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BRIDGING THEORY AND EPIDEMIOLOGY: A NEXT-GENERATION MATHEMATICAL MODEL FOR MALARIA ELIMINATION STRATEGIES.

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ABSTRACT

Malaria remains a formidable global health challenge, necessitating advanced modeling frameworks to inform eradication strategies. Here, we present a refined mathematical model that extends classical approaches by incorporating three critical, yet often overlooked, epidemiological features: (1) waning immunity in human populations (SEIRS dynamics), (2) asymmetric transmission probabilities between vectors and hosts ($b \neq c$), and (3) disease-induced mortality. Our coupled human-mosquito system employs an SEIRS structure for humans and an SEI framework for mosquitoes, explicitly accounting for the decay of acquired immunity—a key driver of reinfection in endemic regions. The derived basic reproduction number (R_0) incorporates mosquito-to-human population ratios, enabling region-specific assessment of intervention efficacy.
Through equilibrium and sensitivity analyses, we demonstrate how our model outperforms conventional approaches in predicting transmission patterns, particularly in high-burden settings with persistent reinfection. Numerical simulations reveal that ignoring immunity loss (as in SEIR models) overestimates the long-term impact of mass drug administration by up to 30%, while neglecting vector-host asymmetry underestimates the required bed-net coverage for outbreak prevention. Furthermore, we identify optimal intervention thresholds by mapping R_0 suppression to combined strategies (e.g., vaccines + vector control).
This work provides a adaptable toolkit for policymakers, bridging theoretical epidemiology and field implementation. By aligning with recent WHO guidelines and empirical data, our framework offers a robust platform for evaluating malaria elimination campaigns in the era of insecticide resistance and climate change.

Keywords: Malaria modeling, SEIRS-SEI framework, waning immunity, basic reproduction number, asymmetric transmission, intervention optimization.

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