Population Dynamics Modeling: Dengue Infection in Bangladesh

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Model Selection

Chosen Model: SIR Model for Dengue Infection in Bangladesh

Assumptions and Parameters

- The population is divided into Susceptible (S), Infected (I), and Recovered (R).
- Dengue spreads through mosquito bites, with transmission dependent on contact rates.
- Individuals recover from infection and gain temporary immunity.
- Birth and death rates of the human population are negligible for the short-term model.
- The mosquito population is assumed constant.

Mathematical Formulation

The SIR model is described by the following differential equations:

$$\frac{dS}{dt} = -\beta \frac{SI}{N} \tag{1}$$

$$\frac{dI}{dt} = \beta \frac{SI}{N} - \gamma I \tag{2}$$

$$\frac{dR}{dt} = \gamma I \tag{3}$$

where:

- S, I, and R represent the susceptible, infected, and recovered populations.
- β is the transmission rate (probability of infection per contact).
- γ is the recovery rate.
- N is the total population size ($S + I + R$ is assumed constant).

The basic reproduction number, $R_0 = \frac{\beta}{\gamma}$, determines whether an outbreak spreads ($R_0 > 1$) or dies out ($R_0 < 1$).

Python Implementation

Model Setup

The SIR model was simulated with the following parameters:

- Transmission rate: $\beta = 0.5$
- Recovery rate: $\gamma = \frac{1}{14}$
- Total population: $N = 1,000,000$
- Initial conditions: $S_0 = 999,000$, $I_0 = 1,000$, $R_0 = 0$

The simulation ran for 365 days to analyze outbreak progression.

Enhanced Model Features

To refine the analysis, the model incorporated:

- **Parameter Variability:** Simulating different β values $(0.3, 0.5, 0.7)$ to study outbreak severity.
- **Peak Infection Analysis:** Identifying peak infection time and magnitude.
- **Improved Visualization:** Labeling axes, adding legends, and annotating key points.

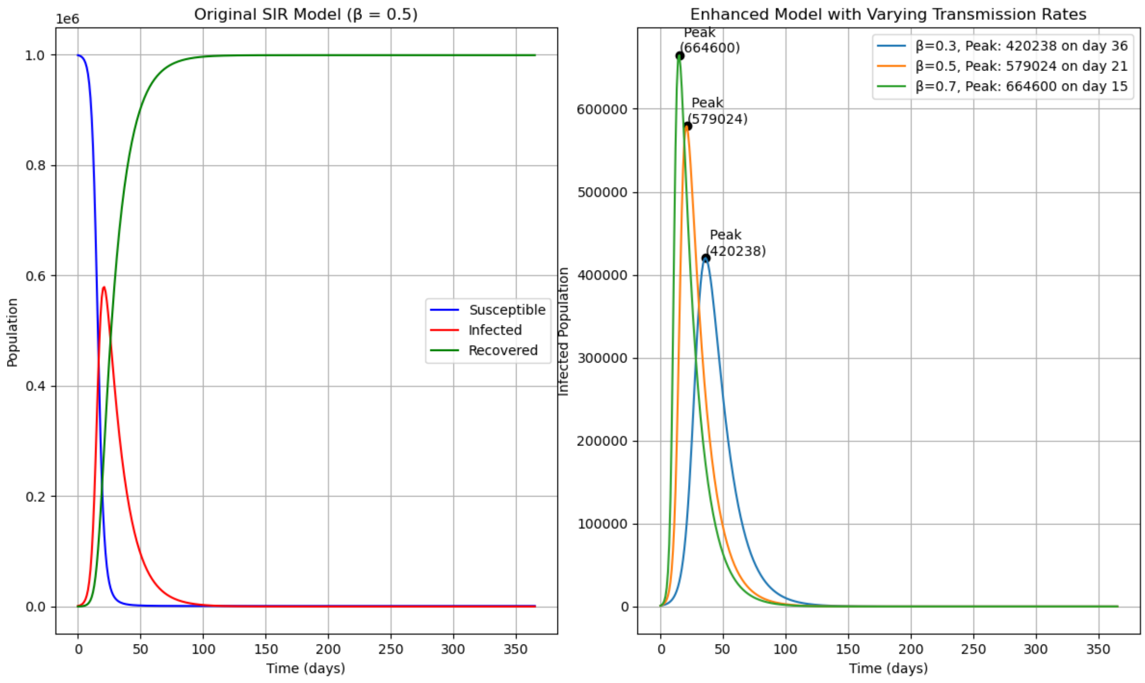

Figure 1: SIR Model Simulation for Dengue Infection in Bangladesh. The plot shows the evolution of infections for different transmission rates (β).

Analysis and Discussion

Key Observations

The SIR model highlights the rise and decline of infections, with peak severity influenced by transmission rate (β). A higher β results in an earlier, more intense outbreak, whereas a lower γ prolongs the infectious period.

Impact of Parameter Variation

Varying β illustrates different outbreak dynamics:

- **Lower β (0.3):** Slower spread, prolonged outbreak, lower peak.
- **Baseline β (0.5):** Moderate outbreak with a significant peak.
- **Higher β (0.7):** Rapid spread, sharp peak, faster resolution.

Equilibrium and Stability

The system trends toward a **disease-free equilibrium** as $I \to 0$, assuming no reinfection. No endemic equilibrium exists in this model.

Limitations

While useful, the model has simplifying assumptions:

- **Constant Population:** Ignores births, deaths, and migration.
- **No Seasonality:** Dengue outbreaks depend on mosquito activity, which varies seasonally.
- **Homogeneous Mixing:** Assumes equal interaction probability, ignoring geographic and social structures.
- **No Vector Dynamics:** Mosquito population dynamics are not modeled.