

Quantifying the Impact of Malaria Interventions on Children Under 5 in Kenya: A Mathematical Modeling Approach

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Introduction: Malaria and Children Under 5

- **Malaria in Children Under 5:** Malaria is one of the top **5 causes** of death in children under 5 globally, especially in sub-Saharan Africa.
- **Kenya's Malaria Burden:** Over **70%** of Kenya is malaria-endemic, with children under 5 being the most vulnerable.
- **Focus:** This study explores how **ITNs**, **Seasonal Malaria Chemoprevention (SMC)**, and the **RTS,S malaria vaccine** can reduce **mortality**, **incidence**, and improve **economic outcomes** for children under 5.

Malaria in Kenya: A Serious Problem

- **Prevalence:** Malaria remains a major health issue, especially in **high-risk areas** where children under 5 are most vulnerable.
- **Statistics:** In 2020, **19%** of children under 5 tested positive for malaria in endemic regions of Kenya, contributing to **significant morbidity** and **mortality**.
- **Seasonal Outbreaks:** Malaria transmission peaks during the rainy season, leading to seasonal surges, particularly among children.

Objective of the Study

- **Goal:** To quantify the impact of malaria interventions (**ITNs**, **SMC**, and **RTS,S vaccine**) on children under 5 in Kenya.
- **Specific Aims:**
 - Assess **reduction in mortality** among children under 5.
 - Estimate the **reduction in malaria incidence** in this age group.
 - Calculate **economic savings** due to malaria prevention.
 - Assess the **effectiveness** of combined interventions (ITNs + SMC + RTS,S).

Malaria Interventions: How They Work

- **Insecticide-Treated Nets (ITNs):** ITNs reduce malaria transmission by **50%** in children under 5, preventing mosquito bites during sleep.
- **Seasonal Malaria Chemoprevention (SMC):** SMC provides seasonal preventive treatment, reducing malaria incidence by **75%** during peak transmission.
- **RTS,S Vaccine:** The RTS,S malaria vaccine reduces severe malaria by **30%** in children under 5, lowering hospital admissions and mortality.
- **Indoor Residual Spraying (IRS):** IRS reduces mosquito populations, resulting in up to a **60% reduction** in transmission.

Methodology: SEIR Model Overview

- **SEIR Model:** The Susceptible-Exposed-Infected-Recovered (SEIR) model simulates the spread of malaria among children under 5 in Kenya.
- **Compartment**s of the SEIR model:
 - **S:** Susceptible (at risk of contracting malaria).
 - **E:** Exposed (infected but not yet infectious).
 - **I:** Infected (transmitting malaria).
 - **R:** Recovered (immune).
- **Key Equations:**

$$\begin{aligned}\frac{dS}{dt} &= -\beta \cdot \frac{S \cdot I}{N} \\ \frac{dE}{dt} &= \beta \cdot \frac{S \cdot I}{N} - \sigma \cdot E \\ \frac{dI}{dt} &= \sigma \cdot E - \gamma \cdot I \\ \frac{dR}{dt} &= \gamma \cdot I\end{aligned}$$

Deriving the Basic Reproduction Number R_0

- **Basic Reproduction Number R_0 :** Represents the average number of secondary infections produced by one infected individual in a completely susceptible population.
- The **next-generation matrix** method helps calculate R_0 .
- Computing for, R_0 in this model we get:

$$R_0 = \frac{\beta \cdot \sigma}{\gamma}$$

- **Interpretation:**

- If $R_0 > 1$, the disease will spread in the population.
- If $R_0 < 1$, the disease will eventually die out.

Parameter Values in the SEIR Model

- The key parameters used in the SEIR model are:
 - β (Transmission rate): $\beta = 0.5 \text{ day}^{-1}$
 - σ (Exposure rate): $\sigma = 0.2 \text{ day}^{-1}$
 - γ (Recovery rate): $\gamma = 0.1 \text{ day}^{-1}$
- **Interpretation of Parameters:**
 - **Transmission rate (β):** This parameter controls how easily malaria is transmitted from infected to susceptible individuals. Higher β means more transmission.
 - **Exposure rate (σ):** The rate at which exposed individuals become infectious. A higher σ indicates faster progression from exposed to infectious.
 - **Recovery rate (γ):** The rate at which infected individuals recover. A higher γ means infected individuals recover faster, reducing the number of people capable of transmitting the disease.

Sensitivity Indices of Model Parameters

- The **sensitivity index (SI)** measures how sensitive R_0 is to changes in each parameter.
- The **sensitivity indices** for each parameter are:
 - For β (Transmission Rate): $S_{\beta}^{R_0} = 1$
 - For σ (Exposure Rate): $S_{\sigma}^{R_0} = 1$
 - For γ (Recovery Rate): $S_{\gamma}^{R_0} = -1$

Interpretation of Sensitivity Indices

- $S_{\beta}^{R_0} = 1$: R_0 is **directly proportional** to β . A 1% increase in β results in a 1% increase in R_0 . This suggests **transmission** plays a critical role in the spread of malaria.
- $S_{\sigma}^{R_0} = 1$: R_0 is **directly proportional** to σ . A 1% increase in σ results in a 1% increase in R_0 . This suggests that **faster progression** from exposed to infectious individuals leads to higher transmission.
- $S_{\gamma}^{R_0} = -1$: R_0 is **inversely proportional** to γ . A 1% increase in γ results in a 1% decrease in R_0 . This indicates that **faster recovery** reduces the number of infectious individuals, thus lowering the transmission rate.

Results: Model Predictions

- **Malaria Mortality Reduction:** The model predicts a reduction of 1,841 deaths annually in children under 5.
- **Malaria Incidence Reduction:** A 40% reduction in malaria incidence is predicted.
- **Economic Savings:** The model estimates savings of Ksh 1.78 billion annually due to reduced treatment costs.
- These predictions are based on model calibration with real-world data.

Sensitivity Analysis of ITNs, SMC, and Combined Interventions

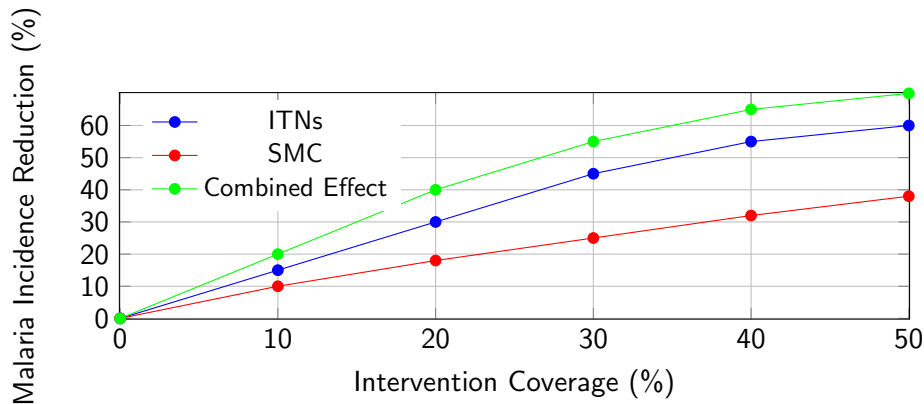


Figure: Sensitivity analysis showing the impact of varying intervention coverage on malaria incidence reduction

- **Expand ITN distribution:** Ensure all children under 5 in endemic areas receive an ITN to reduce transmission.
- **Increase access to SMC:** Expand the use of SMC during peak transmission periods to reduce malaria cases in children.
- **RTS,S vaccine rollout:** Focus on expanding the use of the RTS,S vaccine to prevent severe malaria in young children.

Limitations of the Study

- Relies on **secondary data**, which may not capture regional variations in malaria transmission.
- Assumes **uniform effectiveness** of interventions across all regions of Kenya.
- Does not account for potential changes in **transmission dynamics** due to climate change or **insecticide resistance**.

- **ITNs, SMC, and RTS,S** are highly effective in reducing malaria mortality, incidence, and treatment costs for children under 5 in Kenya.
- These interventions, when widely implemented, have the potential to significantly reduce the malaria burden.
- Continued efforts should focus on increasing **coverage**, especially in underserved regions.

- ① **World Health Organization (WHO).** (2015). *Insecticide-Treated Nets: Impact on Malaria Incidence.*
- ② **Centers for Disease Control and Prevention (CDC).** (2017). *IRS and Malaria Transmission Reduction.*
- ③ **GlaxoSmithKline (GSK).** (2021). *RTS,S Vaccine: Effectiveness in Preventing Severe Malaria.*
- ④ **Kenya Ministry of Health.** (2020). *Malaria Prevalence and Mortality among Children Under 5.*
- ⑤ **Kenya Ministry of Health.** (2019). *Economic Impacts of Malaria Interventions in Kenya.*
- ⑥ **World Health Organization (WHO).** (2020). *Seasonal Malaria Chemoprevention and Its Impact.*



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