA, N.., & UCHE, C. U. (2026). Eradicating the Enemy Within: A Narrative Review of Malaria Elimination Strategies and Future Pathways in Nigeria. International Journal of Medical Science and Dental Health, 12(03), 66-77. https://doi.org/10.55640/ijmsdh-12-03-08

Eradicating the Enemy Within: A Narrative Review of Malaria Elimination Strategies and Future Pathways in Nigeria

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Abstract

Despite decades of coordinated national and international effort, the elimination targets embedded in the National Malaria Strategic Plan 2021 to 2025 remain substantially unmet, exposing a persistent and deeply rooted gap between the demonstrated efficacy of available tools and their real-world programmatic impact. This narrative review critically synthesises current evidence on both established and emerging malaria elimination strategies in Nigeria, examining the implementation landscape across six interrelated domains: vector control, case management and chemoprevention, diagnostic accuracy, malaria vaccination, mobile health surveillance, and genetic vector control. A comprehensive literature search was conducted across PubMed, Google Scholar, Web of Science, and EMBASE, supplemented by grey literature from the World Health Organization, the National Malaria Elimination Programme, and Gavi, with priority given to publications from 2015 to 2025. The review finds that existing tools, including long-lasting insecticide treated nets, artemisinin-based combination therapies, seasonal malaria chemoprevention, and indoor residual spraying, have produced measurable but insufficient reductions in burden, constrained by insecticide resistance, low utilisation rates, supply chain fragility, and weak diagnostic infrastructure. Inaccuracies in rapid diagnostic test performance substantially drive misdiagnosis and fuel antimalarial resistance in Nigeria, with deletions in the hrp2 and hrp3 genes of Plasmodium falciparum emerging as a particularly consequential threat to the reliability of frontline testing. The December 2024 rollout of the R21/Matrix-M vaccine in Bayelsa and Kebbi States represents a historic national milestone, though implementation barriers encompassing vaccine hesitancy, cold chain limitations, health workforce gaps, and the complexity of the four-dose schedule demand systematic and urgent responses. The overarching finding of this review is that no single intervention, however efficacious in trial settings, is sufficient to achieve malaria elimination in Nigeria, and that what is required is a systems-level, integrated strategy aligning biological innovation with health system strengthening, equitable financing, digital infrastructure, and genuine community partnership.

Keywords: Long-lasting insecticide treated nets; Malaria elimination; Plasmodium falciparum; R21/Matrix-M; RTS, S/AS01; Vaccine implementation

1. Introduction

Malaria remains one of the most consequential preventable diseases in human history, and Nigeria sits at its global epicentre. According to the World Malaria Report 2024, Nigeria recorded approximately 67.7 million cases and nearly 200,000 deaths in 2023, accounting for 27% of global cases and 31% of global malaria deaths, figures that dwarf the entire malaria burden of most other world regions (WHO, 2024). Approximately 97% of the Nigerian population is at risk of infection, and the disease is responsible for 60% of outpatient visits, 30% of paediatric deaths, and 11% of maternal mortality (Federal Ministry of Health [FMOH], 2019). The social, economic, and developmental toll of this burden is staggering: annual productivity and treatment losses attributable to malaria are estimated at approximately 132 billion Naira, and the disease functions as a structural impediment to Nigeria's human capital development (Economic Impact of Malaria in Nigeria, 2019).

Malaria in Nigeria is caused almost exclusively by Plasmodium falciparum, transmitted by the female Anopheles gambiae sensu lato mosquito, whose ecology thrives in the country's diverse climatic zones (Chibueze et al., 2021). Transmission is perennial in the humid south, seasonal in the Sahelian north, and heterogeneous across hundreds of local government areas with distinct ecological and socioeconomic profiles. This complexity means that strategies effective in one setting may be inadequate in another, a challenge that has historically been underappreciated in national programme design.

Nigeria's National Malaria Elimination Programme (NMEP), operating under the National Malaria Strategic Plan (NMSP) 2021 to 2025, has deployed a comprehensive portfolio of interventions: universal distribution of long-lasting insecticide treated nets (LLINs), indoor residual spraying (IRS), artemisinin-based combination therapies (ACTs), seasonal malaria chemoprevention (SMC), and intermittent preventive treatment in pregnancy (IPTp). Despite this portfolio, the NMSP's targets of reducing malaria incidence below 10% and mortality below 50 per 1,000 live births by 2025 remain far from achieved (NMEP, 2021). This persistent gap between policy ambition and programmatic reality signals not a failure of evidence but a failure of implementation, driven by health system weaknesses, diagnostic inaccuracies, insecticide resistance, financing fragility, and suboptimal community engagement.

Against this backdrop, several potentially transformative developments have recently emerged: the WHO recommendation and subsequent Nigerian regulatory approval of two malaria vaccines, RTS, S/AS01 and R21/Matrix-M; Nigeria's inaugural vaccine rollout in December 2024; growing evidence on the role of digital mobile health tools in malaria surveillance; and continued advances in genetic vector control. This review synthesises the evidence across all major elimination strategy

domains, drawing critically on diagnostic accuracy, vaccine implementation barriers and solutions, and mobile application-based malaria surveillance, to develop an integrated framework for eliminating malaria in Nigeria.

2. Methods

2.1 Review Design

A narrative review design was selected as the most appropriate approach for the purpose and scope of this paper. Unlike systematic reviews, which aim to exhaustively identify and pool quantitative effect estimates, narrative reviews are designed to synthesise a broad and heterogeneous literature across multiple intervention domains, identify patterns, contradictions, and knowledge gaps, and develop conceptual frameworks to guide policy and practice (Ferrari, 2015). Given that malaria elimination in Nigeria involves distinct but interacting domains, including vector control, chemoprevention, diagnostics, vaccination, digital surveillance, and genetic innovation, each with its own evidence base and methodological traditions, a narrative approach provides the integrative breadth that a single-domain systematic review cannot.

2.2 Literature Search Strategy

A comprehensive literature search was conducted between January and June 2025 across four electronic databases: PubMed/MEDLINE, Google Scholar, Web of Science, and EMBASE via Ovid. Grey literature searches were additionally conducted on the websites of the World Health Organization, the National Malaria Elimination Programme, Gavi, the US President's Malaria Initiative, and the Roll Back Malaria Partnership. Database searches used Boolean combinations of the following terms: 'malaria' OR 'Plasmodium falciparum' AND 'Nigeria' OR 'West Africa' OR 'sub-Saharan Africa' AND 'elimination' OR 'eradication' OR 'control', combined with domain-specific terms including 'insecticide-treated net' OR 'LLIN'; 'indoor residual spraying' OR 'IRS'; 'artemisinin' OR 'ACT'; 'chemoprevention' OR 'SMC' OR 'IPTp'; 'rapid diagnostic test' OR 'RDT' OR 'misdiagnosis'; 'malaria vaccine' OR 'RTS,S' OR 'R21/Matrix-M'; 'gene drive' OR 'genetic vector control'; and 'mHealth' OR 'mobile application' OR 'digital surveillance'. No language restrictions were applied. Searches were not date-limited, but publications from 2015 to 2025 were prioritised; older foundational works were included where they provided essential methodological or historical context.

2.3 Inclusion and Exclusion Criteria

Studies were included if they examined malaria prevention, diagnosis, treatment, or elimination in Nigeria or directly applicable sub-Saharan African settings; reported empirical findings, programmatic evaluations, or evidence-based policy analyses; were published in peer-reviewed journals or credible grey literature sources; or provided essential context regarding global malaria vaccine development, genetic vector control, or digital health innovation with direct relevance to Nigerian application. Studies were excluded if they focused exclusively on Plasmodium species other than falciparum without applicability to Nigeria; were conference abstracts without full-text verification; or reported on in vitro laboratory studies without translational relevance.

2.4 Data Extraction and Synthesis

Data extraction was performed thematically, with relevant findings organised into six primary domains: malaria burden and epidemiology; vector control; chemoprevention and case management; diagnostics; vaccination; and genetic vector control and digital surveillance. For each domain, evidence was synthesised narratively with attention to internal consistency across sources, gaps or contradictions in the evidence base, and the implementation context specific to Nigeria. Where quantitative effect estimates were available from robust studies, these are cited directly. Where evidence was primarily descriptive or qualitative, thematic analysis was applied. Findings are presented in sections corresponding to these thematic domains, followed by an integrated discussion and conclusion.

3. Findings

3.1 The Malaria Burden in Nigeria

3.1.1 Global and National Epidemiology

The scale of Nigeria's malaria burden resists easy comprehension. In 2023, the country recorded approximately 67.7 million confirmed malaria cases, a number exceeding the entire population of the United Kingdom, and approximately 200,000 deaths, representing 27% and 31% of global malaria cases and deaths respectively (WHO, 2024). Nigeria accounts for 38.4% of under-five malaria mortality worldwide and harbours the highest number of at-risk newborns in Africa at 7.2 million annually (Hassan et al., 2025). Children under five years of age and pregnant women bear the greatest burden: malaria contributes to 30% of paediatric mortality in Nigerian children

and is implicated in significant maternal anaemia, placental infection, low birth weight, and premature delivery (FMOH, 2019).

Despite modest improvements in age-standardised incidence over the past decade, population growth has historically outpaced gains from control interventions, meaning absolute case and death counts remain persistently high. The WHO Global Technical Strategy for Malaria 2016 to 2030 sets targets of 90% reductions in incidence and mortality by 2030 compared to 2015 baselines; Nigeria is significantly off-track on both indicators (WHO/AFRO, 2024). The NMSP 2021 to 2025 targets national malaria incidence below 10% and mortality below 50 per 1,000 live births by 2025, against a 2021 baseline of 30.3% incidence and 90 per 1,000 population mortality, underscoring the ambition and the scale of the challenge remaining (NMEP, 2021).

3.1.2 Geographic and Demographic Heterogeneity

Nigeria's malaria epidemiology is spatially heterogeneous, shaped by ecological zones, rainfall patterns, housing quality, socioeconomic conditions, and health system infrastructure. The humid rainforest south experiences perennial, high-intensity transmission, while the Sahelian north experiences shorter but intense seasonal transmission from June to October. The Guinea Savannah middle belt displays intermediate and variable patterns between these extremes. The 2021 Malaria Indicator Survey documented national malaria prevalence of 22% in children aged 6 to 59 months, with subnational variation ranging from below 5% in some urban southern states to over 40% in parts of the northwest (NMEP, 2021). Urban and rural gradients further modulate risk: rural communities with limited infrastructure and proximity to agricultural water bodies consistently experience higher incidence than their urban counterparts (Duodu et al., 2022).

3.1.3 Economic and Social Dimensions

Beyond its direct health impact, malaria imposes profound economic and developmental costs. Annual losses attributable to treatment expenditure, productivity reduction, and child development deficits are estimated at 132 billion Naira (Economic Impact of Malaria in Nigeria, 2019). At the household level, malaria expenditure is regressive, consuming a disproportionately large share of income in the poorest quintiles, who simultaneously face greater exposure through poorer housing conditions and limited access to prevention tools. Repeated malaria infections in childhood are associated with cognitive impairment, school absenteeism, and reduced educational attainment, embedding the disease's impact across generations (Oboh et al., 2022). For Nigeria to realise its human capital potential and achieve its Sustainable Development Goals, malaria elimination is not merely a health goal but a development imperative.

3.2. Established Strategies: Vector Control

3.2.1 Long-Lasting Insecticide Treated Nets

Long-lasting insecticide treated nets remain the cornerstone of malaria vector control globally and in Nigeria. Their mechanism operates through direct toxicity to pyrethroid-susceptible Anopheles mosquitoes upon contact with the net surface, combined with sub-lethal repellent effects that reduce biting frequency even without direct contact. WHO-sponsored meta-analyses confirm reductions in excess of 50% in malaria incidence among children under five when LLINs are used consistently in high-transmission settings (WHO, 2019). Nigeria has been the largest single recipient of donor-distributed LLINs globally: of the 173 million LLINs distributed worldwide in 2018, the greatest national share went to Nigeria, which received the bulk of the 87% of global supply allocated to sub-Saharan Africa (WHO, 2019).

Yet the gap between net ownership and consistent use critically undermines population-level impact. The 2021 Malaria Indicator Survey documented that while 52% of Nigerian households owned at least one LLIN, only 43% of children under five and 49% of pregnant women slept under a net on the night preceding the survey (NMEP, 2021). This gap reflects a complex interaction of sociocultural, economic, and environmental barriers. Maduka (2018) identifies heat discomfort, particularly in households without electricity, tactile and olfactory aversion to treated nets, gendered perceptions of net use, and poor replacement of deteriorated nets as primary barriers. Structural issues compound individual-level factors: Nigeria currently has only one domestic LLIN manufacturer, creating supply chain vulnerability when donor funding is delayed or reduced.

A growing and increasingly consequential threat to LLIN effectiveness is pyrethroid resistance among Anopheles gambiae populations, confirmed in multiple Nigerian states through target-site mutations, particularly kdr alleles, and metabolic resistance mechanisms (Oboh et al., 2022; Akinwale et al., 2026). As resistance prevalence increases, conventional pyrethroid-only nets lose efficacy, and WHO now recommends transition to nets combining pyrethroids with piperonyl butoxide (PBO), chlorfenapyr, or pyriproxyfen in resistance-endemic areas.

Emerging randomised trial evidence from comparable African settings supports the superiority of these combination nets in zones of high resistance. Transitioning Nigeria's LLIN distribution toward these next-generation formulations should be treated as a programmatic priority rather than an optional enhancement.

3.2.2 Indoor Residual Spraying

Indoor residual spraying complements LLINs by targeting indoor-resting Anopheles species through the application of residual insecticide to interior walls. When implemented with household coverage exceeding 85% and appropriate insecticide class rotation, IRS produces substantial but time-limited reductions in vector density and malaria incidence (Ogbonna, 2024; Akinwale et al., 2026). In Nigeria, IRS has been deployed selectively in high-transmission areas rather than at national scale, reflecting resource and logistical constraints. Household acceptance is variable: concerns about insecticide safety, the inconvenience of furniture removal, and cultural objections have limited coverage in some communities. Sustainability is the perennial challenge, since IRS campaigns require annual repetition, skilled operators, functional insecticide supply chains, and sustained financing that has been intermittent in the Nigerian context.

3.3 Chemoprevention and Case Management

3.3.1 Artemisinin-Based Combination Therapies

Artemisinin-based combination therapies, principally artemether-lumefantrine and artesunate-amodiaquine, constitute the first-line treatment for uncomplicated Plasmodium falciparum malaria in Nigeria and remain highly efficacious when properly administered. ACT availability at health facilities stands at approximately 97% nationally (Maduka, 2018), and the Affordable Medicines Facility for malaria initiative drove significant cost reductions in the private sector. However, actual uptake by febrile patients, particularly through the informal sector of patent medicine dealers and community-level self-medication, is substantially lower, with many patients receiving substandard treatments or no antimalarial at all (Oboh et al., 2022).

The emergence of partial artemisinin resistance, associated with kelch13 gene mutations in Plasmodium falciparum, in East African countries including Uganda, Tanzania, and Rwanda presents a serious prospective threat to Nigeria's treatment policy (Oboh et al., 2022). While resistance has not been confirmed in West Africa, the region's epidemiological connectivity demands urgent and proactive molecular resistance surveillance, both through the NMEP and academic research institutions, to detect early warning signals before resistance spreads and to enable rapid treatment guideline revision if necessary.

3.4 Seasonal Malaria Chemoprevention and Intermittent Preventive Treatment in Pregnancy

Seasonal malaria chemoprevention involves the monthly administration of sulfadoxine-pyrimethamine plus amodiaquine to children aged 3 to 59 months during peak transmission seasons and has been WHO-recommended since 2012 for Sahelian-zone countries with highly seasonal malaria. By 2024, SMC had been scaled to all 21 eligible states in Nigeria, reaching tens of millions of eligible children annually (NMEP, 2021). Clinical trial evidence consistently demonstrates between 60% and 80% efficacy against clinical malaria episodes during the transmission season in eligible children (Ogbonna, 2024). Implementation challenges, including drug stock-outs, variable community distributor performance, access gaps in remote communities, and caregiver adherence across four monthly cycles, have been documented in Nigerian programme evaluations and must be addressed through robust community-based delivery platforms and supply chain monitoring.

Intermittent preventive treatment in pregnancy involves the administration of at least three doses of sulfadoxine-pyrimethamine to pregnant women at each antenatal care visit after the first trimester and is an evidence-based strategy with proven efficacy against placental malaria, maternal anaemia, and low birth weight. Coverage in Nigeria remains well below WHO targets: the proportion of women receiving three or more doses during their last pregnancy was only 34% in 2021 against an 80% national target (FMOH, 2019). Barriers include late antenatal care booking, infrequent attendance, drug stock-outs, and inadequate health worker training on dosing protocols, all of which are correctable with appropriate investment and health system strengthening (Ogbonna, 2024; Akinwale et al., 2026).

3.5 The Diagnostic Imperative: Accuracy, Misdiagnosis, and Antimalarial Resistance

Accurate and timely malaria diagnosis is the foundational link in the chain connecting case detection to rational treatment, appropriate drug use, and credible programme surveillance. In Nigeria, where fever is ubiquitous, malaria serves as the reflexive default diagnosis in many clinical settings, and the majority of treatment decisions occur at the primary care or

community level without laboratory confirmation. The consequences of diagnostic error are system-wide: false-positive diagnoses drive unnecessary antimalarial consumption and accelerate drug resistance, while false-negative results delay treatment and generate inaccurate burden data that distort programme planning and resource allocation.

Okereke et al. (2025a) conducted a comprehensive assessment of the influence of rapid diagnostic test accuracy on malaria misdiagnosis and antimalarial resistance in Nigeria. Their review identified a constellation of diagnostic failure mechanisms, including procedural errors arising from inadequate health worker training in test performance and result interpretation, reagent degradation due to poor storage conditions in facilities lacking reliable electricity, sensitivity gaps in low-parasitaemia infections particularly in partially immune individuals where parasitaemia falls below detection thresholds, and, critically, the emergence of Plasmodium falciparum isolates harbouring deletions in the hrp2 and hrp3 genes, which cause false-negative results in the hrp2-based rapid tests that constitute the majority of Nigeria's diagnostic supply (Okereke et al., 2025a). The authors demonstrated that these inaccuracies are not marginal: in a country where most malaria diagnoses and treatment decisions occur at the community level or through patent medicine vendors without laboratory confirmation, the proportion of treatments administered to patients who do not have malaria is substantial and directly exerts selection pressure for antimalarial drug resistance.

The policy implications of this work are significant and layered. For frontline clinicians, the evidence reinforces that clinical diagnosis based on fever alone is unreliable and that test-and-treat protocols must be implemented and adhered to rigorously. For programme managers, it establishes that investment in diagnostic quality assurance, health worker training, and rapid diagnostic test supply chain monitoring is not a peripheral concern but central to the elimination strategy. For policymakers, it provides a clear evidentiary basis for accelerating the transition from hrp2-based to pan-specific, non-hrp2 tests, those detecting PfLDH or pan-aldolase, in regions where hrp2-deletion variants have been documented or are suspected (Okereke et al., 2025a). Molecular diagnostic tools, including loop-mediated isothermal amplification, offer a promising medium-term complement to rapid tests for high-stakes clinical and surveillance settings where greater sensitivity is required.

3.6 Digital Innovation: Mobile Application-Based Malaria Surveillance

The integration of mobile health technologies into malaria surveillance represents one of the most promising and underutilised opportunities for strengthening Nigeria's malaria response. Real-time, geographically granular case data that links case detection to the spatial targeting of vector control interventions is the prerequisite for the adaptive, precision elimination strategy that Nigeria's heterogeneous epidemiological landscape demands. Paper-based reporting systems, which remain prevalent in many Nigerian primary health care facilities, produce delayed, incomplete, and error-prone data that is inadequate for responsive programme management.

Previous study found that while mobile health surveillance tools have been implemented across multiple African and Asian settings with documented improvements in reporting timeliness, case ascertainment, and spatial data quality, integration with vector control decision-making, specifically LLIN distribution, IRS targeting, and larval source management, remained systematically underdeveloped. Critical implementation gaps were identified such as mobile surveillance platforms are often deployed for case reporting in isolation, without the data feedback loops, decision-support algorithms, and intersectoral coordination mechanisms needed to translate case data into vector control action in real time (Okereke et al., 2025c).

These findings carry direct implications for Nigeria's NMEP. Nigeria's District Health Information System provides a national platform for health data aggregation, but its penetration and data quality at the primary health care level remain highly variable. Strengthening the integration of mobile-based case reporting with the national health information system, developing user-friendly applications that community health workers and patent medicine vendors can operate with minimal training, and establishing data-to-decision feedback loops that enable programme managers at the local government level to respond to spatial case clusters with targeted vector control interventions would substantially improve the efficiency and equity of Nigeria's malaria programme. Current evidence synthesised provides a robust evidentiary foundation for this investment, and similar tools have already demonstrated proof of concept in Uganda, India, and Myanmar, offering directly transferable lessons for the Nigerian context (Okereke et al., 2025c).

3.7 Malaria Vaccination: Science, Policy, and Nigeria's Historic Rollout

3.7.1 The Pre-Erythrocytic Vaccine Paradigm

The development of effective malaria vaccines required overcoming the extraordinary biological complexity of Plasmodium falciparum, whose multistage life cycle, extensive antigenic variation, and sophisticated immune evasion mechanisms long confounded conventional vaccine design. The conceptual breakthrough that ultimately yielded licensed vaccines was the targeting of the pre-erythrocytic stage, specifically the circumsporozoite protein expressed on sporozoites during the brief window between mosquito injection and hepatocyte invasion. By generating high-magnitude antibody responses against this protein, pre-erythrocytic vaccines aim to block sporozoite invasion of the liver and prevent the initiation of the erythrocytic cycle that causes all clinical disease (Duffy and Patrick, 2020). The biological advantage of this approach lies in the numerical bottleneck it exploits: an infected mosquito injects only 15 to 200 sporozoites, compared to the billions of merozoites circulating during active blood-stage infection, making the pre-hepatic stage a far more tractable immunological target.

3.7.2 RTS, S/AS01: From Phase 3 to Real-World Implementation

The RTS, S/AS01 vaccine, developed by GlaxoSmithKline with support from PATH and the Bill and Melinda Gates Foundation, became the world's first licensed malaria vaccine following WHO recommendation in October 2021. Its four-dose Phase 3 trial across 11 sites in seven African countries demonstrated efficacy of 39% against clinical malaria over 18 months in children aged 5 to 17 months, modest in isolation but epidemiologically meaningful at scale (Nadeem et al., 2022). The WHO Malaria Vaccine Implementation Programme in Ghana, Kenya, and Malawi subsequently provided critical real-world evidence: over 1.8 million children received at least one dose by August 2023, with the programme demonstrating a 13% reduction in all-cause child mortality, an impact extending beyond direct malaria prevention to include reductions in severe anaemia and disease-related hospitalisations (WHO, 2023).

3.7.3 R21/Matrix-M: Advancing Efficacy and Access

The R21/Matrix-M vaccine, developed through collaboration between the Jenner Institute at the University of Oxford and the Serum Institute of India, represents the second WHO-recommended malaria vaccine and a significant scientific advance on the RTS,S/AS01 platform. R21 achieves a higher ratio of circumsporozoite protein to hepatitis B surface antigen in its virus-like particle structure, producing a more focused and higher-magnitude antibody response, amplified further by the Matrix-M adjuvant developed by Novavax. The Phase 3 randomised controlled trial reported by Datoo et al. (2024) across five sites in four African countries demonstrated efficacy of 75% with seasonal dosing and 68% with age-based dosing in children aged 5 to 36 months over 12 months, substantially exceeding the efficacy of RTS,S/AS01 and approaching the WHO aspirational benchmark. Nigeria granted regulatory approval for R21/Matrix-M through its National Agency for Food and Drug Administration and Control on 17 April 2023, among the earliest regulatory adopters in sub-Saharan Africa (WHO, 2023). The Serum Institute's production capacity of approximately 100 million doses per annum, with planned expansion, and the vaccine's price of approximately US$4 per dose, substantially below that of RTS, S/AS01, make it considerably more scalable for Gavi-supported national programmes (Aderinto et al., 2024).

3.7.4 Nigeria's December 2024 Rollout: Progress, Barriers, and Lessons

Nigeria's inaugural malaria vaccination campaign commenced in December 2024, with the distribution of one million R21/Matrix-M doses across Bayelsa State, where transmission is perennial and intense, and Kebbi State, where transmission is highly seasonal and the malaria burden among children is among the highest nationally. This deliberate two-setting strategy was designed to generate implementation evidence from contrasting epidemiological and health system contexts before national scale-up (WHO/AFRO, 2024). The vaccine is delivered within Nigeria's routine Expanded Programme on Immunisation schedule, with four doses at 5, 6, 7, and 18 months of age, integrated with existing immunisation antigens.

Okereke et al. (2025b) provide the most comprehensive published analysis of the barriers to malaria vaccine implementation in Nigeria, drawing on a systematic search of studies from 2019 to 2024. They identified six major barrier domains: vaccine hesitancy fuelled by social media-mediated misinformation and residual scepticism linked to COVID-19 vaccine campaigns; financial constraints within the national immunisation programme; logistical challenges in last-mile delivery particularly to remote communities; cold chain infrastructure gaps at facility level especially in states with unreliable electricity supply; health workforce shortages limiting the capacity to

administer and track four-dose schedules; and the inherent complexity of the dosing schedule, which demands four health system contacts in the first 18 months of life (Okereke et al., 2025b). Their proposed solutions encompass strong government leadership, multisectoral partnerships with religious and traditional leaders, targeted cold chain investment, and community engagement strategies that directly address specific misinformation narratives, providing a structured operational roadmap that Nigeria's NMEP vaccine rollout team should adopt as a reference.

Experience from the WHO pilot programme in Ghana, Kenya, and Malawi offers directly transferable lessons for Nigeria's scale-up. Osuntoye et al. (2025) documented that community leader engagement, continuity of health worker training, and flexible interpretation of dosing schedules to accommodate missed appointments were critical success factors across all three pilot countries. Vaccine hesitancy diminished progressively as communities observed vaccinated children remaining healthy, underscoring the importance of sustained community presence and trust-building that extends well beyond a single communication campaign. In Nigeria's culturally diverse and multi-faith society, where hundreds of ethnic groups and distinct religious frameworks shape health behaviour, generic community engagement models are inadequate, and context-specific, locally led strategies are essential (Maduka, 2018).

3.8 Genetic Vector Control: Gene Drive Technology

3.8.1 Scientific Basis and Progress

Conventional vector control tools share a fundamental vulnerability: they reduce mosquito populations through chemical action, and mosquito populations evolve resistance to chemical agents. Genetic approaches to vector control circumvent this limitation by introducing heritable biological modifications into mosquito populations, modifications that propagate through wild populations without continued external application and independently of chemical action. Gene drive systems, which use CRISPR-Cas9 molecular machinery to copy engineered sequences to homologous chromosomes in germline cells, can achieve near-complete inheritance transmission rates compared to the 50% Mendelian baseline, theoretically spreading desired traits through entire wild populations from a small initial release (Leftwich et al., 2021).

Two primary strategic approaches are under development for malaria. Population suppression drives spread female-sterility alleles to reduce or collapse mosquito populations, while population replacement drives spread malaria-refractory traits that render mosquitoes unable to transmit the parasite without necessarily reducing population size. The Target Malaria consortium has demonstrated that a population suppression drive targeting the doublesex gene in Anopheles gambiae can collapse laboratory cage populations within 7 to 11 generations (Powell, 2022). Self-eliminating gene drive constructs, proposed by Zapletal et al. (2021), address ecological reversibility concerns by engineering time limits on drive persistence in wild populations, providing a mechanism for removal from the environment if unintended consequences arise and substantially reducing the ecological risk profile of future field trials.

3.8.2 Regulatory and Community Engagement Imperatives

The regulatory pathway for gene drive deployment in Nigeria falls under the National Biosafety Management Agency Act of 2015. Nigeria has approved contained laboratory use of genetically modified Anopheles gambiae for research purposes, positioning it as a comparatively advanced regulatory environment in West Africa (Benedict et al., 2018). However, the path from contained laboratory research to open environmental release involves regulatory, ethical, and social dimensions that extend far beyond existing frameworks for genetically modified organisms. International guidance from WHO and the Convention on Biological Diversity mandates rigorous safety assessment, community consent processes, and international regulatory review before any environmental release (Benedict et al., 2018).

The social dimensions of gene drive acceptance are particularly important and should not be underestimated. Target Malaria's engagement experience across West Africa demonstrates that community acceptance is a multiyear, culturally embedded process rather than a one-time notification exercise. Communities express concerns that extend beyond malaria control to include ecosystem impacts, food web effects, and spiritual dimensions of the natural world. Nigeria's linguistic, ethnic, and religious diversity makes generic engagement models inadequate, and context-specific, community-led dialogue processes are essential prerequisites for any future field programme. Proactive investment in regulatory capacity, community engagement infrastructure, and scientific collaboration with the Target Malaria consortium now, even though environmental release remains a decade or more away, will position Nigeria to act decisively when the evidence and regulatory frameworks justify it.

3.9 Toward an Integrated Elimination Framework

3.9.1 The Limits of Vertical Programming

A persistent structural failure in Nigeria's malaria response has been the deployment of individual interventions in vertical silos, each with its own supply chain, implementation team, reporting structure, and evaluation framework, without the systems architecture to make them function as a coherent and mutually reinforcing programme. The consequences are predictable: interventions that perform strongly in clinical trials consistently underperform in programme evaluations because the enabling conditions for their fidelity and coverage are not systematically created. The diagnostic accuracy work of Okereke et al. (2025a) exemplifies this problem clearly: even where treatment commodities are available, their rational use is undermined by diagnostic failures that are themselves products of systemic weaknesses in training, supply chain monitoring, and quality assurance, weaknesses that treatment commodity procurement alone cannot address.

3.9.2 Mobile Health as a Cross-Cutting Integration Tool

The evidence synthesised by Okereke et al. on mobile application-based surveillance makes a compelling case for mobile health as a cross-cutting integration mechanism that can connect otherwise siloed programme domains (Okereke et al., 2025c). When designed with explicit feedback loops connecting case data to vector control decision-making, mobile surveillance platforms can operationalise the adaptive and data-responsive programming that Nigeria's heterogeneous malaria landscape demands. The practical implication is clear: Nigeria should invest in expanding health information system integration with mobile reporting tools at the primary care level, training community health workers to use standardised reporting applications, and developing real-time dashboard systems for local government area-level programme managers to identify spatial case clusters and trigger targeted vector control responses. The infrastructure built for mobile health malaria surveillance can simultaneously serve vaccine coverage monitoring, an important efficiency gain given the considerable parallel demands of the ongoing vaccine rollout.

3.9.3 Health System Strengthening as the Non-Negotiable Foundation

Every intervention reviewed in this paper, from LLINs to gene drives, depends ultimately on health system infrastructure to deliver it equitably and consistently. Nigeria's primary health care system is chronically underfunded, understaffed, and poorly supplied with essential commodities. Okereke et al. (2025b) identified health workforce shortages as a core barrier to vaccine implementation, an insight that generalises across all malaria programme domains. Each new tool added to Nigeria's malaria portfolio, whether a next-generation LLIN formulation, a molecular diagnostic, or a four-dose vaccine, demands incremental health worker time, skills, and supervisory attention that an already stretched system struggles to provide without additional investment. Health system strengthening is therefore not a background aspiration but a concrete and fundable prerequisite for achieving any of the elimination targets discussed in this review.

3.9.4 Financing and Domestic Resource Mobilisation

Nigeria's malaria programme remains heavily dependent on external financing, with the Global Fund, the US President's Malaria Initiative, Gavi, the World Bank, and UNICEF together providing the majority of commodity and programme support costs. While this support has been indispensable, its structural fragility, subject to global funding cycles, donor policy shifts, and conditionality requirements, represents a persistent threat to programme sustainability. The Nigeria End Malaria Council and the End Malaria Fund provide platforms for domestic resource mobilisation advocacy, and the World Bank, African Development Bank, and Islamic Development Bank provided combined credits of $364 million for health and malaria interventions across 13 states from 2020 to 2024 (WHO/AFRO, 2024). However, state government co-financing of malaria programmes remains minimal in most states. Achieving elimination will require a fundamental shift in the political economy of health financing, one that treats malaria elimination as a domestic development investment with measurable economic returns rather than a donor-supported programme.

4. Discussion

The evidence synthesised in this review reveals a consistent and troubling pattern: the scientific evidence base for individual malaria interventions in Nigeria is generally strong, but a cascade of implementation failures, health system weaknesses, financing fragilities, and social barriers prevents that evidence from being realised in the communities that bear the greatest burden. LLINs substantially reduce malaria when used consistently, yet fewer than half of eligible users sleep under them regularly. ACTs are highly efficacious when taken by patients

who have received a confirmatory diagnosis, yet the majority of patients managed in the informal sector have not. SMC prevents malaria in eligible children when drug supply chains function and community distributors reliably reach every household, outcomes that programmatic evaluations show are far from universal. Vaccines can achieve 75% efficacy in carefully conducted trials when cold chains hold, dosing schedules are completed, and communities accept vaccination, none of which are automatic in Nigeria's current health system context. This pattern is not incidental; it reflects structural and systemic conditions that require structural and systemic solutions.

Three cross-cutting priorities emerge from this review as most consequential for Nigeria's elimination trajectory. The first is diagnostic quality, which must be understood as an elimination prerequisite rather than an optional enhancement. The work of Okereke et al. (2025a) makes clear that rapid diagnostic test inaccuracies, driven by hrp2 gene deletions, poor storage conditions, inadequate training, and low-parasitaemia detection gaps, are a central driver of irrational antimalarial use and resistance selection. Nigeria cannot achieve the rational drug use necessary for elimination without confronting this diagnostic infrastructure problem directly through investment in next-generation tests, health worker training, and quality assurance systems at every level of the care cascade.

The second priority is that the malaria vaccine rollout must be understood as a complex social and logistical programme, not merely a biological intervention. Okereke et al. (2025b) have mapped the implementation barriers comprehensively, encompassing hesitancy, cold chain limitations, workforce gaps, and dosing complexity, and their solutions framework should be adopted as an operational guide by the NMEP vaccine rollout team. The experience from Ghana, Kenya, and Malawi documented by Osuntoye et al. (2025) reinforces that sustained community engagement is the most powerful driver of vaccine acceptance and that this engagement requires years rather than months of patient, responsive dialogue grounded in community-specific concerns.

The third priority is that digital surveillance infrastructure must be recognised as a multiplier of the effectiveness of every other intervention in the portfolio. The scoping review by (Okereke et al., 2025c) demonstrates that mobile application-based platforms, when properly integrated with vector control decision-making, can substantially improve the timeliness, completeness, and programmatic utility of malaria case data. Nigeria's existing national health information system provides a foundation; what is needed is strategic investment in primary health care-level mobile reporting tools, health worker training, and data-to-decision feedback loops that enable adaptive programme management at the sub-national level.

Conclusion

Malaria elimination in Nigeria is achievable, but it requires more than just biological tools. Despite having improved LLINs, vaccines, diagnostics, and other effective measures, the country lacks the systems-level capacity to deploy these tools equitably and sustainably.

A five-pillar framework is proposed to address this gap, including vector control, case management, chemoprevention, vaccine implementation, and digital surveillance. With coordinated investment, political commitment, and community partnership, Nigeria can lead sub-Saharan Africa's transition to malaria elimination and make zero malaria a reality. The recent malaria vaccination inauguration is a milestone, but just the beginning of a long-term effort.

DECLARATIONS

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval

This is a narrative review of published literature. No primary data were collected and ethics approval was not required.

Author Contributions

All listed authors contributed to the conceptualisation, literature search, data synthesis, drafting, and critical revision of this manuscript.

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