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Agricultural Expansion and Urbanization as Drivers of Malaria Transmission: A Narrative Review

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ABSTRACT

Malaria transmission is increasingly shaped by rapid land-use and demographic transitions. Agricultural expansion alters vector ecology through deforestation, irrigation, crop intensification, and labor migration, often creating new larval habitats, changing mosquito species composition, and increasing human–vector contact. Urbanization has historically been associated with reduced malaria risk via improved housing, infrastructure, and reduced vector breeding sites; however, unplanned urban growth, peri-urban agriculture, informal settlements, human mobility, and the invasion of urban-adapted vectors (notably *Anopheles stephensi*) are reshaping urban malaria epidemiology. This review synthesizes evidence on mechanisms linking agricultural expansion and urbanization to malaria transmission, highlights context-specific pathways (with emphasis on sub-Saharan Africa), and proposes an integrated landscape–city approach for malaria control aligned with development planning.

Keywords: malaria, land-use change, deforestation, irrigation, *Anopheles stephensi*, human mobility, vector ecology

INTRODUCTION

Malaria remains one of the most persistent public health threats globally, and its impact is most severe in the WHO African Region [1]. Over the last two decades, substantial progress has been achieved through proven interventions—particularly insecticide-treated nets (ITNs), indoor residual spraying (IRS), seasonal malaria chemoprevention/chemoprophylaxis in eligible groups, improved case management with artemisinin-based combination therapies, and wider availability of rapid diagnostic tests [2]. These strategies have reduced malaria morbidity and mortality in many settings and strengthened national malaria control programs. However, malaria transmission has proven resilient, with progress uneven across countries and within subnational regions. According to WHO estimates, there were 263 million malaria cases and 597,000 deaths in 2023, and the highest burden occurred in Africa. This continuing burden underscores that malaria is not only a biomedical problem but also a complex ecological and socio-environmental challenge that is shaped by how people live, work, and transform their surroundings. A defining feature of malaria transmission is its strong dependence on environmental conditions that support the mosquito vector and the Plasmodium parasite. Temperature, humidity, rainfall patterns, and the presence of suitable aquatic habitats interact to determine vector breeding success, mosquito survival, biting rates, and parasite development within the mosquito [3]. As a result, malaria risk is highly sensitive to changes in local ecosystems, particularly those driven by human activities. In many African settings, rapid population growth, intensified agriculture, expansion of settlements, and infrastructure development are reshaping landscapes at an unprecedented pace. These changes can alter malaria epidemiology by modifying mosquito habitat availability, affecting microclimatic conditions, and changing patterns of human exposure [4].

Land use/land cover change (LULCC) is therefore increasingly recognized as a key driver of malaria dynamics. LULCC refers to transformations in how land is utilized (e.g., farming, settlement, industry) and how it is physically covered (e.g., forest, wetland, cropland, built-up areas). Common LULCC processes in malaria-endemic settings include agricultural expansion into forested or wetland areas, deforestation, irrigation development, mining and brick-making activities that create pits and ponds, and urbanization that converts natural vegetation into built-up spaces [5]. Each of these changes can influence malaria transmission through multiple pathways. For instance, deforestation and vegetation loss can increase sunlight exposure and raise near-ground temperatures, potentially accelerating mosquito development and shortening the parasite's incubation period in the vector. Agricultural practices and irrigation may introduce new standing-water habitats or stabilize water availability across seasons, prolonging breeding opportunities. Conversely, certain forms of urban development may reduce vector habitats in core urban zones, while simultaneously creating high-risk peri-urban fringes where drainage is inadequate, and settlement is unplanned. Importantly, LULCC influences malaria not only through ecological mechanisms but also through social and behavioral pathways [6]. Changes in land use can reorganize human settlement patterns, increase population density in new frontiers, and generate occupational exposures, for example, farm laborers working at dusk, migrant workers living in temporary shelters, or communities settling near water bodies for farming and domestic use. Mobility linked to trade, seasonal work, and rural–urban transitions can introduce parasites into receptive areas or sustain transmission in places where control has reduced local incidence [7]. The interaction between human movement and vector ecology means that malaria can re-emerge or persist even where health systems deliver high intervention coverage. Consequently, malaria control and elimination efforts can be undermined when environmental change creates new pockets of transmission that are not captured by routine surveillance or are not prioritized in intervention planning [8].

Recent reviews on malaria in changing landscapes emphasize that failure to incorporate environmental transitions into malaria planning can redirect elimination trajectories. In many contexts, malaria programs understandably focus on health-sector tools- diagnosis, treatment, and vector control yet these tools operate within broader ecological and development systems. Where land conversion proceeds without multisectoral planning, the result may be a mismatch between where interventions are deployed and where risk is emerging [9]. This makes it increasingly necessary to generate local evidence on how specific LULCC patterns relate to malaria outcomes, so that control strategies can be better targeted, anticipatory, and aligned with land management decisions.

Despite wide-scale implementation of key malaria interventions, including insecticide-treated nets (ITNs), indoor residual spraying (IRS), improved diagnostics, and effective antimalarial treatment, malaria remains a leading cause of morbidity and mortality in the WHO African Region, suggesting that current approaches may be insufficient to sustainably suppress transmission across all ecological and socio-economic settings [10]. While persistent barriers such as insecticide resistance, diagnostic and reporting gaps, delayed or inappropriate treatment-seeking, intermittent funding, and health-system capacity constraints are well documented, the contribution of environmental transformation, particularly land use/land cover change (LULCC), is still not consistently operationalized within routine malaria control planning and decision-making [11]. In many endemic areas, land conversion is accelerating due to agricultural expansion, settlement growth, wetland encroachment, irrigation development, deforestation, and road or infrastructure projects. These landscape changes can modify malaria transmission dynamics by creating new or more productive mosquito breeding habitats (e.g., sunlit puddles, drainage channels, borrow pits, irrigated fields), altering local microclimate conditions such as temperature and humidity that influence vector survival and parasite development, and increasing human–vector contact through emerging settlement patterns, livelihood activities, and nighttime outdoor exposure [12]. However, malaria surveillance systems and program monitoring frameworks often emphasize clinical and parasitological indicators without integrating environmental risk layers, meaning that spatial and temporal shifts in transmission driven by LULCC may go undetected or be recognized too late. As a result, interventions may be deployed uniformly, guided by historical burden maps or administrative convenience rather than real-time, landscape-sensitive risk potentially leaving newly formed hotspots under-protected while resources are allocated to areas where risk has declined. This disconnect also weakens outbreak anticipation and reduces opportunities for coordinated prevention with sectors that shape the environment, including agriculture, water and irrigation management, land administration, housing, and urban planning. Consequently, local authorities and malaria programs may lack actionable evidence to identify where LULCC is intensifying malaria risk, when seasonal peaks are shifting, and which development trajectories are most associated with rising burden. Therefore, there is a critical need to examine how land use/land cover changes in the study setting are associated with malaria morbidity patterns, to support more responsive, locally adapted, and multisectoral malaria control strategies that align public health action with rapidly changing landscapes.

Conceptual framework: how land-use change translates into transmission

Land-use change influences malaria transmission by reshaping the conditions required for sustained spread, namely the co-occurrence of competent mosquito vectors, parasite circulation, and frequent human–vector contact. Agricultural expansion and urbanization can increase or decrease risk through several linked mechanisms [13]. First, they can create or eliminate breeding habitats: irrigation canals, puddles, borrow pits, construction sites, and water-holding containers often generate new larval sites, while forest clearance may remove shaded pools that previously supported certain vectors. Second, land clearing alters local microclimates by changing canopy cover, temperature, and sunlight; even small temperature increases can speed up mosquito development and shorten parasite incubation, potentially intensifying transmission. Third, environmental modification can shift vector community composition, favoring different Anopheles species with distinct biting times, host preferences, and insecticide resistance patterns. Fourth, land-use transitions alter human exposure through frontier migration, seasonal farm labor, housing quality, sleeping behavior, and occupational activities that increase outdoor biting risk [14]. Finally, development can change access to health services and surveillance improving diagnosis and control in some areas while leaving informal settlements underserved. These pathways interact, meaning the same driver (e.g., deforestation) may raise or reduce malaria risk depending on intensity, timing, and socio-ecological context.

Agricultural expansion as a driver of malaria transmission

Agricultural expansion can intensify malaria transmission by reshaping landscapes, water ecology, and human movement in ways that favor mosquito breeding and human–vector contact. Through deforestation and frontier settlement, forest clearing often creates warmer, sunlit pools and puddles that are ideal larval habitats, while simultaneously drawing people into vector-rich zones for farming, logging, and settlement [15]. These frontiers also attract migrants who may lack immunity, increasing susceptibility and sustaining transmission; evidence from the Amazon suggests deforestation can raise malaria incidence at municipal scales and even create feedback loops where malaria influences land-use decisions. However, the effect is not always linear: malaria risk frequently peaks at intermediate disturbance such as mosaic landscapes with fragmented forest edges and expanding settlements, then may decline as agriculture becomes more intensively managed or areas urbanize, though this varies by context [16]. Irrigation, especially rice cultivation, further amplifies risk by expanding aquatic habitats and boosting vector densities; meta-analytic evidence from Africa shows rice-growing communities often face higher mosquito exposure unless mitigation is embedded into agronomy and water management. Beyond rice, dams, drainage changes, and irrigation for sugarcane or vegetables can create persistent breeding sites depending on water stagnation, vegetation, shading, proximity to homes, and local vector preferences. Finally, large-scale farming drives labor migration, which can introduce parasites, increase night-time exposure, and strain prevention and treatment systems [17].

Urbanization as a driver (and modifier) of malaria transmission

Urbanization is often linked to lower malaria transmission because cities tend to improve key protective factors, such as better housing (e.g., screened windows and closed eaves), reduced vegetation, improved drainage, and closer access to healthcare, thereby limiting mosquito breeding and speeding diagnosis and treatment [18]. However, this "urban advantage" can disappear when growth is rapid and unplanned. WHO emphasizes that while urbanization overall is expected to reduce malaria, unplanned urbanization can concentrate malaria risk among the urban poor, demanding city-led, multisectoral action rather than health-sector-only responses. In many settings, the highest risk occurs at peri-urban fringes and informal-settlement ecotones where drainage is incomplete, construction leaves puddles and borrow pits, peri-urban farming introduces irrigation and standing water, and housing quality remains weak, conditions that can sustain local transmission despite "urban" classification [19]. Mobility further complicates control: frequent travel between cities and rural endemic areas can import parasites and maintain urban reservoirs; a 2025 systematic review/meta-analysis in sub-Saharan Africa identified travel history as an important factor associated with urban malaria infection. Finally, the spread of Anopheles stephensi is a potential game-changer because it thrives in towns and cities by breeding in man-made water containers, with WHO urging strengthened surveillance and tailored control given resistance concerns [20].

Interactions: agricultural expansion × urbanization

Agricultural expansion and urbanization often interact in ways that amplify vector-borne disease risk rather than acting independently. A common coupled pathway is peri-urban agriculture, where irrigation, vegetable gardens, and small-scale farming at city fringes create persistent standing-water habitats that favor mosquito breeding, while nearby dense human populations increase biting opportunities and sustain transmission [21]. Food-supply chains and mobility further connect rural and urban ecologies: routine rural–urban movement of workers and traders can introduce parasites into cities, and rapid urban growth raises demand for fresh produce, encouraging intensified agriculture close to urban markets, often with poorly managed water. Meanwhile, infrastructure transitions such as road building, housing construction, and land clearing can accelerate both deforestation and urban sprawl, leaving borrow pits, clogged drains, and temporary puddles that support seasonal surges in vector abundance. Finally, **socioeconomic gradients** shape exposure within the same city: wealthier urban cores may benefit from improved housing, piped water, and waste management, while informal settlements face overcrowding, inadequate drainage, and limited protection, producing localized "micro-epidemics" that persist even when overall city-level risk appears low [21].

Implications for malaria control and policy

For malaria control and policy, malaria risk should be treated as a land-planning variable, much like flooding: it must be mapped, anticipated in development decisions, and reduced through engineering and design. This aligns with WHO's urban malaria approach, which emphasizes city leadership and multisectoral action linking health outcomes to housing quality, WASH, drainage, and infrastructure. Environmental management should then be tailored to the land-use context. In agricultural frontier zones, where mobility and land clearing can trigger outbreaks, stronger surveillance for early warning is needed alongside prevention packages targeting migrants and farm workers [22]. In irrigation schemes, malaria control should be built into water and site management—using feasible intermittent irrigation, targeted larval source management, and designs that prevent stagnant water accumulation. In urban settings, priorities shift to improved drainage, solid-waste control, and container management, which become especially urgent where *Anopheles stephensi* is present or likely to spread. Finally, surveillance systems must capture malaria's heterogeneity across space and time by mapping incidence at the neighborhood level, routinely monitoring vector species shifts, documenting travel history during case investigations, and integrating satellite or land-cover data with routine surveillance to guide targeted, cost-effective interventions [23].

Research gaps and agenda

A clear research agenda is needed to strengthen evidence and guide policy on land-use/land-cover change (LULCC) and malaria, especially in rapidly urbanizing settings. First, causal inference remains weak: future studies should apply stronger quasi-experimental designs (e.g., natural experiments, difference-in-differences, instrumental variables) to distinguish the true effects of deforestation and land conversion from confounders such as migration, artisanal mining, and unequal access to healthcare. Second, urban malaria research needs harmonized metrics and standardized definitions of "urban," "peri-urban," and "informal settlement" to improve comparability across studies and enable reliable meta-analyses [24]. Third, the expanding threat of *Anopheles stephensi* demands operationally scalable city-adapted control, including container habitat management, insecticide resistance monitoring and management, and integrated vector management tailored to dense urban environments. Fourth, agriculture–health co-optimization should identify irrigation and rice-production practices that maintain or increase yields while reducing vector breeding at scale, linking agronomy, hydrology, and public health outcomes [25]. Finally, mobility-aware interventions are essential in cities: targeted chemoprevention, screening, or surveillance strategies should focus on high-mobility populations (e.g., traders, commuters, migrant workers) that may sustain transmission across urban networks and administrative boundaries.

CONCLUSION

In conclusion, addressing malaria in the context of land-use/land-cover change and rapid urban growth requires a shift from descriptive associations to decision-ready evidence and implementable solutions. Stronger causal designs will clarify which landscape transitions truly increase transmission risk and which apparent effects are driven by migration, mining, or inequitable healthcare access. At the same time, harmonized urban definitions will improve comparability across studies, strengthen meta-analyses, and support more consistent monitoring of malaria dynamics in cities. The emergence and spread of *Anopheles stephensi* further raises the urgency for operational control strategies that fit urban realities, including scalable container management and robust insecticide resistance stewardship within integrated vector management. Co-optimizing agricultural productivity with vector suppression can reduce trade-offs between food security and disease prevention, particularly in irrigated and rice-growing systems. Finally, mobility-aware interventions can close persistent gaps by targeting high-mobility groups that connect transmission hotspots across urban networks. Together, these priorities provide a practical roadmap for research and policy toward more effective, equitable malaria control.

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