

Urban, Peri-Urban, and Rural Malaria Transmission Dynamics in Sub-Saharan Africa: A Comparative Review

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ABSTRACT

Malaria transmission dynamics in sub-Saharan Africa (SSA) exhibit significant spatial heterogeneity, with rural areas historically accounting for the majority of cases. However, the rapid urbanization of SSA has led to an increasing incidence of malaria in urban and peri-urban areas, where unplanned settlements, poor sanitation, and the emergence of urban-adapted mosquito vectors are driving new transmission patterns. This comparative review examines the malaria transmission dynamics across urban, peri-urban, and rural settings, highlighting the ecological, environmental, and socio-economic factors influencing malaria burden in each context. Urbanization has altered traditional transmission patterns, creating focal points in informal settlements, while peri-urban zones experience a blend of rural and urban transmission drivers. Understanding these distinct dynamics is critical for tailoring malaria control strategies. The review emphasizes the need for fine-scale surveillance, targeted interventions, and integrated environmental and vector management across diverse settings. By synthesizing the key factors that influence transmission, the study aims to improve the effectiveness of malaria control programs, ensuring they are context-specific and responsive to evolving transmission challenges in SSA.

Keywords: Malaria transmission, urbanization, peri-urban areas, rural settings, vector ecology, *Anopheles stephensi*.

INTRODUCTION

Malaria remains one of the most significant public health challenges in Sub-Saharan Africa, despite decades of global efforts to combat its transmission. The disease continues to affect millions of individuals annually, with the majority of cases occurring in rural and peri-urban areas of the region. However, a rapidly growing body of evidence suggests that the transmission dynamics of malaria differ significantly across urban, peri-urban, and rural environments [1-5]. These differences can be attributed to variations in environmental, socioeconomic, and behavioral factors that influence the breeding patterns of *Anopheles* mosquitoes, the vectors of malaria. Understanding these varying transmission dynamics is critical for designing targeted interventions and public health strategies tailored to the unique challenges faced by different communities [6-9].

The complexity of malaria transmission in Sub-Saharan Africa is influenced by diverse factors such as urbanization, land use changes, climate variability, and population mobility. As urbanization continues to accelerate in many Sub-Saharan African countries, it is crucial to investigate how these changes impact malaria transmission. The rapid expansion of urban areas may alter the traditional patterns of malaria transmission, which were predominantly seen in rural and peri-urban areas [10-14]. While rural areas have historically been more susceptible due to widespread environmental factors that support mosquito breeding, urban environments are increasingly facing challenges posed by inadequate waste management, water storage practices, and informal settlements that may provide new breeding grounds for malaria vectors. In contrast, peri-urban areas, characterized by transitional living conditions, may exhibit a combination of both rural and urban transmission dynamics, with unique implications for malaria control [15-18]. This review aims to provide a comparative analysis of malaria transmission dynamics in urban, peri-urban, and rural settings in Sub-Saharan Africa. By examining the interplay of various factors such as ecological, social, and economic determinants, this study seeks to identify the key drivers of malaria transmission in these distinct

environments. The findings will help in understanding how malaria dynamics evolve with urbanization and offer recommendations for improving malaria control and prevention strategies across different settings [19-25].

Sub-Saharan Africa is home to the highest burden of malaria globally, with the World Health Organization (WHO) estimating that over 200 million cases of malaria occur annually, predominantly in the African region. The disease continues to result in a substantial number of deaths, particularly among young children and pregnant women [26-30]. Malaria transmission in Sub-Saharan Africa is largely determined by the presence of *Anopheles* mosquitoes, which breed in stagnant water sources such as ponds, puddles, and marshes. These mosquitoes thrive in both rural and urban environments, but the ecological and anthropogenic factors that influence their breeding and survival differ significantly depending on the setting [31-36].

Historically, malaria transmission has been more prevalent in rural areas where the landscape is dominated by agricultural practices, open water bodies, and natural habitats conducive to mosquito breeding. Rural communities often face challenges in accessing adequate healthcare and preventive measures, which contributes to the higher incidence of malaria in these areas. In contrast, urban areas in Sub-Saharan Africa, characterized by dense populations and infrastructure development, have witnessed changes in the patterns of malaria transmission [8,37-40]. In cities, malaria vectors may exploit stagnant water in poorly managed urban areas, such as open drains, construction sites, and informal settlements, where the conditions are conducive to mosquito breeding despite the high population density and relative availability of health services. Peri-urban areas, located on the fringes of cities, present a hybrid environment where both urban and rural malaria transmission dynamics can be observed. These areas are typically characterized by rapid urban expansion, migration from rural regions, and limited access to health services [41-46]. The transitional nature of these areas makes them unique in terms of the factors influencing malaria transmission, and understanding these dynamics is essential for effective control.

Recent studies have indicated that malaria transmission in urban and peri-urban areas is not simply a reduced version of rural transmission but instead follows its own unique set of ecological and social dynamics. For example, urban areas with higher socioeconomic status may experience reduced transmission rates due to improved infrastructure and better access to healthcare [47-52]. However, informal settlements with poor sanitation and unplanned infrastructure may create favorable conditions for malaria vectors. In peri-urban areas, the coexistence of both urban and rural transmission factors can lead to a complex transmission pattern that is difficult to manage with conventional malaria control measures.

Malaria transmission in Sub-Saharan Africa has historically been studied predominantly in rural settings, where the majority of the population lives. However, urbanization in the region is progressing at an unprecedented rate, with millions of people moving to cities and peri-urban areas in search of better economic opportunities. Despite the increasing urbanization, there is limited research examining how malaria transmission dynamics differ across urban, peri-urban, and rural environments, and how these differences impact the design of control strategies [11,53-56].

The problem lies in the fact that urban, peri-urban, and rural areas each present unique challenges for malaria control, and current malaria intervention strategies are often designed based on assumptions rooted in rural transmission dynamics. The rising prevalence of malaria in urban areas and the ongoing urbanization process necessitate a more nuanced understanding of the complex factors influencing transmission across different settings [57-60]. This review aims to address the knowledge gap regarding malaria transmission dynamics in urban, peri-urban, and rural areas, and to provide insights into how these dynamics vary and what interventions are most effective in each environment. This comparative review aims to investigate the factors that influence malaria transmission across urban, peri-urban, and rural areas in Sub-Saharan Africa, focusing on ecological, social, and economic determinants [61-65]. Specifically, it seeks to examine the key drivers of malaria transmission in these settings, compare the dynamics of the disease across these environments, and evaluate the effectiveness of malaria control interventions tailored to each context. Urbanization and environmental changes are also key areas of investigation, as they play a significant role in altering malaria transmission patterns. The review will address questions related to the main factors contributing to malaria in each setting, the differences in transmission dynamics, challenges and successes in control strategies, and how urbanization impacts malaria transmission. The findings will be significant in informing more effective malaria control programs by providing insights into the unique challenges and opportunities within urban, peri-urban, and rural settings. As urbanization continues to rise in Sub-Saharan Africa, understanding the relationship between urban growth, environmental changes, and malaria transmission will be crucial for developing future interventions. By offering policy recommendations tailored to these environments, this study aims to improve the relevance and effectiveness of malaria control efforts, ultimately reducing the burden of the disease across the region.

METHODOLOGY

The methodology employed in this study is a narrative literature review that synthesizes a broad range of sources to explore malaria transmission dynamics across urban, peri-urban, and rural settings in sub-Saharan Africa (SSA). The review focuses primarily on three key sources: (a) authoritative global reports, particularly the World Health

Organization's (WHO) *World Malaria Reports*, which provide comprehensive insights into malaria trends, interventions, and challenges at a global scale, (b) recent scoping and systematic reviews, along with high-impact primary research studies that delve into urban and peri-urban malaria transmission and vector ecology, and (c) studies that examine environmental and infrastructural drivers of malaria transmission. These include papers utilizing remote sensing techniques, as well as research on the impact of infrastructure projects like dams and drainage systems on malaria spread. This narrative approach prioritizes a thematic synthesis of the literature, rather than a quantitative meta-analysis, to focus on practical implications for malaria control programs. By emphasizing the environmental, infrastructural, and ecological factors influencing malaria transmission, the review aims to offer actionable insights for policymakers and public health professionals working in diverse SSA contexts. The narrative method allows for a comprehensive understanding of malaria transmission patterns while drawing attention to regional variabilities and their implications for targeted interventions.

Comparative epidemiology: urban vs peri-urban vs rural

Comparative epidemiology of malaria transmission across urban, peri-urban, and rural settings highlights significant variability in disease burden and transmission dynamics. While the WHO African Region accounts for the majority of global malaria cases and deaths, rural and peri-urban populations bear the brunt of this burden, although urban areas are increasingly affected [61-63]. Historically, urban areas in Africa had lower malaria prevalence due to well-drained environments and better access to health services, but urban malaria has become more focal and heterogeneous. Informal settlements, peri-urban fringes, and areas with inadequate drainage or water storage are witnessing higher transmission, exacerbated by rapid, unplanned urbanization and the spread of urban-adapted mosquito vectors [14,64-67]. Peri-urban zones, on the other hand, experience unstable transmission due to a combination of environmental factors such as stagnant water and high population density. These areas often serve as bridges for malaria transmission between rural and urban zones. Rural regions remain the primary hotspot for malaria due to the abundance of natural breeding sites, high vectorial capacity, and limited access to healthcare and vector control. Additionally, ecological factors like rainfall and land use contribute significantly to transmission intensity. In summary, while urbanization reduces malaria risk, it does not eliminate it, creating complex patterns of malaria transmission across different geographic zones [15,68-71].

Vector and ecological drivers across settings

Vector composition and ecological drivers vary significantly across rural, peri-urban, and urban settings, influencing malaria transmission patterns and vector control strategies. In rural areas, classical malaria vectors such as *Anopheles gambiae* and *An. funestus* dominate, thriving in natural and agricultural breeding sites like swamps, puddles, and rice paddies. However, urbanization has facilitated the adaptation of certain species, such as *Anopheles stephensi*, which has been detected in urban areas of sub-Saharan Africa (SSA) [16]. This species is particularly concerning because it breeds in man-made habitats, especially urban water storage containers, construction sites, and blocked drains. Its adaptation to artificial breeding sites has been linked to outbreaks in urban centers. In peri-urban areas, breeding sites tend to be a mix of natural and man-made habitats, including irrigation and drainage ditches. Urban environments, on the other hand, concentrate vector breeding in ephemeral, polluted, or artificial containers, with unplanned urban infrastructure exacerbating the creation of such microhabitats. Remote sensing and geo-ecological studies reveal spatial patterns that correlate with observed differences in transmission, highlighting the importance of habitat suitability in vector distribution [17]. Furthermore, urban heat islands and altered hydrology can extend vector populations' activity, prolonging transmission seasons locally. Thus, effective vector control strategies must be tailored to specific habitats and species, addressing container-based breeding in urban areas and larger landscape-scale habitats in rural settings [18].

Infrastructural, environmental, and socio-demographic determinants

Infrastructural, environmental, and socio-demographic factors play a critical role in malaria transmission, especially in urban and peri-urban areas. Housing quality, sanitation, and drainage systems significantly influence the risk of malaria. Well-constructed housing, such as those with screened windows and sealed eaves, has been linked to reduced malaria transmission. In contrast, inadequate drainage systems, blocked sewers, and poorly managed construction create ideal breeding grounds for mosquitoes [19]. Poorly sealed water storage containers further exacerbate the situation. In rural and peri-urban areas, infrastructure projects like dams and irrigation schemes can increase standing water, fostering mosquito breeding and amplifying transmission risks if not managed effectively. Population density and human mobility are also crucial factors. High population density in urban areas increases the likelihood of malaria outbreaks where vector populations exist. Additionally, rural-urban migration, seasonal labor movements, and commuting patterns facilitate the spread of malaria, as people bring in parasites from different areas, creating reservoirs in peri-urban spaces and complicating efforts to eliminate the disease [20]. Socio-economic status further contributes to vulnerability, with low-income groups in peri-urban and rural areas often facing limited access to malaria prevention tools, such as insecticide-treated nets, and healthcare services. These populations experience higher exposure and delayed diagnosis, worsening outcomes. Climate change also acts as a modifier of

malaria risk by altering rainfall, temperature, and the timing of transmission seasons, which may shift risk patterns into new urban and peri-urban areas [21].

Surveillance, control implications, and recommendations (programmatic)

Surveillance, control implications, and recommendations play a critical role in effectively managing malaria transmission across diverse environments. A key recommendation is to strengthen subnational surveillance with fine-scale stratification, monitoring urban cores, informal settlements, peri-urban belts, and rural clusters separately [22]. This tailored approach, utilizing case data, entomological surveillance, and geospatial analytics, enables the identification of malaria hotspots and the detection of importation routes, which are crucial for targeted interventions. In terms of vector control, urban and peri-urban areas should prioritize larval source management (including drainage and container management), targeted larviciding, and rapid environmental sanitation. Additionally, the emergence of urban-adapted vectors, such as *Anopheles stephensi*, requires specific attention. For rural settings, interventions like insecticide-treated nets (ITNs), indoor residual spraying (IRS), and environmental management of larger water bodies should be maintained [23]. Integrating malaria control efforts with agricultural water management and dam planning is vital to ensure sustainability. To improve health services and access, mobile clinics and community health workers can be deployed in peri-urban and informal settlements, addressing socio-economic barriers to diagnosis, treatment, and ITN uptake. Addressing population movement, including seasonal workers and commuters, through mobility data integration, is essential for targeted risk mapping and communication. Lastly, research investments should focus on entomological capacity, urban vector ecology, and the influence of urbanization on transmission dynamics, while policy must integrate environmental and health considerations across sectors [24].

CONCLUSION

Malaria transmission in sub-Saharan Africa (SSA) is characterized by significant spatial heterogeneity, with rural areas continuing to account for the majority of cases. However, urban and peri-urban areas present emerging challenges due to rapid, unplanned urbanization, the creation of specific mosquito breeding habitats, and increased population mobility. These factors facilitate the spread of malaria, especially as urban-adapted vectors emerge and the effects of the pandemic disrupt previous gains in malaria control. The shifting malaria dynamics across different settings require a nuanced approach to intervention. Effective malaria control programs must integrate fine-scale surveillance to monitor the evolving spread of the disease in diverse environments. Furthermore, interventions should be tailored to the specific characteristics and risks of urban, peri-urban, and rural areas. A combination of entomological monitoring, environmental management, and customized service delivery is crucial to addressing the distinct drivers of malaria transmission in these varied contexts. This integrated approach will ensure more effective and context-sensitive malaria control.

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