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REVIEW ARTICLE

Beyond nets and sprays: transformative strategies for malaria resilience in Sub-Saharan Africa

Além de redes e sprays: estratégias transformadoras para a resiliência contra a malária na África Subsaariana

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Abstract

Objective: This narrative review assesses the effectiveness of malaria interventions in Sub-Saharan Africa in alignment with the World Health Organization's (WHO) Global Technical Strategy for Malaria 2016–2030. **Methods:** Literature searches utilized WHO malaria reports from 2015 to 2023, along with published articles from databases including Springer, Hindawi, PubMed, Google Scholar, BioMed, and Elsevier. **Results**: The review highlights that interventions such as habitat modification and house improvements are effective, particularly in addressing human-related factors in mosquito breeding. However, challenges persist in epidemic preparedness, diagnostic methods, and malaria research, all of which are crucial for effective management. Weak healthcare systems, limited funding, and insufficient surveillance capabilities further undermine malaria control strategies in Sub-Saharan Africa. The importance of research and innovation especially from scientists within malaria-affected regions is emphasized as vital to achieving malaria elimination. Coordinated efforts, alongside substantial investments in basic science and implementation research, are also essential. Despite these obstacles, recent success in malaria elimination in China illustrates the feasibility of control and eradication through well-coordinated initiatives. **Conclusion**: modifying houses is one of the simplest and most eco-friendly strategies to control indoor malaria transmission. However, achieving sustainable progress in malaria control across Sub-Saharan Africa demands a comprehensive, collaborative, and adaptive approach. This review highlights the need for diverse and innovative strategies to meet the goals set forth by the WHO Global Technical Strategy.

Keywords: malaria control strategies; global technical strategy; Sub-Saharan Africa; house modifications; epidemic preparedness.

Resumo

Objetivo: esta revisão narrativa avalia a eficácia das intervenções contra a malária na África Subsaariana em conformidade com a Estratégia Técnica Global para a Malária da Organização Mundial da Saúde (OMS) para o período de 2016 a 2030. **Métodos**: foram realizadas pesquisas bibliográficas utilizando relatórios de malária da OMS publicados entre os anos de 2015 a 2023, juntamente com artigos publicados em bases de dados como Springer, Hindawi, PubMed, Google Scholar, BioMed e Elsevier. **Resultados:** essa revisão destaca que intervenções como modificação de habitat e melhorias em habitações são eficazes, especialmente ao lidar com fatores humanos no ciclo reprodutivo dos mosquitos. No entanto, persistem desafios na preparação para epidemias, nos métodos de diagnóstico e na pesquisa sobre a malária, todos cruciais para uma gestão eficaz. Sistemas de saúde fracos, financiamento limitado e capacidades insuficientes de vigilância continuam a comprometer as estratégias de controle da malária na África Subsaariana. Enfatiza-se a importância da pesquisa e da inovação, especialmente dos cientistas nas regiões afetadas pela malária, como essenciais para alcançar a eliminação da malária. Esforços coordenados, juntamente com investimentos substanciais em ciência básica e pesquisa de implementação, também são essenciais. Apesar desses obstáculos, o recente sucesso na eliminação da malária na China ilustra a viabilidade do controle por meio de iniciativas bem coordenadas. **Conclusão:** alcançar progresso sustentável no controle da malária na África Subsaariana exige uma abordagem abrangente, colaborativa e adaptativa. Esta revisão destaca a importância de estratégias multifacetadas e inovadoras para atingir as metas da Estratégia Técnica Global da OMS.

Palavras-Chave: estratégias de controle da malária; estratégia técnica global; África Subsaariana; melhorias em habitações; preparação para epidemias.

BACKGROUND

Adherence to malaria control strategies is paramount in mitigating the risks, morbidity, and mortality associated with malaria. The global technical strategy for malaria 2016–2030 serves as a comprehensive framework, guiding countries to accelerate progress towards reducing malaria incidences and mortality rates by at least 90% by 2030[1]. Although the targets remain consistent, strategies for tackling the disease have evolved in response to the changing malaria landscape in certain regions[2] . In Sub-Saharan Africa (SSA), malaria prevalence has steadily declined due to intensive interventions like indoor residual spraying (IRS), Long-lasting Insecticidal Nets (LLINs), malaria rapid diagnostic tests (mRDTs), and the judicious use of anti-malarial drugs[3,4].

The implementation of IRS has notably reduced the population of the malaria vectors *Anopheles gambiae s.s*[5]. Furthermore, the combination of IRS + LLIN has proven effective in diminishing the densities and human biting rates of An. *Arabiensis*[6,7]. Despite

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these successes, malaria vectors have developed resistance to insecticides[8] and expanded into areas previously devoid of these arthropods[9], necessitating diversified strategies tailored to assorted malaria landscapes.

In the highlands of western Kenya, *An. gambiae s.s* and *An. funestus* were traditionally dominant vector species[10]. However, recent shifts in vector population composition, particularly the decline in *An. gambiae s.s* populations have led to a surge in the population of *An. arabiensis* to approximately 33% [11,12]. These changes in species composition and population coincide with behavioral shifts, including species-specific circadian rhythms of feeding[13]. Species once known for nocturnal and indoor feeding now exhibit indoor and outdoor feeding patterns during the night and late evening, effectively transmitting malaria[14].

The colonization and adaptation of malaria vectors in SSA areas previously deemed unfavorable for their survival have intensified due to the rapid growth of the human population[15]. Changes in land cover patterns resulting from agricultural activities have created favorable habitats for malaria vectors[16–18].

While insecticide resistance and changes in land-use patterns pose challenges to malaria vector control, insecticide-treated nets (ITNs) and IRS remain central to indoor malaria control. However, the efficacy of indoor interventions may be compromised if the focus on malaria control through insecticides primarily targets households. According to the World Health Organization's report[19], malaria causes illness in approximately 200 million people and results in nearly half a million deaths each year. Over 90% of these fatalities occur in Sub-Saharan Africa, with children under five years old being the most vulnerable. Since young children are typically indoors at night when most malaria transmissions happen, this age group is disproportionately affected. Therefore, optimizing vector control tools to target indoor and outdoor-biting mosquitoes at the adult or immature stages is essential to complement ITNs and IRS. This review provides a narrative account of the use of strategies in the ongoing efforts to combat malaria in SSA, specifically house modification and malaria epidemic preparedness.

The aspiration of the World Health Organization (WHO) and the global malaria community is to envision a world completely free from the scourge of malaria[1]. To materialize this vision, the World Health Organization formulated the Global Technical Strategy for Malaria 2016-2030. This strategy is designed to aid nations in mitigating the human suffering inflicted by the deadliest mosquito-borne disease worldwide. The strategy's objectives, markers of progress, and benchmarks are defined as follows: (i) To globally reduce malaria mortality rates by a minimum of 40% in 2020 compared to the figures in 2015, followed by reaching 75% by 2025 and eventually achieving at least a 90% reduction by 2030; (ii) To globally lower malaria case incidence by at least 40% in 2020 in contrast to the statistics of 2015, followed by a 75% reduction by 2025, and ultimately achieving a minimum of 90% reduction by 2030; (iii) To eliminate malaria transmission in countries where the disease was prevalent in 2015, aiming for at least ten (10) countries by 2020, expanding to a minimum of 20 countries by 2025, and targeting a presence in at least 35 countries by 2030; (iv) To safeguard against the resurgence of malaria in all malaria-free countries by implementing robust preventive measures.

These objectives collectively represent the commitment of the global community to create a future free from the grip of malaria. The strategy's meticulously outlined goals and targets serve as guideposts in the ongoing fight against this relentless disease.

To expedite the journey towards elimination, a strategic framework has been developed to empower vulnerable communities, amplifying the effectiveness of existing life-saving measures and approaches. This strategy is anchored in three foundational pillars, bolstered by two complementary elements, collectively directing worldwide endeavors toward the ultimate goal of malaria elimination. These pillars are:

i) Ensuring Universal Access that focuses on achieving widespread malaria prevention, diagnosis, and treatment availability. It is paramount to make these essential tools and interventions accessible to all who need them. It is a cornerstone in the battle against malaria; ii) Accelerating Elimination Efforts, which revolves around intensifying initiatives that hasten progress towards elimination and the achievement of malaria-free status. It necessitates unrelenting dedication to proactive strategies that curtail the spread of the disease and push boundaries in the pursuit of a malaria-free world; iii) Transforming Surveillance, which seeks to elevate malaria surveillance to the status of a core intervention. By strengthening surveillance systems and their efficiency, early detection and prompt response become possible, critically aiding the overall endeavor to eliminate malaria.

Ensuring universal access to malaria prevention involves strategic approaches, two of which are crucial for effective control: house modifications and epidemic preparedness. This paper documents innovative strategies in malaria vector control in sub-Saharan Africa, aligning with the global technical strategy for malaria 2016–2030.

House modifications: a long-term solution

Implementing house modification strategies holds significant potential in malaria control, especially in endemic regions. These strategies create physical barriers, such as window screens and door sweeps, reducing mosquito-human contact and disease transmission[14]. This approach offers a long-term solution, providing ongoing protection with minimal maintenance. House modifications empower communities, involving them directly in malaria control efforts and complementing other interventions like bed nets and indoor spraying.

Despite the potential impact, challenges related to cost,

maintenance, cultural acceptance, and equity must be addressed for successful implementation. When integrated comprehensively with other interventions, house modifications become a vital tool in the fight against malaria.

Epidemic preparedness: a proactive approach

As of 2023, the World Health Organization (WHO) launched an initiative targeting *Anopheles stephensi.* Malaria cases and fatalities remain concentrated in the WHO African Region, predominantly affecting young children (under 5). Disease pandemics such as COVID-19 exacerbate the challenges faced in malaria control.

Epidemic preparedness is crucial for anticipating, planning, and responding to potential outbreaks. This proactive approach involves:

i. Surveillance and Early Warning: utilizing robust surveillance systems to detect unusual increases in malaria cases, triggering rapid responses.
ii. Risk Assessment: evaluating factors contributing to outbreaks, including population movement, climate changes, and vector behavior.
iii. Mobilizing Resources: allocating resources in advance to regions prone to outbreaks, ensuring swift response measures.
iv. Rapid Response Plans: developing detailed plans covering case management, vector control, community engagement, and communication strategies.
v. Community Engagement: involving local communities in outbreak response, fostering awareness and cooperation.
vi. Vector Control: employing interventions like indoor spraying and bed net distribution to rapidly reduce mosquito populations.
vii. Case Management and Healthcare Strengthening: training healthcare workers and reinforcing health systems for efficient response during outbreaks.
viii. Data Analysis and Learning: conducting post-outbreak analysis to refine future preparedness plans.

In essence, epidemic preparedness is a holistic, proactive approach that enhances overall malaria control efforts, preventing epidemics from escalating. This strategy acknowledges the multi-faceted nature of malaria control and emphasizes proactive measures that significantly impact transmission rates. By focusing on house modifications and epidemic preparedness, the global community moves closer to a malaria-free future. This paper contributes to this goal by documenting strategic innovations in malaria vector control in sub-Saharan Africa, aligning with the global technical strategy for malaria 2016–2030.

MATERIALS AND METHODS

This review draws on peer-reviewed studies, malaria epidemiology reports, and WHO publications. A comprehensive literature search was conducted using databases such as Google Scholar, PubMed, Elsevier, and other health-related journal sites. The inclusion criteria targeted articles reporting data from Sub-Saharan Africa on vector control interventions, insecticide resistance, and knowledge of malaria and its vectors between 2015 to 2023.

RESULTS

Out of 121 papers initially retrieved, only 23 met the criteria for inclusion in the study. Generally, malaria control in sub-Saharan Africa is multifaceted, focusing on habitat modification, housing improvements, epidemic preparedness, diagnostics, and research. Environmental management (EM) addresses mosquito breeding through actions like draining stagnant water and marshes, reducing approximately 40% of breeding sites and malaria cases. Species sanitation, such as installing screens on doors and windows, targets mosquitoes at larval and adult stages. House modifications further reduce malaria risk, with initiatives such as screening windows, closing eaves, and installing insecticide-treated eave tubes, which lower mosquito populations and Plasmodium prevalence.

The World Health Organization (WHO) recommends untreated screening in high-transmission areas, with well-constructed homes potentially reducing malaria by 9–14%. Community-led house modifications show promise, yet face economic and socio-cultural barriers, necessitating collaborative efforts for accessibility in low-income regions. Cost-effectiveness is a consideration, as community-based improvements offer a viable long-term solution.

Effective epidemic preparedness is essential, particularly in the face of disruptions from the COVID-19 pandemic and climate-induced challenges. Surveillance systems aid in early detection, resource mobilization, and community education. Rapid diagnostic tests (RDTs) are critical in resource-limited settings, complemented by research initiatives supporting vaccine and diagnostic advancements. Malaria control efforts must overcome funding and infrastructure challenges, reinforced by campaigns like the African Union's "Zero Malaria Starts with Me."

Research remains vital to achieving the WHO Global Technical Strategy goals by 2030. Regional initiatives and training programs drive local scientific capacity and innovation, essential to counter evolving malaria parasites. A comprehensive approach, involving political, community, and health sector collaboration, is needed to progress toward a malaria-free future in sub-Saharan Africa.

Habitat modification

Addressing human-induced factors contributing to mosquito breeding is crucial in malaria prevention. It includes eliminating preventable breeding sites, stagnant waters, and settlements

in swampy/marshy areas. Approximately 40% of Anopheles mosquito breeding sites (and malaria cases) could be mitigated through environmental management (EM) efforts[20]. Initiatives such as installing screens on doors and windows, coupled with engineering projects to eliminate breeding sites (e.g., draining marshes), constitute species sanitation. These efforts target both larval stages and adult mosquitoes[20] .

House modifications

House modifications emerge as a promising strategy against malaria[22]. The Global Strategy for Malaria Control 2016-2030 highlights house modification as a key component of malaria vector control programs. Improved housing positively impacts living environments and the quality of housing stock[23]. Communities in malaria-endemic areas accept interventions such as screening windows, ceilings/eaves, and doors, along with placing eave tubes and ribbons to control malaria. These interventions fall into three categories: (a) design and material specifications for primary household construction, (b) modifications to existing structures, and (c) incorporating insecticide delivery systems. Notable modifications include screening windows, doors, ceilings, eave closure, roof modification, and eave tube installations[24]. Evidence supports their efficacy, showing reduced mosquito populations, lower malaria incidence, and decreased Plasmodium prevalence in modified houses[25,26]. Thus, the World Health Organisation[27] recommends untreated screening for malaria prevention in areas with ongoing transmission.

Well-constructed and mosquito-proof houses can reduce malaria risk by 9% to 14%, with reports of a 37% reduction in mosquito populations in modified houses[25]. Additionally, modified houses are associated with a lower prevalence of Plasmodium parasites and reduced anemia. Challenges in implementing modifications include the influence of local context on participant experience, with limited discussions on the socio-cultural aspects of urban and rural settings[22]. Despite economic challenges, community-led house improvement interventions show promise, contributing to reduced malaria burden and high acceptability[28]. The cost-effectiveness of these interventions needs consideration, with community-led house improvement costing $27.04, offering a potential alternative for long-term malaria prevention[29]. Collaborative efforts are necessary to overcome barriers and make housing modifications accessible to low-income households in endemic settings.

Malaria epidemic preparedness

Malaria epidemics often follow abnormal weather conditions and other factors like drug resistance and population movement. Effective surveillance systems are essential for early detection, risk assessment, resource mobilization, rapid response planning, community engagement, vector control, case management, healthcare strengthening, and data analysis and learning[1]. The COVID-19 pandemic disrupted routine health services, resulting in increased malaria cases and deaths, emphasizing the need for resilient health systems.

Challenges to epidemic preparedness include setbacks from previous outbreaks like the Ebola virus and the increased risk of infections, including malaria, due to floods[30,31]. Despite significant progress, seasonal outbreaks persist in sub-Saharan Africa. Health promotion messages, consistent use of protective measures, and community education are crucial for sustained efforts in epidemic preparedness[32].

Diagnostic approaches and research initiatives

Efficient and timely diagnosis is essential for effective malaria management. Among the available diagnostic methods, rapid diagnostic tests (RDTs) are particularly recommended for settings with limited resources, offering a cost-effective and user-friendly solution. Capacity-building initiatives like the European & Developing Countries Clinical Trials Partnership (EDCTP) support research in vaccines, drugs, and diagnostics, promoting collaboration and innovation in malaria control efforts[33].

Challenges and strategies for malaria control in sub-Saharan Africa

Despite significant progress, malaria control in sub-Saharan Africa faces challenges such as weak health systems, insufficient funding, and inadequate surveillance. Achieving the WHO Global Technical Strategy goals by 2030 requires a stratified approach, recognizing variations within countries and regions. The zero-malaria agenda, supported by campaigns like the AU's "zero malaria starts with me," holds promise but requires enforced changes and collaboration across sectors for success[34–36].

Research and innovation

The achievement of malaria elimination goals necessitates robust research and innovation, particularly driven by scientists directly impacted by the disease in their daily lives[35,37]. Collaborative efforts, idea sharing, and the training of young scientists have been facilitated through initiatives like the Malaria Capacity Development Consortium (MCDC), Multilateral Initiative on Malaria (MIM), African Malaria Network Trust (AMANET), West Africa Network for Clinical Trials for Anti-malarial Drugs (WANECAM), African Media and Malaria Research Network (AMMREN), West Africa Malaria Initiative (WAMI), Malaria Research and Training Center (MRTC), and Anti-malarial Drug Resistance Network (ADRN). However, Sub-Saharan Africa (SSA) still requires substantial investment in basic science, implementation research, and innovation to develop new tools and strategies to combat the continuously evolving parasites[38].

An examination of health systems, campaign strategies, and reluctance to embrace the zero-malaria agenda reveals that, with less than a decade to achieve a 90% reduction in malaria in endemic zones, rapid attainment of zero malaria targets in SSA

may face challenges. However, it remains possible if necessary changes are enforced. The African Union's "Zero Malaria Starts with Me Campaign" represents a positive step, capable of mobilizing all sectors critical to ending malaria, from political leaders to community members most affected by the disease. Malaria can be minimized, if not eradicated, through concerted efforts from political leaders, the private sector, and community members. Additionally, health education interventions play a moderate yet valuable role in improving malaria knowledge and the usage of insecticide-treated nets (ITNs), contributing to the global malaria strategy[36].

Path to malaria control in sub-Saharan Africa

The recent elimination of malaria in China highlights the possibility of achieving malaria control and elimination through coordinated efforts and scientifically prudent means. Sub-Saharan African countries must strengthen health systems, address drug and insecticide resistance, and intensify regional efforts to move closer to a malaria-free future[39]. Rethinking control strategies and embracing holistic, systemic approaches involving communities are imperative to achieve the ambitious goals set by the WHO Global Technical Strategy[40].

DISCUSSION

The review of malaria control strategies presents a comprehensive understanding of multifaceted approaches to combat malaria, emphasizing habitat modification, house improvements, epidemic preparedness, diagnostic techniques, and the role of research and innovation. The discussion unfolds as follows:

Habitat Modification: addressing human-induced factors in mosquito breeding is pivotal for malaria prevention. Environmental Management (EM) efforts could mitigate 40% of Anopheles mosquito breeding sites. Initiatives like installing screens and engineering projects target both larval and adult mosquitoes. House modifications, including improved housing and screening, prove promising against malaria vectors. Well-constructed houses reduce malaria risk by 9-14%, with notable reductions in mosquito populations.

House modifications: house modifications emerge as a key strategy, positively affecting living environments. Screening windows, doors, and eave tubes show efficacy, reducing mosquito populations and malaria incidence. Despite economic challenges, community-led house improvement initiatives show promise in reducing malaria, particularly benefiting the most vulnerable group, children under five. Cost-effectiveness and collaborative efforts are essential for accessibility in low-income endemic settings.

Malaria epidemic preparedness: effective surveillance systems are crucial for early detection, risk assessment, and rapid response to malaria epidemics. Challenges include setbacks from outbreaks such as the Ebola virus and COVID-19 and increased infection risks due to factors like floods. Health promotion and consistent protective measures are emphasized for sustained epidemic preparedness.

Diagnostic approaches and research initiatives: rapid and effective diagnosis is crucial for malaria management. Rapid diagnostic tests (RDTs) are recommended for resource-limited settings, providing cost-effective solutions. Capacity-building initiatives, such as the European & Developing Countries Clinical Trials Partnership (EDCTP), support research on vaccines, drugs, and diagnostics.

Challenges and strategies for malaria control in sub-Saharan Africa: challenges include weak health systems, insufficient funding, and inadequate surveillance. Achieving WHO Global Technical Strategy goals requires a stratified approach, recognizing variations within countries and regions. The zero-malaria agenda, supported by campaigns like the AU's "Zero Malaria Starts with Me," holds promise but requires enforced changes and collaboration across sectors.

Research and innovation: robust research and innovation, driven by scientists directly impacted by malaria, are imperative for elimination. Collaborative efforts, training, and initiatives like the Malaria Capacity Development Consortium (MCDC) are critical. Substantial investment in basic science and implementation research is needed to combat continuously evolving parasites.

Path to malaria control in sub-Saharan Africa: the recent elimination of malaria in China underscores the possibility of achieving control and elimination through coordinated efforts. Strengthening health systems, addressing drug and insecticide resistance, and embracing holistic approaches involving communities are crucial. Rethinking control strategies is imperative to achieve ambitious goals set by the WHO Global Technical Strategy.

CONCLUSION

In conclusion, the review of malaria control strategies highlights a multifaceted approach to combat malaria, encompassing habitat modification, house improvements, epidemic preparedness, diagnostic techniques, and the pivotal role of research and innovation. The synthesized discussion underscores key findings and implications across these domains.

Habitat modification and house improvements: addressing human-induced factors in mosquito breeding emerges as a pivotal strategy for malaria prevention. Environmental Management (EM) efforts, such as installing screens and engineering projects, show promise in mitigating Anopheles mosquito breeding sites. House modifications, including improved housing and screening, exhibit efficacy in reducing mosquito populations, with well-constructed houses demonstrating a risk reduction of 9-14%.

Malaria epidemic preparedness: effective surveillance systems are deemed crucial for early detection, risk assessment, and

rapid response to malaria epidemics. The challenges posed by outbreaks like Ebola and COVID-19 underscore the need for resilient health systems. Health promotion and consistent protective measures are emphasized to ensure sustained epidemic preparedness.

Diagnostic approaches and research initiatives: rapid and effective diagnosis remains a cornerstone in malaria management. Rapid diagnostic tests (RDTs), particularly in resource-limited settings, offer cost-effective solutions. Capacity-building initiatives, such as the European & Developing Countries Clinical Trials Partnership (EDCTP), play a vital role in supporting research on vaccines, drugs, and diagnostics.

Challenges and strategies for malaria control in sub-Saharan Africa: despite significant progress, challenges persist, including weak health systems, insufficient funding, and inadequate surveillance. Achieving WHO Global Technical Strategy goals necessitates a stratified approach, recognizing variations within countries and regions. The zero-malaria agenda, supported by campaigns like the AU's "Zero Malaria Starts with Me," holds promise but demands enforced changes and collaboration across sectors.

Research and innovation: robust research and innovation, particularly driven by scientists directly impacted by malaria, are identified as imperative for elimination. Collaborative efforts, training programs, and initiatives like the Malaria Capacity Development Consortium (MCDC) are crucial components. Substantial investment in basic science and implementation research is deemed necessary to combat the continuously evolving parasites.

Path to malaria control in sub-Saharan Africa: the recent success in eliminating malaria in China serves as a beacon, highlighting the potential for control and elimination through coordinated efforts. Strengthening health systems, addressing drug and insecticide resistance, and embracing holistic community-centric approaches are identified as crucial steps. In essence, the path to malaria control in Sub-Saharan Africa demands a comprehensive, collaborative, and adaptive approach that integrates scientific advancements, community engagement, and strategic policy interventions to achieve sustained progress in the fight against malaria. Thus, rethinking control strategies and approaches is imperative to align with the determined goals set by the WHO Global Technical Strategy.

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