Developing a Mathematical Model to Study Dynamics of Dengue Epidemics and Controllability of Transmission of Dengue

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Abstract

Dengue disease, which is a mosquito-borne disease, has been an important public health problem specially in the tropical and sub-tropical regions in the world. Neither vaccine nor successful treatment has been found yet to dengue disease. Therefore prevention and control play a vital role in minimizing the risk of dengue and its burden from the vulnerable populations.

Mathematical models of dengue with fixed parameters do not completely describe the dynamics of the dengue transmission since the dynamics of dengue depend on various external factors such as climate, human mobility, geography and demography. We use wavelet and cross wavelet approach to understand the patterns of dengue outbreaks in urban Colombo and their relationships with external factors such as climate and human mobility. The rainfall is found to have a leading effect to dengue incidents in Colombo with a lag of approximately eight weeks.

A climate risk index is developed using fuzzy set theory to investigate the risk from rainfall and temperature to dengue. We validate the predicted risk by the fuzzy model with the reported dengue incidents in Colombo from year 2006-2011. The risk index is found to be 80 percent accurate (error is less than 0.4) to predict the real risk of dengue in 72.28% of the time. This climate risk index is used to model the nonlinear dynamics of the dengue mosquito density. This model to mosquito density addresses both the biological spread of mosquitoes and the climate favorability to their reproduction. The outcome of this model is also validated with reported dengue incidents in Colombo. The level of accuracy of the model is at least 90 percent accurate (error less than 0.25) in 74.19% of the time and it is at least 80 percent accurate (error less than 0.4) in 94.77% of the time. We simulate the SIR (Susceptible, Infected and Recovered) model for dengue with climate varying mosquito density. The simulated infected human distribution is observed to have captured the significant properties such as trend, periodicity and peaks in the reported dengue incidents time series in Colombo. We fix the influence from temperature and the

SIR model is simulated only considering the variation of rainfall. This dynamic model can be used to set up an early warning system for dengue in Colombo with respect to approximately two months leading rainfall.

We introduce two measures u_1 and u_2 to control adult mosquitoes and growing juveniles. We implement control measures with four combinations of u_1 and u_2. The numerical results of the SIR model suggest that the dynamic of the infections has changed and the number of infections is reduced as the efficiency of the control measures are increased.