Identifying Key Factors in Predicting *Plasmodium Falciparum* Malaria Transmission in Maharashtra: A Data-Driven Mathematical Model

THE COLLEGE OF WOOSTER

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ABSTRACT

Malaria remains a major health issue in India, with ***Plasmodium falciparum*** as the deadliest parasite. This study develops a data-driven **SIR-SI** model to predict malaria transmission in **Maharashtra**, focusing on Nashik, Brihan Mumbai, and Gadchiroli. Incorporating human and mosquito populations, the model integrates seasonality, immunity loss, control measures, and mosquito breeding dynamics. Using **real-world data and parameter estimation**, results reveal regional differences in transmission, influenced by climate, population density, healthcare access, and vector control. Sensitivity analysis highlights the impact of human-to-mosquito transmission and interventions, offering insights for targeted malaria prevention in Maharashtra and other endemic regions.

BACKGROUND

Why India?

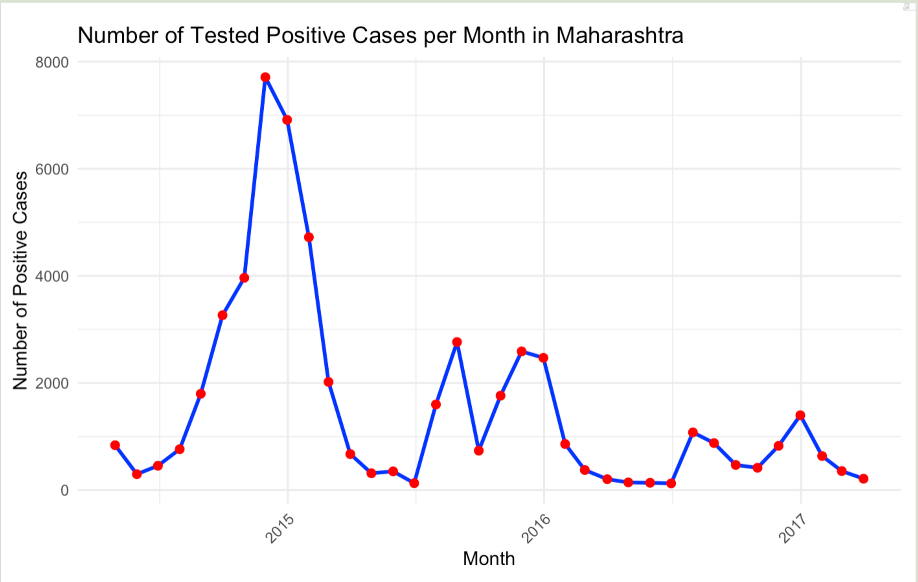
- India accounts for a significant portion of Southeast Asia's malaria cases and spends approximately **$1.9 billion** annually combating the disease
- Large population and poverty
- Family history

Why *Plasmodium Falciparum?*

- It causes the **most deaths** globally due to rapid multiplication and resistance to treatment
- Lack of research predicting only *Plasmodium falciparum*

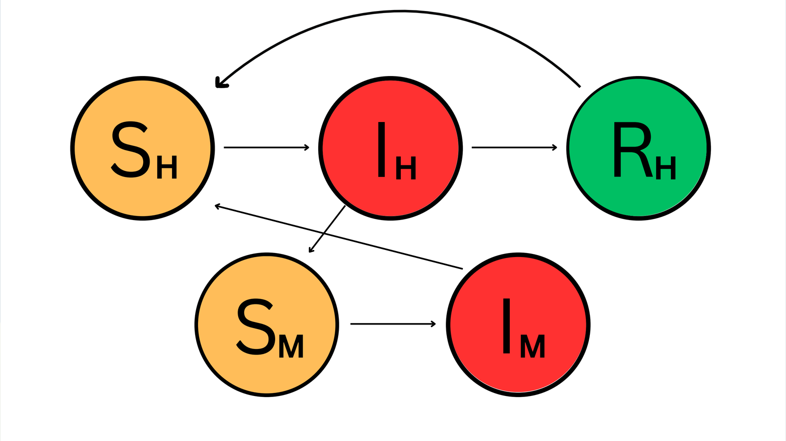
Why Maharashtra?

- Differing climates, population, urbanization throughout districts
- Districts chosen: **Nashik, Brihan Mumbai, Gadchiroli**
    - Each with varying number of cases



METHODOLOGY

SIR-SI Model



Key Parameters

- Human-to-Mosquito transmission rate (β^*_{HM})
- Mosquito-to-Human transmission rate (β^*_{MH})
- Human recovery rate (γ_H)
- Mosquito death rate (μ_M)
- Base immunity loss rate (δ_0)
- Seasonality factor (σ) → ***SF***
- Immunity loss factor (ρ)
- Control measures (ζ)
- Rainfall effect (η) → ***MBF***

Final Differential Equations

- $\frac{dS_H}{dt} = -\beta^*_{HM} \cdot SF \cdot S_H \cdot I_M \cdot (1-\zeta) + \delta \cdot R_H$
- $\frac{dI_H}{dt} = \beta^*_{HM} \cdot SF \cdot S_H \cdot I_M \cdot (1-\zeta) - \gamma_H \cdot I_H$
- $\frac{dR_H}{dt} = \gamma_H \cdot I_H - \delta \cdot R_H$
- $\frac{dS_M}{dt} = -\beta^*_{MH} \cdot SF \cdot S_M \cdot I_I \cdot MBF$
- $\frac{dI_M}{dt} = \beta^*_{MH} \cdot SF \cdot S_M \cdot I_H \cdot MBF - \mu_M \cdot I_M$

R Code

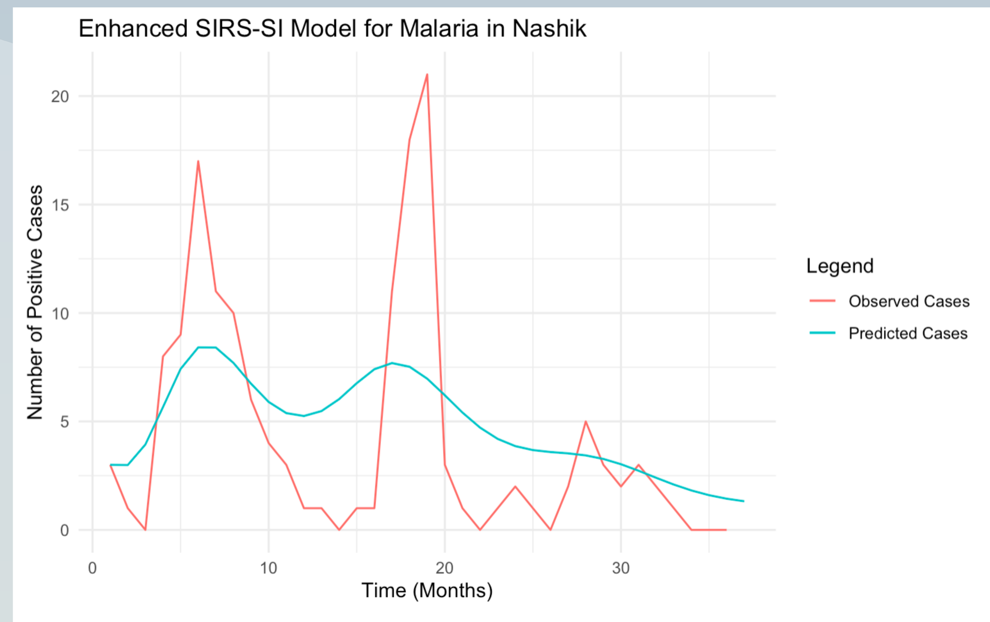
- **Goal: Optimization** of parameters so the predicted model fits closely to the observed data
- Use **Sum of Squared Errors (SSE)** for optimization

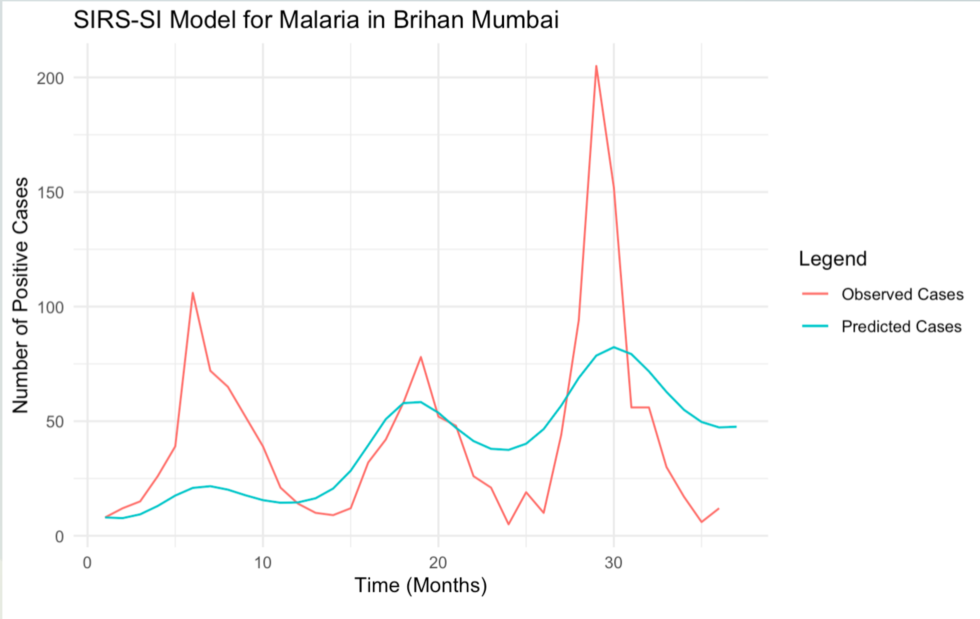
$$SSE = \sum_{i=1}^{n} (Observed_i - Predicted_i)^2$$

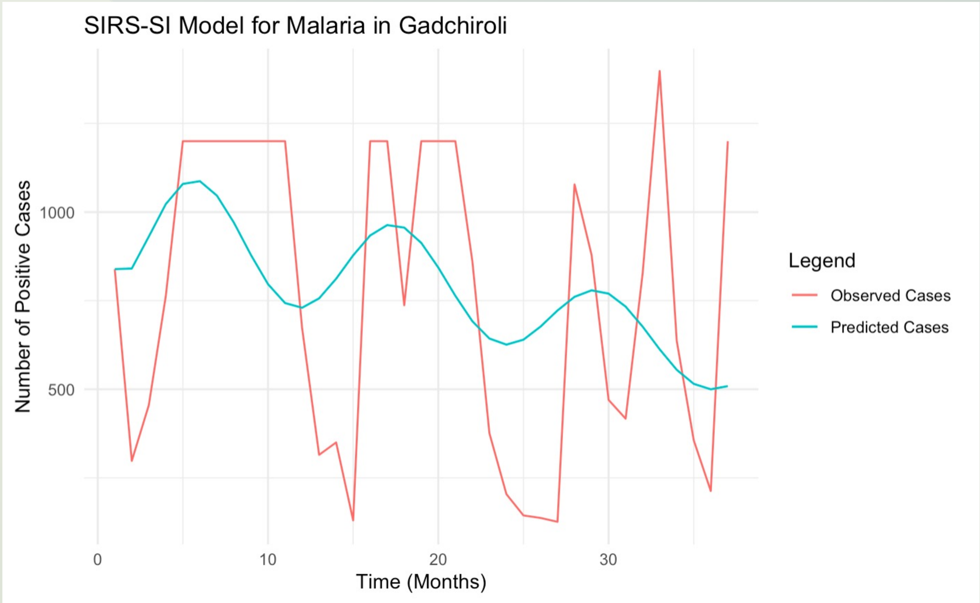
- Sensitivity Analysis using **Partial Rank Correlation Coefficient (PRCC)**
    - 0 = parameter has no real effect
    - -1 or 1 = parameter has a very string effect

RESULTS

Graphs of Observed vs Predicted







Sensitivity Analysis

	Nashik	Mumbai	Gadchiroli
β^*_{HM}	+ 0.70	+ 0.35	+ 0.60
β^*_{MH}	+ 0.125	+ 0.15	+ 0.075
γ_H	- 0.54	- 0.70	- 0.58
μ_M	- 0.48	- 0.56	- 0.31
δ_0	+ 0.004	+ 0.04	+ 0.03
σ	+ 0.99	+ 0.98	+ 0.99
ρ	+ 0.15	+ 0.33	+ 0.15
ζ	+ 0.99	+ 0.99	+ 0.98
η	+ 0.94	+ 0.79	+ 0.94

Conclusions

Data Findings

- **Seasonality and control efforts** are the most influential factors across all districts
- **Human recovery rate** and **mosquito mortality** greatly impact urban areas like Brihan Mumbai
- **Human-to-mosquito transmission rates** are especially critical in rural areas like Gadchiroli

Recommendations

- Intensifying **IRS/LLIN distribution** and **health campaigns** before monsoon seasons
- Expanding **access to the RTS,S/AS01 vaccine** for children and at-risk groups
- Improving **healthcare infrastructure** in remote areas and urban slums.

Future Research

- Enhance the Model Structure – add **Exposed (E)**
- Account for Vector Resistance – mosquitoes **develop resistance** with repeated exposure
- Expand Disease and Geographic Scope
    - More malaria species
    - Including variables like temperature and humidity
- Apply the Model Across India
    - Add additional districts/states

References

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