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INVESTMENT CASE FOR INTEGRATED MALARIA CONTROL IN RWANDA – INTERVENTION EFFICACY, CHALLENGES AND COST-EFFECTIVENESS

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Abstract
Malaria presents a persistent public health challenge in Rwanda, exhibiting fluctuating incidence despite substantial investments in control interventions. This paper synthesizes recent analyses concerning the impact of long-lasting insecticidal nets (LLINs), indoor residual spraying (IRS), rapid diagnostic tests (RDTs), and emerging vaccine strategies. Integrating epidemiological data, cost-effectiveness projections, and vector ecology findings, we deliver a comprehensive overview of Rwanda's malaria control landscape up to 2022. Results indicate that integrated interventions, particularly LLINs and IRS, have driven notable reductions in malaria morbidity and mortality. However, challenges persist due to climate variability, insecticide resistance, and underdiagnosis in school-age children. Pragmatic recommendations for sustaining and augmenting malaria control efforts are discussed, emphasizing innovative strategies and adaptive measures to ensure continued progress toward malaria elimination.

I. Introduction

Malaria, a vector-borne disease caused by parasites of the genus *Plasmodium*, remains a leading cause of morbidity and mortality across sub-Saharan Africa. Rwanda has demonstrated significant advancements in malaria control since the early 2000s, propelled by the introduction and scale-up of LLINs, IRS, and artemisinin-based combination therapy (ACT). Despite these efforts, the nation has experienced a resurgence in malaria cases in recent years, underscoring the necessity for sustained and adaptive intervention strategies. According to the Institute for Health Metrics and Evaluation (IHME), malaria accounts for 12.83% of deaths in children under five years of age in Rwanda. Rwanda's experience mirrors the fragility of gains made through malaria control, as evidenced by dramatic increases in cases starting in 2012. This paper elucidates the challenges in sustaining malaria reduction, including climatic, environmental, technical, operational, and financial factors, as well as issues related to human mobility, malaria parasites, and vectors exhibiting resistance to drugs and insecticides. The future implications hinge on implementing robust strategies to combat these multifaceted challenges.

II. Methods

A. Literature and Data Review

We conducted a thorough review of peer-reviewed literature, national health reports, and WHO databases, focusing on malaria incidence, intervention coverage, and vector ecology in Rwanda from 2000 to 2022. This included an assessment of relevant mathematical modeling studies evaluating the impacts of various interventions on malaria transmission dynamics. The reviewed sources also encompassed insights from the Disease Control Priorities, 3rd edition (DCP3), and equity analyses from EQUIST, providing a comprehensive view of malaria control strategies and their effectiveness.

B. Epidemiological Data Analysis

Epidemiological data were synthesized from Rwanda's Health Management Information System (HMIS), WHO World Malaria Reports, and population health surveys. Time-series analyses were performed to identify trends in malaria incidence and prevalence, correlating these trends with the implementation and scale-up of specific interventions. Climate data, including rainfall and temperature, were incorporated to evaluate potential confounding influences on malaria transmission dynamics, ensuring a nuanced interpretation of intervention impacts.

C. Mathematical Modeling

We referenced mathematical models assessing the impact of LLINs, IRS, and other interventions on malaria transmission dynamics. These models, often incorporating differential equations and agent-based simulations, provide insights into the complex interactions between vectors, parasites, and human populations. Sensitivity analyses were conducted to evaluate the effects of intervention coverage and decay rates, allowing for a more robust understanding of the potential long-term impacts of malaria control efforts.

III. Burden of Disease - Malaria

Malaria remains a primary driver of under-5 mortality in Rwanda, responsible for nearly 13% of deaths in this age group. Incidence increased dramatically from 48 per 1,000 in 2012 to 403 in 2018. However, subsequent scale-up of interventions led to a drop to 85 cases per 1,000 in 2021 (Figure 1). The burden remains highest in Eastern provinces. Climate change, urbanization, and weak intervention continuity exacerbate risk.

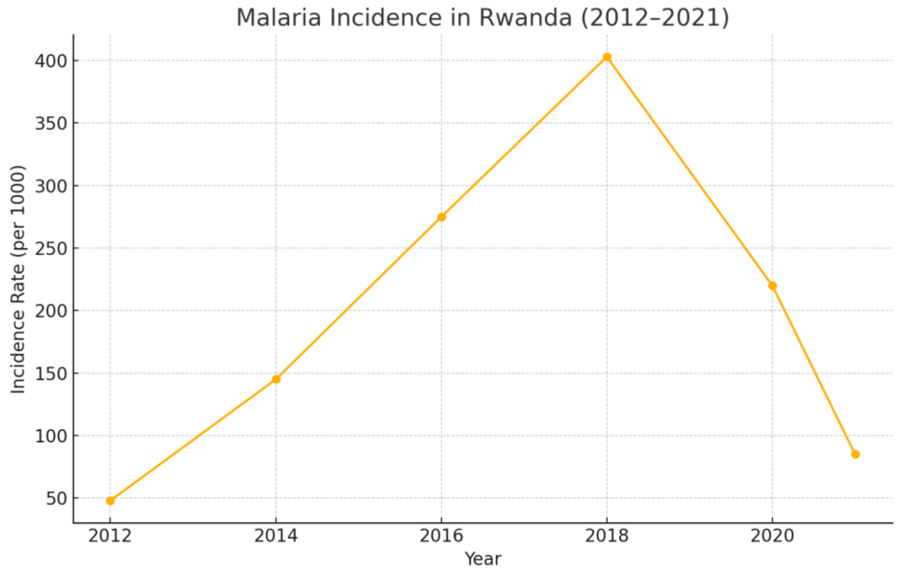

Figure 1: Malaria Incidence in Rwanda (2008–2020). Source: WHO, IHME, HMIS.

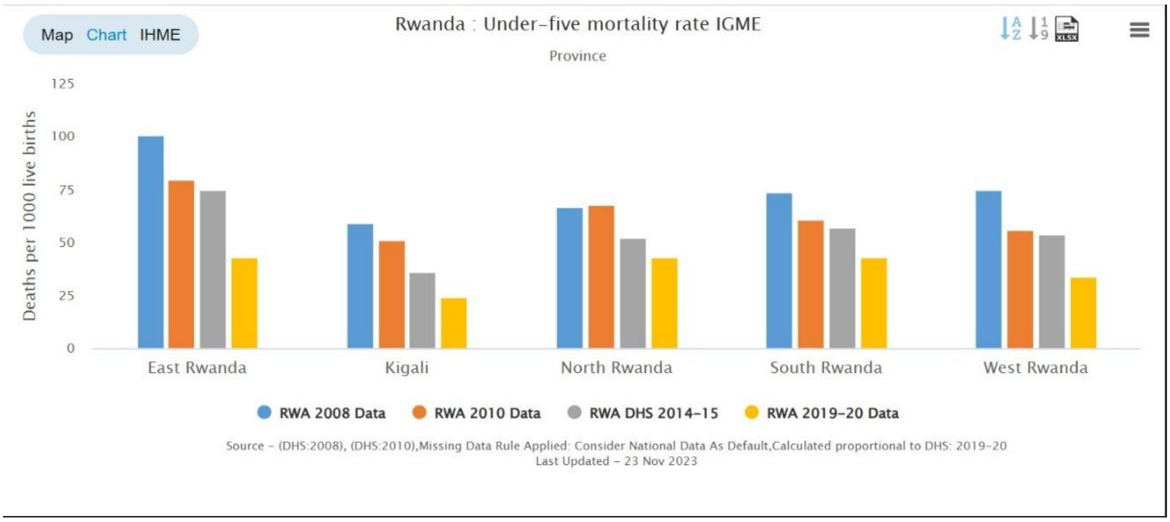

Figure 2: Malaria Incidence in Rwanda (2012–2021). Source: Equist Dashboard, IHME

Environmental factors such as rainfall, deforestation, and land use contribute to vector proliferation. Social factors—migration, housing quality, and health system access—compound vulnerability. Financial affordability and stock availability are the primary bottlenecks for preventive tools like ITNs (coverage at 52%, affordability bottleneck at 42%). Figure 2 highlights trends in ITN distribution.

IV. Results

A. Historical Trends and Intervention Coverage

Rwanda's malaria control history can be divided into distinct phases, with a notable period from 2006 to 2018 marked by unprecedented investments in LLINs, IRS, and ACT. During this phase, nearly 22 million LLINs were distributed, specifically targeting children under five and pregnant women. IRS was strategically implemented in high-endemic districts to disrupt malaria transmission, while ACT became the first-line treatment for confirmed cases. These combined efforts led to significant reductions in malaria incidence and mortality rates, showcasing the effectiveness of integrated control strategies.

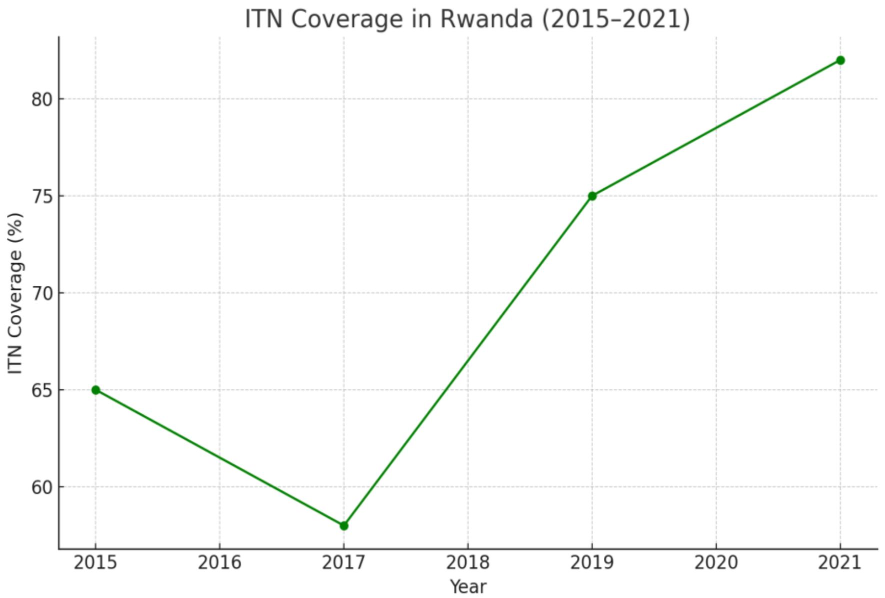

Figure 3: ITN Coverage in Rwanda (2015–2021). Source: DHS, HMIS

B. Impact of Interventions

LLINs and IRS have demonstrably reduced malaria prevalence and mortality. Mathematical models suggest that increased LLIN utilization and extended IRS coverage yield pronounced reductions in symptomatic malaria prevalence. In Huye District, *Anopheles gambiae* s.l. remains the dominant vector, with a sporozoite rate of 1.9%. According to EQUIST, East Rwanda requires the most attention due to equity disparities. equity analyses from EQUIST, providing a comprehensive view of malaria control strategies and their effectiveness.

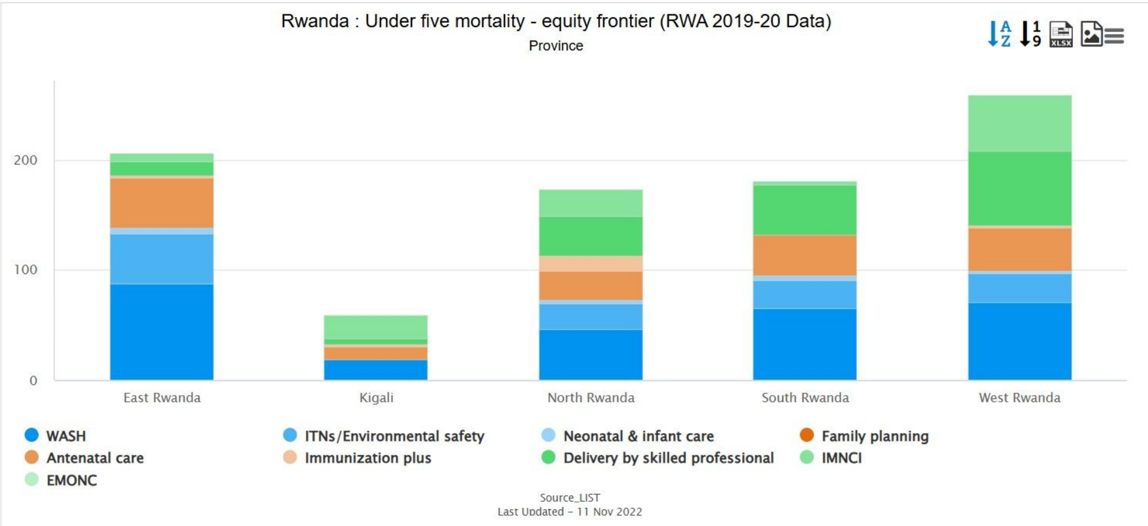

Figure 4: Impact of Interventions in Rwanda by Province (2019–2020). Source: Equist Dashboard, IHME

C. Climate and Non-Intervention Factors

Frameworks now account for rainfall and temperature, which can confound assessments of intervention impact. In Rwanda, there was no strong difference in climate suitability for malaria in pre- and post-intervention periods, suggesting changes are likely due to interventions rather than climate variability. Such considerations underscore the importance of integrating environmental data into comprehensive analyses of malaria control effectiveness.

D. Diagnostic Innovations

Recent studies highlight the role of rapid diagnostic tests (RDTs) and novel smartphone-based risk stratification in improving malaria detection, particularly among school-age children—a key reservoir for transmission. These innovations enable more targeted interventions, such as prompt and appropriate treatment for infected individuals, thereby reducing the overall transmission potential.

E. Vector Ecology

Anopheles gambiae s.l. accounts for 70% of malaria vectors in southern Rwanda, with breeding sites concentrated in sunlit stagnant water bodies such as rice paddies. Targeted vector control remains essential. Vector control measures should include larvicides and habitat modification to disrupt vector breeding cycles.

V. Discussion

A. Efficacy and Limitations of Current Interventions

Integrated interventions, especially LLINs and IRS, have reduced malaria burden, but resurgence since 2012 signals challenges such as insecticide resistance and underdiagnosis. School-age children, often asymptomatic, contribute to ongoing transmission. Strategies to address insecticide resistance might include rotating insecticides or implementing integrated resistance management plans.

B. Cost-Effectiveness

LLINs and IRS remain cost-effective, especially when targeted to high-risk districts. Mathematical models suggest that sustained high coverage is necessary to prevent outbreaks and achieve elimination thresholds. The financial affordability bottleneck is approximately 42% for ITNs, with availability just above 50%. LLINs(long lasting insecticidal nets) have been responsible for nearly 70 percent of the gains made against malaria over the past 15 years, in combination with IRS. This progress averted an estimated 663 million malaria cases.(2)

For insecticide treatment of existing nets, the cost-effectiveness range was US$4-10 per DALY averted; for provision of nets and insecticide treatment $19-85; for residual spraying (two rounds per year) $32-58; for chemoprophylaxis for children $3-12 (assuming an existing delivery system which earlier caused the decline in the cases).(4) **The combination of the above preventive interventions with the vaccine in play would be the ultimate weapon for Rwanda to battle malaria** (0.4 million children vaccinated, 38 thousand cases averted, and 573 deaths averted with child vaccination). (5)

Country	Vaccinees	Cases averted	Deaths averted	DALYs averted discounted	Discounted vaccination costs USD	Discounted health system cost offset USD	Discounted societal cost offset USD
Rwanda	401,461	38,076	573	15,339	11,315,829	16,556	53,491

The costs of preventive treatments in infants and children are low (on average US$2.20 and US$2.90 respectively) The costs and cost-effectiveness of malaria control interventions have been extensively evaluated, and a systematic review found that in most settings, malaria interventions are among the best buys in global health based on relevant indicators. (2)

The curative treatments include Artemisinin combination therapy (ACTs) which are very effective in treating the disease after infection. These anti-malarial drugs were able to cope with the chloroquine resistant types of malaria. Using combination treatments in malaria is essential to prevent losing effective medicines to resistance as ACTs treat almost 98 percent of the cases in Rwanda (2). Rapid testing and quick diagnosis of cases of malaria helps prevent the disease progression while saving millions of dollars.

The reason for the massive rise in the incidence of Malaria after a considerable decline of the number of cases are some of the challenges of the health system to achieve effective coverage for the malaria control interventions. The intervention package needs to be sustained over time to see the reduction and ultimately eradication of the disease. Interestingly, the correlation between effective coverage and economic development was weak, indicating that resource constraints play only a limited role. Such patterns suggest that many system failures are amenable to change. Priority areas for malaria control and eradication policies include identifying the reasons for poor health system performance, intervening to address them, and implementing the respective strategies in program activities. (2)

In 2011, a cost–benefit analysis was conducted that demonstrated that a sustained control program for Malaria in Rwanda would avert an estimated 38 million cases, saving $267 M for the country’s health system, and $547 M in household costs, which is equivalent to 7% of household income. (6) The steep rise in the incidence of malarial cases demands to double down on innovative intervention packages and strategies to reduce the burden of Malaria on the children and society of Rwanda.

C. Recommendations

- Sustain and expand LLIN and IRS coverage, prioritizing high-incidence districts.
- Integrate RDTs and innovative screening (e.g., smartphone imaging) in schools.
- Monitor vector species and insecticide resistance.
- Adjust intervention strategies based on real-time epidemiological and climate data.
- Addressing bottlenecks in commodity availability and financial affordability.

VI. Conclusion

Rwanda's malaria control efforts have achieved substantial gains through integrated interventions. Continued investment in vector control, diagnostics, and adaptive strategies is essential to sustain progress and move toward elimination. In conclusion, recognizing that the disease burden associated with Malaria is responsible for increased Under 5 mortality rates in Rwanda is important now more than ever. Urgent action is required to tackle this public health issue, especially now that the COVID-19 pandemic has affected the coverage of health services and broad socioeconomic determinants of health.

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