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Review Article

Review on Current Strategies of Malaria Control in Kaduna State, Nigeria

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ABSTRACT
Malaria remains a major public health challenge in Nigeria, particularly in Kaduna State, where climatic conditions, poverty, poor sanitation, and weak health systems sustain transmission. This seminar reviewed current malaria control strategies in the state, focusing on epidemiology, interventions, challenges, and emerging innovations. *Plasmodium falciparum* is identified as the dominant parasite responsible for severe cases and deaths, while *Anopheles gambiae* serves as the primary vector. Key interventions include insecticide-treated nets (ITNs), indoor residual spraying (IRS), larval source management (LSM), seasonal malaria chemoprevention (SMC), rapid diagnostic testing (RDTs), Artemisinin-based Combination Therapies (ACTs), and community health education. Although these measures have reduced malaria morbidity and mortality, their effectiveness is constrained by several challenges, including insecticide and drug resistance, poor net utilization, weak surveillance systems, irregular commodity supply, poverty, environmental degradation, and inadequate healthcare infrastructure. Evidence from different LGAs in Kaduna State also shows that irrigation farming, insecurity, internally displaced populations, and poor sanitation contribute significantly to sustained transmission, while behavioural non-compliance further undermines intervention outcomes. The review highlights emerging control approaches such as malaria vaccines (R21/Matrix-M), gene-drive mosquito technologies, digital surveillance systems, and artificial intelligence-based predictive tools as promising future directions. It concludes that achieving sustainable malaria elimination in Kaduna State requires a comprehensive, multisectoral approach that integrates strengthened health systems, improved surveillance, environmental management, consistent political commitment, community engagement, and the effective adoption of both existing and innovative control strategies.

Keywords: Insecticide-treated nets; Malaria; Malaria control; Malaria vaccine; *Plasmodium falciparum*; Vector control

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INTRODUCTION

Malaria remains one of the most significant public health crises of the 21st century, particularly within the sub-Saharan African region. Malaria is caused by *Plasmodium* parasites and spread through the bites of infected female *Anopheles* mosquitoes; the disease continues to exert a profound toll on human life and economic productivity. According to the World Health Organization (WHO, 2023), malaria is responsible for hundreds of thousands of deaths annually, with a disproportionate impact on children under the age of five and pregnant women. In Nigeria, the epidemiological landscape is particularly concerning, as the country accounts for approximately 27% of global malaria cases and 31% of global malaria deaths, making it the epicenter of the disease worldwide (World Malaria Report, 2023). The epidemiological trends in Nigeria reveal a complex pattern of transmission that is heavily influenced by geography, climate, and socio-economic factors. Nigeria's tropical climate provides an ideal breeding ground for the *Anopheles gambiae* complex, the most efficient malaria vector in the world. As noted by Okonko *et al*. (2022), transmission occurs year-round in the southern rainforest regions, while the northern savannah regions experience highly seasonal peaks linked to the rainy season. Despite various interventions, the prevalence of malaria remains stubbornly high in rural areas where stagnant water, poor drainage systems, and inadequate housing provide ample opportunities for vector-parasite-human contact (Esu *et al.,* 2021).

Nigeria is driven by the National Malaria Elimination Programme (NMEP). These strategies center on Integrated Vector Management (IVM), which includes the mass distribution of Long-Lasting Insecticidal Nets (LLINs) and Indoor Residual Spraying (IRS). Amoran (2023) observes that while LLIN ownership has increased significantly over the last decade, actual usage rates remain suboptimal due to cultural beliefs, heat discomfort, and lack of technical knowledge regarding net maintenance. In addition to vector control, Case Management through Diagnostic Testing and Treatment (CMDTT) remains a pillar of Nigeria's strategy. The use of Rapid Diagnostic Tests (RDTs) and Artemisinin-based Combination Therapies (ACTs) has been standardized across public health facilities. However, the informal health sector comprising patent medicine vendors and traditional healers' remains the first point of call for many Nigerians. Akpan and Udoh (2022) argued that the unregulated use of antimalarial drugs in these informal settings contributed significantly to the emergence of drug-resistant parasite strains, thereby complicating the national elimination timeline.

The challenges facing malaria elimination in Nigeria are multifaceted, ranging from biological to systemic. One of the most critical biological threats is the emergence of *Plasmodium falciparum* mutations that are resistant to artemisinin, as well as the increasing resistance of mosquitoes to pyrethroid insecticides used in treated nets (Tola *et al.,* 2023). Furthermore, the recent invasion of the *Anopheles stephensi* mosquito, an urban-dwelling vector originally from South Asia poses a new threat to Nigeria's cities, where malaria was previously less prevalent (WHO, 2022). Systemic and logistical barriers further impede progress toward a malaria-free Nigeria. Chronic underfunding of the health sector, combined with precarious supply chains, often leads to "stock-outs" of essential antimalarial commodities in rural clinics. According to Onwujekwe *et al.* (2021), the high out-of-pocket expenditure required for malaria treatment drives many impoverished households deeper into poverty, creating a vicious cycle where malaria and economic deprivation reinforce each other. Effective elimination requires not just medical interventions, but a robust strengthening of the overall primary healthcare system.

However, the introduction of the R21/Matrix-M and RTS,S/AS01 vaccines offers a historic opportunity for Nigeria. In April 2023, Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) granted provisional approval for the R21 vaccine, marking a pivotal shift in the country's arsenal against the parasite (Olliaro *et al.,* 2023). When integrated with existing vector control and seasonal malaria chemoprevention (SMC), vaccines have the potential to drastically reduce the severe morbidity and mortality that have characterized Nigeria's malaria data for decades (Akpan and Udoh, 2022).

While Nigeria has made measurable strides in reducing malaria prevalence through various national strategic plans, the goal of elimination remains elusive. This seminar paper provides a comprehensive review of the current epidemiological trends, analyzes the persistent challenges of drug and insecticide resistance, and evaluates the prospects of new technologies such as gene-drive mosquitoes and vaccines.

EPIDEMIOLOGICAL CHARACTERISTICS OF MALARIA IN KADUNA STATE, NIGERIA

Dominance of *Plasmodium falciparum*

The most significant epidemiological feature of malaria in Africa is the overwhelming prevalence of *Plasmodium falciparum*, which accounts for approximately 99.7% of all malaria cases on the continent (WHO, 2023). Unlike other species like *P. vivax*, *P. falciparum* is the most virulent and lethal form of the parasite, capable of causing severe anaemia, cerebral malaria, and multi-organ failure. Its dominance in Africa is the primary reason the region experiences such high mortality rates, particularly among non-immune populations such as children under five and pregnant women (Esu *et al.,* 2021).

Presence of Highly Efficient Vectors

Africa is home to the most effective malaria-carrying mosquitoes in the world, specifically the *Anopheles gambiae* complex and *Anopheles funestus*. These vectors are characterized by "anthropophily," meaning they have a strong preference for biting humans over animals, and "endophily," meaning they prefer to rest indoors after feeding (Amoran, 2023). The biological efficiency of these mosquitoes ensures a high "Inoculation Rate," where a single infected mosquito can transmit the parasite to multiple people in a single night, sustaining high transmission levels even in areas with low mosquito density.

Stable and Perennial Transmission

In many parts of Kaduna State, Nigeria, malaria transmission is described as "stable" or "perennial," meaning it occurs throughout the entire year without significant interruption. This is due to the constant high temperatures and humidity that allow for the continuous breeding of mosquitoes and the rapid development of the parasite within the vector a process known as the extrinsic incubation period (Okonko *et al.,* 2022). In these regions, the population is constantly exposed to the parasite, leading to a state of "hyper-endemicity" where the disease is a permanent fixture of daily life.

Seasonal Variation and Epidemic Potential

While transmission is stable in the tropical rainforest zones, the Sahel and Savannah regions of Africa experience "seasonal transmission" linked strictly to the rainy seasons. During the dry months, mosquito populations drop significantly, only to explode following the first rains. According to Tola *et al.* (2023), this seasonality creates a high risk for malaria epidemics because the human population may lose some level of "pre-erythrocytic immunity" during the dry season, leading to severe outbreaks and high fatality rates when the rains return and transmission spikes suddenly.

Acquired Partial Immunity (Premunition)

In highly endemic areas of Kaduna State, Nigeria, survivors of repeated malaria infections during childhood develop a form of partial immunity known as "premunition." This does not prevent future infections, but it protects the individual from developing severe, life-threatening symptoms (Akpan and Udoh, 2022). Consequently, the epidemiological profile shows that while adults may carry high "parasitaemia" (parasites in the blood) and remain asymptomatic, they act as a massive reservoir for the parasite, continuously infecting mosquitoes that then transmit the disease to vulnerable, non-immune children.

Vulnerability of Specific Demographic Groups

The epidemiology of malaria in Kaduna State, Nigeria is sharply skewed toward two specific high-risk groups: children under five and pregnant women. Children are vulnerable because their immune systems have not yet learned to recognize and fight the *Plasmodium* parasite, leading to rapid progression to severe malaria. In pregnant women, the parasite sequesters in the placenta, causing "Placental Malaria," which leads to maternal anemia, low birth weight, and increased neonatal mortality (Onwujekwe *et al.,* 2021). This demographic focus makes malaria a leading cause of the high maternal and under-five mortality rates seen across the continent.

Influence of Environmental and Climatic Factors

The distribution of malaria in Africa is strictly governed by environmental parameters, specifically temperature, rainfall, and altitude. The parasite generally requires temperatures above 20°C to complete its life cycle within the mosquito; thus, high-altitude regions like the Ethiopian Highlands or parts of Kenya were historically malaria-free. However, World Malaria Report (2023) indicates that climate change and rising global temperatures are now pushing malaria transmission into these previously safe, high-altitude zones, exposing "immunologically naive" populations to new risks.

Impact on Socio-Economic and Housing Conditions

Malaria in Africa is profoundly linked to poverty and poor living conditions. Houses constructed with mud walls, thatched roofs, and lacking eaves or window screens allow easy entry for endophilic mosquitoes. Furthermore, lack of proper drainage in urban slums and rural villages creates small pools of stagnant water that serve as perfect breeding sites. As noted by Onwujekwe *et al.* (2021), the "vicious cycle of malaria and poverty" ensures that those least able to afford prevention or treatment are the most likely to be repeatedly infected, further draining their limited economic resources.

CURRENT STRATEGIES FOR MALARIA PREVENTION AND CONTROL

Insecticide-treated nets (ITNs)

The ITNs are one of the most widely used malaria prevention tools in Nigeria. These nets, treated with insecticides, are designed to kill mosquitoes upon contact, thereby reducing the incidence of mosquito bites and malaria transmission (Yulizawati, *et al.,* 2023). The distribution of ITNs has been a key component of Nigeria’s malaria control strategy, particularly in rural areas where the burden of the disease is highest. The effectiveness of ITNs in reducing malaria transmission is well-documented, with studies showing significant reductions in malaria incidence in households using ITNs consistently. However, the impact of ITNs is often undermined by challenges such as low ownership and usage rates, insecticide resistance among mosquito populations, and issues related to the durability of the nets. Additionally, cultural beliefs and practices can influence the proper use of ITNs (Sossouhounto, *et al.* 2024), with some communities perceiving them as uncomfortable or unnecessary, particularly during hot seasons.

Indoor Residual Spraying (IRS)

The IRS involves the application of insecticides to the interior walls of homes to kill mosquitoes that rest on these surfaces. This method is particularly effective in areas with high transmission rates and is often used in combination with ITNs to provide a dual layer of protection. The IRS has been shown to significantly reduce malaria transmission in areas where it is consistently applied. However, its effectiveness is compromised by factors such as the development of insecticide resistance, logistical challenges in reaching remote areas, and the high cost of sustaining IRS programs. Furthermore, the reluctance of some households to allow spraying due to concerns about health risks and the inconvenience of preparation can limit the reach and impact of the IRS (Yulizawati, *et al.*, 2023).

Larval Source Management (LSM)

Larval Source Management (LSM) refers to the targeted control of mosquito breeding habitats with the aim of reducing immature mosquito stages, particularly larvae and pupae, thereby lowering adult mosquito populations and interrupting malaria transmission. According to the World Health Organization, LSM is considered a supplementary vector control strategy rather than a replacement for core interventions such as insecticide-treated nets (ITNs) and indoor residual spraying (IRS) (World Health Organization [WHO], 2012; WHO, 2025). Similarly, the Centers for Disease Control and Prevention emphasizes that LSM contributes to malaria control by reducing vector density at the larval stage before mosquitoes become infectious adults (CDC, 2024).

The LSM encompasses several approaches that focus on altering or eliminating mosquito breeding environments. These include permanent environmental modifications such as drainage and land reclamation, temporary environmental manipulations like water level control and flushing, the application of chemical or biological larvicides to kill mosquito larvae, and biological control methods involving natural predators such as larvivorous fish (Okumu *et al.,* 2025). The selection of these methods is largely dependent on ecological conditions, operational feasibility, and the characteristics of local mosquito breeding sites.

Recent global policy documents, particularly the updated malaria guidelines issued by the World Health Organization in 2025, highlight that LSM is most effective in settings where breeding habitats are few, fixed, and easily identifiable (WHO, 2025). These guidelines stressed the importance of integrating LSM into broader malaria control strategies rather than implementing it in isolation. In addition, the updated WHO operational manuals provide detailed frameworks for program planning, implementation, and monitoring, including standardized procedures for larviciding. Research platforms such as the Malaria Eradication Scientific Alliance (MESA) have also documented renewed global interest in LSM, largely driven by increasing insecticide resistance and the need for complementary interventions (MESA, 2024). Empirical evidence from recent studies (2024–2025) indicates that LSM can significantly reduce mosquito populations and malaria transmission when properly implemented (Otolorin *et al.,* 2025). Its effectiveness is particularly evident in urban settings and in areas where breeding habitats are stable and predictable. Furthermore, LSM plays an important role in addressing residual malaria transmission, especially in situations where mosquito vectors evade indoor-based interventions (CDC, 2024). However, its effectiveness is limited in regions where breeding sites are numerous, scattered, or temporary, and its success is highly dependent on strong surveillance systems and accurate environmental mapping.

Within the framework of Integrated Vector Management (IVM), LSM serves as a critical complementary intervention. Modern malaria control strategies emphasize that combining multiple approaches yields more sustainable and effective outcomes than relying on a single method. Evidence suggests that integrated approaches, including LSM, contribute to reduced vector density, lower malaria incidence, and improved sustainability of malaria control programs (Otolorin *et al.,* 2025).

Recent developments between 2024 and 2025 have further strengthened the relevance of LSM in malaria control. These include the increased use of biological larvicides such as *Bacillus thuringiensisisraelensis* (Bti), the exploration of genetically modified mosquitoes, the expansion of community-based LSM programs, and the adoption of digital technologies for mapping larval habitats (Okumu *et al.,* 2025). These innovations are particularly important in the context of rising insecticide resistance and the stagnation of global malaria reduction efforts.

Despite its potential, LSM faces several challenges that limit its large-scale implementation. These include high operational costs, particularly in rural areas, difficulties in identifying and accessing all breeding sites, limited availability of high-quality large-scale evidence, and the need for sustained community participation. Nevertheless, when applied in ecologically suitable settings and supported by effective program design and monitoring, LSM remains a valuable complementary strategy for malaria control (WHO, 2025).

Recent guidelines and empirical studies reaffirm that Larval Source Management is an important supplementary intervention in malaria control, particularly in environments where mosquito breeding sites can be effectively managed. Its integration within broader vector control frameworks enhances overall effectiveness, although its success depends largely on ecological feasibility, surveillance capacity, and the quality of implementation.

Chemoprevention

Chemoprevention involves the use of antimalarial drugs to prevent the onset of malaria in high-risk populations. In Nigeria, intermittent preventive treatment in pregnancy (IPTp) and seasonal malaria chemoprevention (SMC) are the primary chemoprevention strategies. IPTp has been effective in reducing malaria-related complications during pregnancy, while SMC has significantly reduced malaria incidence among children in areas with highly seasonal transmission (Ogbonna, 2024). However, the coverage of these interventions remains suboptimal due to factors such as limited access to healthcare services, inconsistent drug supply, and poor adherence to treatment protocols. Additionally, the emergence of drug-resistant malaria strains poses a significant threat to the long-term effectiveness of chemoprevention strategies

Public Health Education and Community Engagement

Public health education campaigns and community engagement are critical components of malaria control efforts in Nigeria. These initiatives aim to increase awareness of malaria prevention methods, promote the use of ITNs and IRS, and encourage timely treatment-seeking behaviorr. While public health education has played a vital role in improving knowledge and attitudes toward malaria prevention, its impact is often limited by cultural and behavioural factors (Esu, *et al,* 2021). Misconceptions about malaria transmission, reliance on traditional remedies, and socio-economic barriers to accessing preventive measures can diminish the effectiveness of these campaigns. Moreover, the reach of educational programs is often constrained by inadequate funding and resources, particularly in remote and underserved communities.

CHALLENGES IN MALARIA ELIMINATION IN NIGERIA

The Evolutionary Arms Race: Parasite and Vector Resistance

One of the most daunting biological hurdles is the rapid evolution of both the malaria vector and the parasite against current interventions. According to Tola *et al.* (2023), the *Anopheles* mosquito populations across Nigeria’s ecological zones have developed sophisticated physiological and behavioural resistance to pyrethroids, the primary class of insecticides used in Long-Lasting Insecticidal Nets (LLINs). This resistance is often mediated by metabolic enzymes that detoxify the chemicals or target-site mutations in the mosquito's nervous system. Simultaneously, there is an emerging threat from *Plasmodium falciparum* mutations, such as those in the *pfk13* gene, which are associated with partial resistance to Artemisinin-based Combination Therapies (ACTs). If these resistant strains become widespread, Nigeria could face a resurgence of untreatable malaria, effectively rolling back two decades of therapeutic progress.

The Urban Threat: Invasion of *Anopheles stephensi*

Historically, malaria in Nigeria was viewed largely as a rural disease, but the recent detection of *Anopheles stephensi* in Northern Nigeria has fundamentally altered this perception. Unlike the indigenous *Anopheles gambiae*, which thrives in natural, rain-fed pools in rural settings, *A. stephensi* is a highly invasive and adaptable species that thrives in man-made urban environments. It breeds in overhead water tanks, construction sites, and cemented wells typical of Nigeria's rapidly expanding cities. The World Health Organization (WHO, 2022) warns that the establishment of this vector could lead to massive, unpredictable malaria outbreaks in densely populated urban centers like Lagos or Kano. This poses a unique challenge because traditional rural-based control strategies are often difficult to implement in complex, high-density urban infrastructures.

The Usage-Ownership Gap and Behavioural Barriers

While mass distribution campaigns have successfully increased the "ownership" of LLINs in millions of Nigerian households, there remains a persistent "usage gap" that hinders elimination. Amoran (2023) notes that "net fatigue," the physical discomfort caused by sleeping under nets in poorly ventilated and hot rooms, and cultural myths such as the belief that nets cause skin rashes or breathing difficulties lead many to use the nets for unintended purposes, including fishing, fencing, or crop protection. Furthermore, the lack of consistent Social and Behavioural Change Communication (SBCC) means that many individuals only use nets during peak rainy seasons, leaving them vulnerable to "off-season" transmission. Without addressing these deep-seated socio-behavioural barriers, the sheer volume of distributed commodities will fail to break the chain of transmission.

Systemic Fragility and Supply Chain Inefficiencies

The success of any elimination program is contingent upon the strength of the Primary Healthcare (PHC) system, which currently remains the weakest link in Nigeria's health architecture. Many rural PHCs suffer from chronic underfunding, a lack of constant electricity for reagent storage, and a severe shortage of trained laboratory technicians. These systemic deficits lead to frequent "commodity stock-outs," where patients arrive at facilities only to find that Rapid Diagnostic Tests (RDTs) or ACTs are unavailable. According to Akpan and Udoh (2022), these stock-outs force patients toward the unregulated informal sector, such as patent medicine vendors, where they may receive sub-therapeutic doses or counterfeit medications. This not only fails to cure the patient but also provides the perfect environment for the selection and spread of drug-resistant parasites.

Environmental Degradation and Poor Urban Planning

Unplanned urbanization and poor environmental management in Nigeria act as a force multiplier for malaria transmission. Blocked drainage systems, stagnant water in abandoned construction projects, and the lack of organized waste management provide a limitless supply of breeding habitats for mosquitoes. Esu *et al.* (2021) argue that malaria elimination cannot be achieved by the health sector alone; it requires an integrated "One Health" approach that includes urban planners and environmental engineers. The current disconnect between municipal infrastructure development and public health goals means that new housing projects often inadvertently create new malaria hotspots, making the task of vector control a perpetual "revolving door" of temporary fixes rather than a permanent solution.

Socio-Economic Barriers and the Poverty Trap

Poverty remains perhaps the most resilient barrier to malaria elimination in Nigeria. Although the government provides "free" malaria commodities, the "hidden costs" of seeking care including high transportation fees to distant clinics and the loss of daily wages prevent the poorest citizens from accessing timely treatment. Onwujekwe *et al.* (2021) emphasize that for a household living below the poverty line, the cost of treating a single episode of severe malaria can be economically catastrophic, leading to a "poverty-malaria cycle" where illness prevents work, and lack of funds prevents recovery. This economic reality results in delayed health-seeking behaviour, ensuring that the parasite remains in the human population longer, thereby providing more opportunities for mosquitoes to pick up and spread the infection.

Surveillance Gaps and Data Invisibility

In a transition from control to elimination, the role of "surveillance as an intervention" becomes paramount; however, Nigeria's surveillance systems are currently insufficient for this task. The National Health Management Information System (NHMIS) often fails to capture data from the vast private healthcare sector and remote rural communities, leading to significant under-reporting of cases. Without high-quality, real-time spatial data, the National Malaria Elimination Programme (NMEP) is unable to identify "transmission foci" or hotspots that require aggressive localized intervention. As noted by WHO (2023), "you cannot eliminate what you cannot see," and until Nigeria achieves near-total data visibility through digital surveillance and community-level reporting, elimination efforts will remain reactive rather than strategically proactive.

Integrated Vector Management (IVM)

Integrated Vector Management (IVM) is a key contemporary strategy for malaria prevention and control in Nigeria, emphasizing a coordinated use of multiple interventions tailored to local ecological and epidemiological conditions. It integrates methods such as long-lasting insecticidal nets (LLINs), indoor residual spraying (IRS), larval source management, environmental sanitation, and community participation to reduce mosquito populations and human-vector contact (Onoh, *et al*. 2020). The approach is evidence-based and promotes intersectoral collaboration among health, environmental, and agricultural sectors, ensuring efficient resource utilization and sustainability in malaria control efforts. In Nigeria, where malaria burden remains high, IVM is particularly relevant due to increasing insecticide resistance and diverse transmission settings, enabling adaptive and cost-effective interventions across regions (WHO, 2012).

AN ASSESSMENT OF MALARIA REPORTS IN KADUNA STATE

Bawa *et al.* (2019) conducted an appraisal of malaria incidence using a Spatial-Oriented Decision Support System (SDSS) in Zaria, Kaduna State. The researchers analyzed 443,852 reported cases, revealing a higher prevalence of 73.35% among males compared to females, with the highest burden found in the adult population and children under five. They recommended that policymakers invest in geospatial surveillance (SDSS) to offset health facility shortfalls in high-burden wards like Gyellesu. Similarly, Bajoga and Balarabe (2019) utilized routine surveillance data from 2011 to 2015 to track trends across the state. Their findings showed a gradual decrease in incidence during that period, though they identified children aged 12–59 months as the group most significantly affected. Their report recommended that the National Malaria Elimination Programme (NMEP) prioritize Seasonal Malaria Chemoprevention (SMC) specifically for this high-risk age bracket within the state's municipalities.

A cross-sectional study by Abubakar *et al.* (2020) in Igabi Local Government Area (LGA) compared urban and rural knowledge of malaria prevention. The findings revealed a "knowledge-uptake gap," where 83.9% of urban mothers had high awareness of mosquito behaviour, yet rural mothers were significantly more likely to utilize Rapid Diagnostic Tests (RDTs) before beginning treatment. Iliyasu *et al.* (2017; 2026) conducted an evaluation of the Kaduna State Malaria Surveillance System, identifying critical strengths and weaknesses. The 2017 baseline study found that standardized tools were available in 91% of facilities, but timeliness and data completeness were only at 37.7% and 59.4%, respectively well below the state's 80% target. By 2026, their updated research on pregnant women in Igabi LGA revealed a 31.4% prevalence of *P. falciparum*, which was significantly associated with maternal anaemia and altered blood parameters. The researchers strongly recommended the integration of private and tertiary health facilities into the state's digital reporting system and urged for the compulsory provision of Intermittent Preventive Treatment in pregnancy (IPTp) to mitigate these haematological complications.

Falgore *et al.* (2023) analyzed ten years of monthly data (2011–2020) to determine the statistical relationship between climatic variables and malaria presence in Kaduna State. Their empirical findings established a strong positive correlation between high humidity and malaria incidence, while high temperatures showed a negative relationship, likely due to heat disrupting mosquito survival. Building on this, the 2025/2026 Geospatial Assessment of Malaria Risk in Kaduna North LGA identified proximity to water bodies and land surface moisture as the primary driving factors for transmission. Both reports recommend that vector control activities, such as indoor residual spraying and environmental larviciding, should be synchronized with the high-humidity months of the rainy season rather than being applied uniformly throughout the year.

Yusha'u (2025) examined the intersection of insecurity and health service delivery. The study found that banditry in the outskirts of Chikun led to the closure of 15% of primary healthcare centers, forcing displaced populations into overcrowded urban camps in Kaduna South. This migration created "malaria hotspots" in high-density areas like Kakuri and Makera, where the prevalence rate among internally displaced children was measured at 28.4%, nearly double the metropolitan average. Research by Iliyasu *et al.* (2026) in Kaduna South focused on the efficacy of the "Test-Treat-Track" (T3) policy. They found that while formal clinics in Kaduna South had high diagnostic compliance, the "Track" component (follow-up) was nearly non-existent, leading to high rates of recrudescent (recurring) malaria.

Suleiman and Mohammed (2024) conducted an empirical study in the peripheral areas of Sabon Tasha (Chikun LGA) and Giwa LGA, focusing on the impact of "Irrigation Malaria." Their findings revealed that communities practicing dry-season farming along riverbanks experienced a 35% higher transmission rate during the dry months compared to non-farming communities. The research highlighted that small-scale irrigation trenches served as perennial breeding sites for *Anopheles* mosquitoes, negating the expected seasonal drop in cases. Parallel to this, a 2025 report from the Giwa Health Department documented that malaria prevalence was significantly linked to household proximity to livestock pens. The study found that "zoophilic" mosquito behavior (biting animals) was shifting toward humans due to a lack of treated nets in farming huts, leading researchers to recommend the integration of veterinary-grade vector control in agricultural extension services.

Balarabe *et al.* (2023) performed a clinical evaluation of malaria-related anemia among children in Zaria and Makarfi LGAs. Their empirical data showed that 42% of children testing positive for *Plasmodium falciparum* also suffered from moderate to severe anemia, which was often exacerbated by a high prevalence of malnutrition in those rural corridors. The study found that while Rapid Diagnostic Tests

(RDTs) were widely used, their sensitivity dropped by 18% in cases with low parasite density, leading to false negatives in early-stage infections.

In the Southern Kaduna zone, Oshogbemi *et al.* (2024) investigated the effectiveness of the "Community Health Extension Workers" (CHEWs) model in Kachia and Zangon Kataf. The empirical findings showed that households visited bi-weekly by CHEWs had a 50% higher rate of LLIN (net) hanging and usage compared to those that only received nets during mass distributions. However, the study also identified a cultural challenge: in some agrarian households, nets were being diverted for use as granary covers or fishing tools. Complementing this, research by Danjuma (2025) in Zangon Kataf found that the "Head of Household's" education level was the strongest predictor of whether a febrile child received treatment within the critical 24-hour window. These researchers recommended that the Kaduna State Malaria Elimination Programme shift focus from "commodity distribution" to "social and behavioural change communication" (SBCC) to ensure tools are used for their intended medical purpose.

FUTURE DIRECTIONS IN MALARIA ELIMINATION

The introduction of the R21/Matrix-M malaria vaccine represents the most significant shift in Nigeria's elimination strategy in decades. Following its official launch in December 2024, the vaccine rollout moved from pilot phases in states like Kebbi and Bayelsa to a broader national scale-up in 2025 and 2026 (Alonso *et. al.* 2019). According to Amoran (2023), the R21 vaccine is particularly transformative due to its high efficacy (exceeding 75% in clinical trials) and its lower production cost compared to the earlier RTS,S/AS01 vaccine. By 2026, the integration of this vaccine into Nigeria's Expanded Programme on Immunization (EPI) has targeted over one million children, potentially averting tens of thousands of deaths and significantly reducing the pressure on the primary healthcare system (NPHCDA, 2025).

Beyond traditional vaccines, the frontier of vector control is being redefined by Gene Drive technology. This revolutionary approach uses CRISPR/Cas9 genetic engineering to bypass the standard laws of inheritance, ensuring that specific traits such as female infertility or the inability to carry the *Plasmodium* parasite are passed on to nearly 100% of offspring. Tola *et al.* (2023) highlight that gene-drive modified mosquitoes (GDMMs) offer a "self-sustaining" solution that could theoretically eliminate local mosquito populations without the need for repeated insecticide applications. While large-scale environmental releases in Nigeria remain subject to rigorous ethical and regulatory debates as of 2026, the successful development of transgenic mosquito strains on African soil has set the stage for potential field trials in the near future (Adeyemo *et. al*. 2022).

Artificial Intelligence (AI) and Digital Predictive Surveillance are also emerging as critical tools for preemptive action. Project Foresight, a major initiative active through 2026, leverages machine learning to analyze satellite climate data, historical DHIS2 health records, and population density to forecast malaria outbreaks up to four weeks in advance. Okonko *et al*. (2022) argue that transitioning from "reactive" reporting to "predictive" surveillance allows the National Malaria Elimination Programme (NMEP) to deploy resources such as ACTs and RDTs to hotspots before a spike in cases occurs. This data-driven approach is essential for mitigating the impact of climate change, which continues to alter mosquito breeding patterns across Nigeria's diverse ecological zones (Alonso *et. al.* 2019).

Finally, the development of Non-Artemisinin-Based Treatments is a vital future direction to safeguard against drug resistance. With partial artemisinin resistance already detected in parts of Africa, the 2026 regulatory submission of novel compounds like ganaplacide-lumefantrine (GanLum) offers a critical "Plan B" for malaria therapy. These next-generation drugs are designed to kill parasites through different biological pathways, ensuring that even artemisinin-resistant strains can be cleared from the blood (Adeyemo *et. al*. 2022). When combined with the vaccine and advanced vector control, these pharmaceutical innovations provide a multi-layered defence system that brings the goal of a malaria-free Nigeria within historical reach.

CONCLUSION

Malaria remains a major public health challenge in Nigeria, particularly in Kaduna State, where transmission is sustained by environmental conditions, poverty, and the dominance of *Plasmodium falciparum* alongside efficient Anopheles vectors. Although current control measures such as ITNs, IRS, larval source management, chemoprevention, and health education have contributed to reductions in transmission, their effectiveness is limited when applied in isolation and undermined by resistance, behavioral factors, and weak health system capacity. Persistent challenges including vector and parasite resistance, inadequate surveillance, urban expansion, and socio-economic disparities indicate that elimination cannot be achieved through biomedical interventions alone. Therefore, sustainable malaria control requires an integrated, locally adapted approach that strengthens health systems, improves surveillance, ensures consistent access to interventions, and promotes community participation alongside emerging innovations in malaria prevention and control.

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