Spatiotemporal Modelling of Dengue

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The management of infectious diseases, such as dengue, is becoming an increasingly important public health issue. However, the implementation of effective preventative and control methods is hindered by a lack of understanding of the roles that intrinsic and extrinsic factors play in transmission. Dengue is an emerging and re-emerging disease and is rapidly becoming one of the most significant arthropod-borne diseases of humans, both in terms of morbidity and mortality. An estimated 2.5 – 3 billion people live in areas that are at risk for epidemic transmission. Dengue exhibits complex spatiotemporal dynamics, and so both the spatial and social structures of populations over time must be considered to produce accurate models.

We have investigated an individual-based, spatiotemporal simulation model to examine the effect that the mobility of dengue patients has on transmission dynamics. The model describes a simple village situation whereby the individuals of the population may move between houses and public locations. Each house and public centre contains a colony of immobile vectors. It was found that the mobility of the infected host does indeed affect the transmission dynamics of dengue. As the mobility of the infected hosts increased, so did the probability of an epidemic occurring; the number of infected individuals and the maximum daily case numbers, whilst the duration of the epidemics decreased. That is, more infections occurred over a shorter period of time when dengue patients continued to move about the village. Since the severity of the disease will affect the mobility of the patient, we propose that it is in the virus' best interest not to incapacitate its host. Therefore the mobility of the host will not be significantly affected and will increase the exposure of the virus to susceptible vectors and hosts.

We also evaluated the impact of weather and climatic variables on the incidence of dengue in Cairns, Queensland from 1993-2005. Three types of models were explored: Binary, Poisson Regression and Zero-inflated count models. Within these, General Linear Models, Generalised Linear Models (GLM) and Generalised Additive Models (GAM) were investigated, using time-series analysis of the monthly case incidence of dengue. The weather and climatic variables that were included in this study were: monthly rainfall and evaporation; average maximum monthly temperature; average minimum monthly temperature and average monthly temperature. The model equations that were found to describe the incidence of dengue in Cairns from 1993-2005 were:

1. $$\boldsymbol{\mu_t = 0.78 + s_1(Z_{t-1}, 7.63) + s_2(MinT_t, 8.32) + s_3(\mathrm{MaxT_t}, 3.73) + s_4(Rainfall_t, 7.97) + s_5(Evaporation_t, 4.49) + s_6(Rainfall_{t-1}, 8.31) + s_7(Evaporation_{t-1}, 7.61)}$$

2. $$\boldsymbol{\mu_t = 0.77 + s_1(Z_{t-1}, 7.39) + s_2(Rainfall_t, 8.20) + s_3(Evaporation_t, 8.34) + s_4(Rainfall_{t-1}, 8.78) + s_5(Evaporation_{t-1}, 7.50)}$$

Where Z_t is the number of dengue cases at time t (current month) and $Z_t \sim Poisson(\mu_t)$;
Z_{t-1} is the number of dengue cases one month prior to time t ;
$MinT_t$ and $MaxT_t$ are the average minimum and maximum monthly temperatures at time t respectively; $Rainfall_t$ and $Evaporation_t$ are the amount of Rainfall and Evaporation (measured in mm) at time t;
$Rainfall_{t-1}$ and $Evaporation_{t-1}$ are the amount of Rainfall and Evaporation (measured in mm) at one month prior to time t;
$S_i(X)$ where $i = 1...7$ are non-parametrically smoothed functions (spline)

A predictive model was also developed so that future dengue case incidence may be predicted, given previous months' data. The predictive model that was obtained is:

3. $$\boldsymbol{\mu_t = 0.79 + s_1(Z_{t-1}, 8.74) + s_2(MinT_{t-1}, 7.44) + s_3(Rainfall_{t-1}, 8.96) + s_4(Evaporation_{t-1}, 8.63)}$$

The models were validated by comparing the number of cases that were predicted by the models to the observed number of dengue cases from 1993-2005.

Our Binary models were found to be less accurate than the above Poisson Regression Models:

4. $$logit(p_t) = -0.7801 + 1.0652 \cdot Z_{t-1} + s_1(MinT_t, 4.139) + s_2(MaxT_t, 6.195) + s_3(Rainfall_t, 1) + s_4(Evaporation_t, 7.555) + s_5(MinT_{t-1}, 1) + s_6(MaxT_{t-1}, 3.166) + s_7(Rainfall_{t-1}, 1) + s_8(Evaporation_{t-1}, 1)$$

5. $$logit(p_t) = -0.6122 + 0.9372 \cdot Z_{t-1} + s_1(MinT_{t-1}, 3.016) + s_2(MaxT_{t-1}, 1) + s_3(Evaporation_{t-1}, 1)$$

Where

$$Z_{t-1} = \begin{cases} 1 \text{ if there is at least 1 dengue case per month} \\ 0 \text{ otherwise} \end{cases} \quad ; \quad Z_t \sim Bernoulli(p_t)$$

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Table 1. Goodness of fit statistics for chosen models

Model	**1**	**2**	**3 (Predictive)**	**4**	**5**
Model Type	Poisson Regression	Poisson Regression	Poisson Regression	Binary	Binary
AIC	665.02	677.3	729.95	195.24	199.35
Adjusted R^2	0.982	0.979	0.969	0.282	0.136
Deviance Explained	95.4%	94.5%	92.4%	34.5%	13.9%

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