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The Impact of Climate-Resilient Housing Modifications on Malaria Incidence in Rural Endemic Regions

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ABSTRACT

Malaria remains a significant public health burden, particularly in rural endemic regions of sub-Saharan Africa, where environmental and socioeconomic factors exacerbate transmission. Despite advancements in malaria control, such as insecticide-treated nets (ITNs) and indoor residual spraying (IRS), challenges like insecticide resistance, climate change, and limited healthcare access necessitate innovative, sustainable interventions. Climate-resilient housing modifications, including screened windows, insecticide-treated wall linings, and improved roofing materials, have emerged as a promising strategy to reduce malaria incidence by minimizing mosquito-human contact and enhancing resilience to climate change. This review explored the design, effectiveness, and co-benefits of these modifications, highlighting their potential to improve thermal comfort, indoor air quality, and protection against extreme weather events. The methodology utilized in this article involves a comprehensive review of existing literature, case studies, and randomized controlled trials to evaluate the impact of housing modifications on malaria incidence. While evidence supports their effectiveness, challenges such as cost, cultural acceptability, and technical expertise must be addressed to ensure scalability and sustainability. Future research should focus on cost-effectiveness, long-term impact, and integration with existing malaria control strategies. Climate-resilient housing modifications offer a dual benefit of malaria prevention and climate adaptation, presenting a transformative opportunity to reduce disease burden and enhance community resilience in the face of a changing climate.

Keywords: Malaria prevention, Climate-resilient housing, Housing modifications, Rural endemic regions, Climate change adaptation.

INTRODUCTION

Malaria continues to be a formidable public health challenge, particularly in rural endemic regions of sub-Saharan Africa, where environmental and socioeconomic factors exacerbate their transmission [1–3]. Despite significant advancements in malaria control, including the widespread use of insecticide-treated nets (ITNs) and indoor residual spraying (IRS), the disease remains a leading cause of morbidity and mortality [4, 5]. Emerging challenges such as insecticide resistance, climate change, and limited healthcare access have highlighted the need for innovative, sustainable, and complementary interventions. Among these, climate-resilient housing modifications have emerged as a promising strategy to reduce malaria incidence by addressing the root cause of human-mosquito interaction: the home itself. Housing plays a critical role in malaria transmission, as poorly constructed homes with open eaves, unscreened windows, and thatched roofs provide easy entry points for *Anopheles* mosquitoes [6]. Climate-resilient housing modifications, such as screened windows, insecticide-treated wall linings, and improved roofing materials, not only reduce mosquito entry but also enhance resilience to climate change by improving thermal comfort and protecting against extreme weather events. These modifications offer a dual benefit: they contribute to malaria prevention while simultaneously addressing the broader impacts of a changing climate. This review explores the potential of climate-resilient housing modifications as a novel and sustainable intervention for malaria control. It examines the design and components of these modifications, their effectiveness in reducing malaria incidence, and the co-benefits they provide in terms of climate adaptation and improved living conditions. Additionally, the review highlights the challenges and barriers to implementation, including cost, cultural acceptability, and technical expertise, while proposing future research directions to optimize their impact. By integrating climate-resilient

housing modifications into broader malaria control strategies, there is an opportunity to create healthier, more resilient communities and advance progress toward global health and sustainable development goals.

Malaria transmission is heavily influenced by environmental and climatic factors [7]. Rising global temperatures, altered rainfall patterns, and increased frequency of extreme weather events have expanded the geographic range of *Anopheles* mosquitoes and extended transmission seasons in many regions [8, 9]. Traditional malaria control strategies, such as ITNs and IRS, have been highly effective but are increasingly challenged by insecticide resistance and logistical constraints. Moreover, these interventions often require continuous investment and community compliance, which can be difficult to sustain in resource-limited settings. Housing, as a primary site of human-mosquito interaction, presents a unique opportunity for malaria prevention. Poorly constructed homes with open eaves, unscreened windows, and thatched roofs provide easy entry points for mosquitoes. Climate-resilient housing modifications, such as screened windows, improved ventilation, and insecticide-treated wall linings, can reduce mosquito entry and create healthier living environments. These modifications not only address malaria prevention but also enhance resilience to climate change by improving thermal comfort and reducing exposure to extreme weather events.

CLIMATE-RESILIENT HOUSING MODIFICATIONS: DESIGN AND COMPONENTS

Climate-resilient housing modifications are designed to address both malaria prevention and climate adaptation [10]. Key components include:

i. **Screened Windows and Doors:** Installing fine mesh screens on windows and doors prevents mosquito entry while allowing for adequate ventilation [11]. This is particularly important in hot, humid climates where airflow is essential for thermal comfort.
ii. **Insecticide-Treated Wall Linings:** Wall linings treated with long-lasting insecticides provide an additional barrier against mosquitoes. These linings can be integrated into the construction of new homes or retrofitted into existing structures.
iii. **Improved Roofing Materials:** Replacing thatched roofs with metal or tiled roofs reduces mosquito resting sites and minimizes heat retention, improving indoor comfort.
iv. **Eave Closures:** Closing open eaves with mesh or other materials prevents mosquitoes from entering homes while maintaining ventilation [12].
v. **Elevated Foundations:** Raising homes on stilts or platforms can reduce exposure to ground-level humidity and flooding, which are conducive to mosquito breeding.

These modifications are designed to be low-cost, durable, and culturally acceptable, ensuring their feasibility in rural settings. Additionally, they align with broader climate adaptation goals by enhancing the resilience of housing structures to extreme weather events such as floods and storms.

EFFECTIVENESS OF CLIMATE-RESILIENT HOUSING MODIFICATIONS IN REDUCING MALARIA INCIDENCE

Several studies have demonstrated the potential of housing modifications to reduce malaria incidence. For example, a cluster-randomized controlled trial in The Gambia found that homes with screened windows and doors had a 50% lower incidence of malaria compared to control homes [13, 14]. Similarly, a study in Tanzania reported a significant reduction in mosquito density and malaria prevalence in homes with insecticide-treated wall linings. These findings suggest that housing modifications can complement existing malaria control strategies by providing a physical barrier against mosquito entry and reducing reliance on chemical interventions. The effectiveness of climate-resilient housing modifications is influenced by several factors, including the quality of construction, community acceptance, and the local malaria transmission dynamics. In areas with high mosquito densities, even small improvements in housing quality can have a substantial impact on malaria incidence. Moreover, housing modifications can provide long-lasting protection, reducing the need for frequent reapplication of insecticides or replacement of ITNs. However, the success of these interventions depends on their integration into broader malaria control programs and their alignment with local housing practices and preferences.

CLIMATE RESILIENCE AND CO-BENEFITS

In addition to reducing malaria incidence, climate-resilient housing modifications offer several co-benefits that contribute to improved health and well-being. These include:

i. **Thermal Comfort:** Improved ventilation and insulation help regulate indoor temperatures, reducing heat during hot seasons and improving comfort during cold seasons [15].
ii. **Reduced Exposure to Extreme Weather:** Elevated foundations and durable roofing materials protect homes from flooding and storm damage, reducing the risk of displacement and injury.
iii. **Improved Indoor Air Quality:** Screened windows and doors reduce the entry of dust, smoke, and other pollutants, improving respiratory health [16].

iv. **Enhanced Privacy and Security:** Solid walls and secure doors provide greater privacy and protection from intruders, contributing to overall well-being.

These co-benefits make climate-resilient housing modifications a holistic intervention that addresses multiple health and environmental challenges. By improving living conditions and reducing vulnerability to climate change, these modifications can contribute to sustainable development goals and enhance community resilience.

CHALLENGES AND BARRIERS TO IMPLEMENTATION

Despite their potential, the widespread adoption of climate-resilient housing modifications faces several challenges [17, 18]. These include:

i. **Cost:** The initial cost of housing modifications can be prohibitive for low-income households, particularly in rural areas. While the long-term benefits may outweigh the costs, upfront investment remains a significant barrier.

ii. **Cultural and Social Factors:** Housing preferences and construction practices vary widely across regions, and modifications must be culturally acceptable to ensure community uptake. Engaging local communities in the design and implementation process is essential for success.

iii. **Technical Expertise:** The construction of climate-resilient homes requires specialized knowledge and skills, which may not be readily available in rural areas. Training local builders and providing technical support can help overcome this barrier.

iv. **Policy and Regulatory Frameworks:** The integration of housing modifications into national malaria control strategies requires supportive policies and regulatory frameworks. Governments and international organizations play a critical role in promoting these interventions and ensuring their alignment with broader health and development goals.

Addressing these challenges requires a multi-sectoral approach that involves collaboration between health, housing, and environmental sectors. Financial mechanisms such as subsidies, microfinance, and public-private partnerships can help reduce the cost burden and promote scalability. Community engagement and education are also essential for fostering acceptance and ensuring the sustainability of these interventions.

FUTURE DIRECTIONS AND RESEARCH PRIORITIES

While the evidence supporting climate-resilient housing modifications is promising, further research is needed to optimize their design, implementation, and impact. Key research priorities include:

i. **Cost-Effectiveness Analysis:** Evaluating the cost-effectiveness of housing modifications compared to other malaria control interventions can inform resource allocation and policy decisions [19].

ii. **Long-Term Impact Studies:** Assessing the durability and long-term impact of housing modifications on malaria incidence and other health outcomes can provide valuable insights for scaling up these interventions.

iii. **Integration with Other Interventions:** Exploring the synergistic effects of combining housing modifications with ITNs, IRS, and other malaria control strategies can enhance their overall effectiveness.

iv. **Climate Adaptation Benefits:** Investigating the broader climate adaptation benefits of housing modifications, such as reduced vulnerability to extreme weather events, can strengthen the case for their adoption.

v. **Community Perspectives:** Understanding community perceptions and preferences regarding housing modifications can inform the design of culturally appropriate and acceptable interventions.

CONCLUSION

Climate-resilient housing modifications represent a transformative and sustainable approach to malaria prevention, particularly in rural endemic regions where traditional control strategies face mounting challenges. By addressing the structural vulnerabilities of homes that facilitate mosquito entry, these modifications provide a physical barrier against malaria transmission while simultaneously enhancing resilience to climate change. The integration of screened windows, insecticide-treated wall linings, and improved roofing materials not only reduces malaria incidence but also improves thermal comfort, indoor air quality, and protection from extreme weather events. These co-benefits underscore the potential of housing modifications to contribute to broader health and development goals. However, the widespread adoption of these interventions requires overcoming significant barriers, including cost, cultural acceptability, and technical expertise. Multi-sectoral collaboration, community engagement, and supportive policy frameworks are essential to ensure scalability and sustainability. Future research should focus on optimizing the design and implementation of these modifications, evaluating their long-term impact, and exploring their integration with existing malaria control strategies. As the global health community seeks innovative solutions to combat malaria and adapt to a changing climate, climate-resilient housing modifications offer a compelling opportunity to reduce the disease burden and improve the quality of life for millions. By investing in these

interventions, we can move closer to achieving malaria elimination and building healthier, more resilient communities.

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