Review article

Climate–Mosquito Mismatch: Why Changing Rainfall Cycles Are Rewriting Nigeria's Malaria Transmission Patterns

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ABSTRACT

Climate variability is increasingly disrupting rainfall seasonality across Nigeria, reshaping the ecological conditions that govern mosquito breeding and malaria transmission. This commentary synthesizes recent climatic modelling, entomological observations, and national surveillance data to examine how shifts in rainfall onset, intensity, and duration are generating a climate–mosquito mismatch. Altered precipitation patterns now produce earlier or delayed vector peaks, expanded breeding windows, and transmission surges outside traditional rainy seasons. These ecological disruptions undermine malaria prediction accuracy and reduce the timeliness of vector control interventions. By highlighting this emerging desynchronization between climate and vector ecology, the paper underscores the urgent need for climate-informed malaria surveillance, adaptive intervention scheduling, and stronger multisector collaboration to sustain Nigeria's malaria control gains under a changing climate.

Keywords: *Malaria, Climate Change, Rainfall Variability, Mosquito Ecology, Anopheles, Nigeria.*

1. Introduction

Nigeria bears the world's heaviest malaria burden, accounting for approximately 27% of global cases and remaining the epicenter of transmission in sub-Saharan Africa[1]. Malaria transmission in the country is profoundly influenced by climatic conditions, particularly rainfall, temperature, and humidity, which shape the breeding ecology and survival of Anopheles mosquitoes[7,9]. Traditionally, predictable rainfall cycles guided the timing of vector control interventions and surveillance activities. However, in recent years, Nigeria has witnessed destabilized rainfall seasonality characterized by erratic onset, prolonged dry spells, and short, intense precipitation bursts[2,3,8]. These climatic shifts are increasingly disrupting the synchronization between rainfall patterns and mosquito population dynamics, generating a "climate–mosquito mismatch" that undermines existing malaria control calendars. This commentary examines how altered rainfall cycles reshape malaria transmission patterns in Nigeria and argues that recognizing and addressing such mismatches is vital for improving epidemiological forecasting and sustaining control efforts[4].

2. Climate–Mosquito Mismatch: Mechanisms and Implications

2.1 Altered Rainfall Patterns in Nigeria

Nigeria's rainfall regime is becoming increasingly erratic, reshaping the ecological timing of mosquito breeding. Across the Sahelian, Sudan, and Guinea savanna zones, studies report earlier or delayed rainfall onset disrupting the synchronization between rainfall and Anopheles reproductive cycles[3,5]. Earlier rains trigger premature formation of larval habitats before peak vector control activities commence, while delayed rains compress transmission into shorter but more intense windows. These irregularities weaken the predictability that once guided malaria preparedness across ecological regions. In parallel, intensified short-burst rainfall events now dominate many states, causing flash floods that temporarily inundate urban and peri-urban landscapes. These transient pools provide highly productive breeding sites for Anopheles gambiae and related species, enabling rapid larval development and enhanced vector proliferation[10,11]. Conversely, prolonged intra-seasonal dry spells, increasingly common during wet months, destroy immature stages and delay vector population peaks, generating asynchronous fluctuations that distort traditional seasonal malaria calendars[12].

2.2 Ecological Disruption in Anopheles Vector Dynamics

These hydrological perturbations have profound ecological consequences. Erratic rainfall patterns destabilize conventional breeding habitats—such as puddles, rice paddies, and drainage ditches— while encouraging the emergence of novel larval niches in degraded or semi-urban environments[6]. Vector monitoring over the last decade has revealed bimodal or even double seasonal peaks of mosquito abundance in several Nigerian states, reflecting rainfall fragmentation and extended habitat persistence[6,10]. This shift undermines long-held assumptions of a single annual transmission peak and produces off-season malaria surges that challenge control logistics. Moreover, climate- induced ecological stress is altering species composition within local Anopheles complexes. A gradual rise in the prevalence of drought-tolerant Anopheles arabiensis has been documented in the northern and middle belt zones, replacing or coexisting with A. gambiae s.s., thereby modifying biting behavior, vector competence, and indoor resting habits[8]. These compositional changes further complicate intervention effectiveness, as species differ in their response to long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS).

2.3 Epidemiological Implications for Malaria Transmission

The ecological desynchronization between rainfall and vector dynamics is producing increasingly unpredictable malaria transmission patterns across Nigeria. Conventional prediction models, reliant on linear rainfall–infection relationships, now underperform in anticipating epidemic timing[12]. Outbreaks are emerging before scheduled LLIN or IRS cycles, leaving populations exposed during periods previously considered low-risk. In the semi-arid northern states, rainfall variability is extending malaria transmission well beyond the typical June–October window, eroding the natural dry-season protection that historically constrained transmission[9]. These climatic disruptions disproportionately burden vulnerable populations—particularly pregnant women and children under five—who face heightened exposure in communities lacking adaptive early-warning systems[11]. The combination of expanding transmission periods and weakened intervention synchrony portends a future of more frequent and geographically diffuse malaria outbreaks if climate variability remains unaddressed[1].

2.4 Consequences for Public Health Preparedness and Malaria Control

This climate–mosquito mismatch carries direct implications for national malaria preparedness. Control interventions in Nigeria—such as LLIN mass campaigns, IRS operations, and larval source management—are still scheduled according to historical rainfall assumptions[4]. When actual vector peaks deviate from these cycles, operational efficiency declines, and the protective value of interventions wanes. Surveillance systems like the National Malaria Indicator Survey (NMIS) and the District Health Information System (DHIS2) remain largely reactive, depending on case notifications rather than predictive climate–vector analytics[9]. Furthermore, coordination between meteorological agencies, public health institutions, and ecological researchers remains fragmented[4,5]. This institutional siloing limits Nigeria's capacity for anticipatory climate-informed responses, resulting in recurrent misalignment between environmental signals and public health actions.

2.5 Opportunities for Climate-Smart Malaria Control

Addressing these challenges demands a paradigm shift toward climate-smart malaria control. Integrating real-time meteorological and satellite-derived rainfall data into surveillance platforms can generate predictive maps of mosquito emergence and malaria risk[3,7]. Such systems would allow health authorities to preempt transmission peaks and allocate resources dynamically. Flexible, rapid-response strategies—such as adaptive IRS scheduling or community-based larval management—should replace rigid, calendar-driven interventions[4]. Strengthening One Health collaboration through joint meteorology–entomology–public health task forces would facilitate data sharing and early outbreak detection[2]. Finally, improving climate literacy among frontline health workers through tailored training can enhance responsiveness to evolving ecological cues[7]. Embedding these adaptive, cross-sectoral mechanisms will be essential to mitigate the destabilizing effects of climate variability and sustain Nigeria's progress toward malaria elimination.

3. Conclusion

Rainfall variability is fundamentally altering mosquito breeding rhythms and malaria transmission patterns across Nigeria. The emerging climate–mosquito mismatch is eroding the precision of predictive models and diminishing the effectiveness of established control interventions. Safeguarding vulnerable populations now requires a transition toward climate-informed malaria surveillance systems, adaptable vector control strategies, and cohesive collaboration between health, meteorological, and environmental sectors. As climate change accelerates, proactive recognition and management of these ecological mismatches swill be crucial to sustaining national malaria control achievements and preventing resurgence in an increasingly unpredictable climatic era.

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