Modelling the risk of dengue for tourists in Rio de Janeiro, during the FIFA confederation cup in Brazil 2013

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Mathematical modeling

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We study a mathematical modeling technique to estimate the risk for travelers of contracting dengue in Rio de Janeiro during the FIFA Confederations Cup Brazil 2013. We used as basis an adaptation from the mathematical model developed by Massad et al.[1].

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- The dengue virus (DEN) comprises four distinct serotypes (DEN-1, DEN-2, DEN-3 and DEN-4) which belong to the genus Flavivirus, family Flaviviridae.
- Symptoms range from a mild fever to incapacitating high fever, with severe headache, pain behind the eyes, muscle and joint pain, and rash.

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- Dengue incidence is on the rise as a consequence of an increasing distribution of the vector *Aedes aegypti* (as well as a second vector, *A. albopictus*) as a result of urbanization, increased human migrations and air travel, flooding from global warming, and serious public health lapses in effective vector containment.

Figure: http://www.dedetizacaoinsetan.com.br/wp-content/uploads/2010/12/aedesegyptihighres.jpg

Dengue in the world

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- International travel is one of the factors that implicate in the increase in the incidence of dengue, because it introduces new strains to different parts of the world. The urbanization; overpopulation; crowding; poverty; and a weakened public health infrastructure, also interfere in this incidence[4],[5].
- "Dengue is endemic in most tropical and subtropical countries, many of which are popular tourist destinations"[6].

Rio de Janeiro

Rio de Janeiro, a State of Brazil with a population of about 16 million, is endemic for dengue. In the first 12 weeks of 2013 it was reported more than 28,000 cases.[7].

It is possible to calculate risk estimates for dengue-endemic countries as long as local data on the force of infection and variations over time are available[8].

The Model

$$
Humans \begin{cases}
\dfrac{dS_H(t)}{dt} - abI_M(t)\dfrac{S_H(t)}{N_H(t)} - \mu_H S_H(t) + \\
\qquad r_H N_H(t)\left(1 - \frac{N_H(t)}{\kappa_H}\right) \\
\dfrac{dI_H(t)}{dt} = abI_M(t)\dfrac{S_H(t)}{N_H(t)} - (\mu_H + \gamma_H + \alpha_H)I_H(t) \\
\dfrac{dR_H(t)}{dt} = \gamma_H I_H(t) - \mu_H R_H(t)
\end{cases} \tag{1}
$$

The Model

$$
Mosquitoes \begin{cases}
\frac{dS_M(t)}{dt} = -\mu_m S_M(t) - acS_M(t)\left[\frac{I_H(t)+I'_H(t)}{N_H(t)}\right] + \\
\quad r_M N_M \left(1 - \frac{N_M(t)}{\kappa_M}\right) \\
\frac{dL_M(t)}{dt} = acS_M(t)\left[\frac{I_H(t)+I'_H(t)}{N_H(t)}\right] - \\
\quad e^{-\mu_m \tau} acS_M(t-\tau)\left[\frac{I_H(t-\tau)}{N_H(t-\tau)}\right] - \mu_m L_M(t) \\
\frac{dI_M(t)}{dt} = e^{-\mu_m \tau} acS_M(t-\tau)\left[\frac{I_H(t-\tau)}{N_H(t-\tau)}\right] - \mu_m I_M(t)
\end{cases} \tag{2}
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The Model

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Travellers \begin{cases} \dfrac{dS'_H(t)}{dt} = -abI_M(t)\dfrac{S'_H(t)}{N_H(t)} - \mu_H S'_H(t) \\[2ex] \dfrac{dI'_H(t)}{dt} = abI_M(t)\dfrac{S'_H(t)}{N_H(t)} - (\mu_H + \gamma_H + \alpha_H)I'_H(t) \\[2ex] \dfrac{dR'_H(t)}{dt} = \gamma_H I'_H - \mu_H R'_H(t) \end{cases} \tag{3}
$$

$$\pi^{Dengue}_{Travellers} = \frac{\int_{\Omega}^{\Omega+\omega} S'_h(t)h(t)dt}{N'_H(\Omega)} \tag{4}$$

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Where $S'_h(t)$ is the number of susceptible humans in the cohort. And $h(t)$ is the force of infection of dengue, defined as the per capita number of new cases per time unit[1] and expressed as

$$h(t) = ab\frac{I_M(t)}{N_H(t)} \tag{5}$$

A stochastic approximation

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- The proportion of bites that are actually from infective mosquitoes,
- The mosquitoes daily mortality rate,
- The dengue induced mortality rate of humans .

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Now, with this result,to obtain the risk, it isn't necessary all those data. We need simply determine the force of infection and we will have the risk.

Estimate the force of infection

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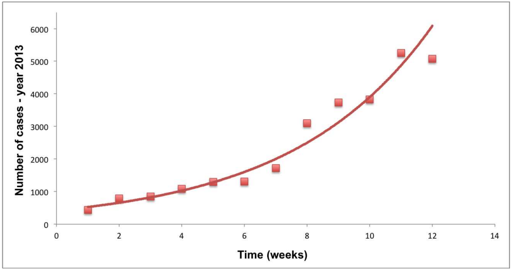

Figure: Number of weekly dengue cases for the first 12 weeks of the year 2013 in Rio de Janeiro.

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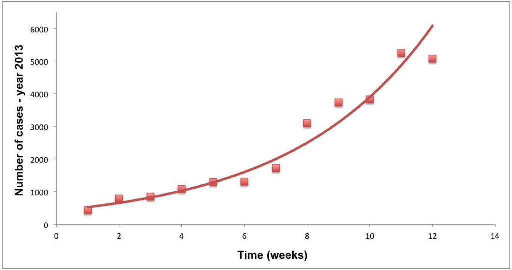

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$\lambda_{2013} = 0.032.$

Correction factor

To achieve a better fit, i.e. find λ that the tourist is susceptible to, we opted to obtain the rate between the risk of a native and the risk of a tourist, for the years 2008 and 2010 in order to remedy the λ_{2013} found. We named this rate correction factor.

Number of tourists infected in Rio de Janeiro

Underreporting	2008	2010
1 : 3	2.22	6.49
1 : 5	3.70	10.82
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Then, dividing the total number of tourists infected by total number of tourists who visited Rio de Janeiro, we obtain the per capita risk for tourists.

Estimated risk per capta for tourists in 2008 and 2010

Underreporting	2008	2010
1 : 3	$6,42\text{x}10^{-6}$	$1,75\text{x}10^{-5}$
1 : 5	$1,07\text{x}10^{-5}$	$2,92\text{x}10^{-5}$
1 : 10	$2,14\text{x}10^{-5}$	$5,84\text{x}10^{-5}$

In 2008, 345,832 tourists went to Rio de Janeiro and in 2010 this number rose to 370,425.

Force of infection

Through the number of infections in the first weeks of 2008 and 2010, we obtained the corresponding λ.

Force of infection in 2008

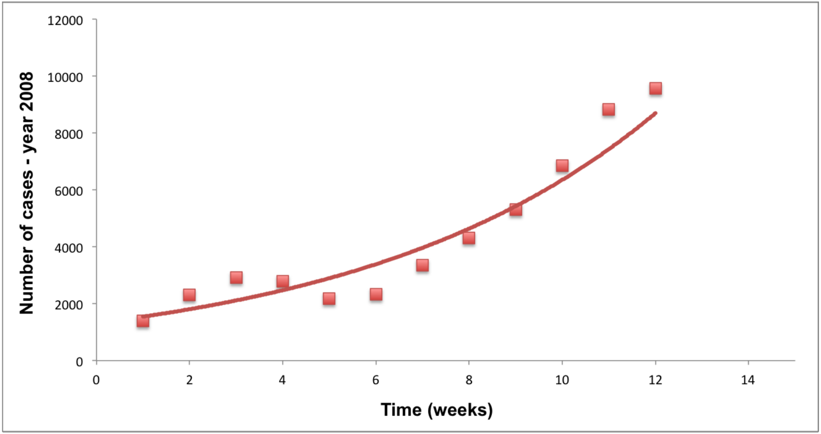

Figure: Number of weekly dengue cases for the first weeks of the year 2008 in Rio de Janeiro.

Force of infection in 2010

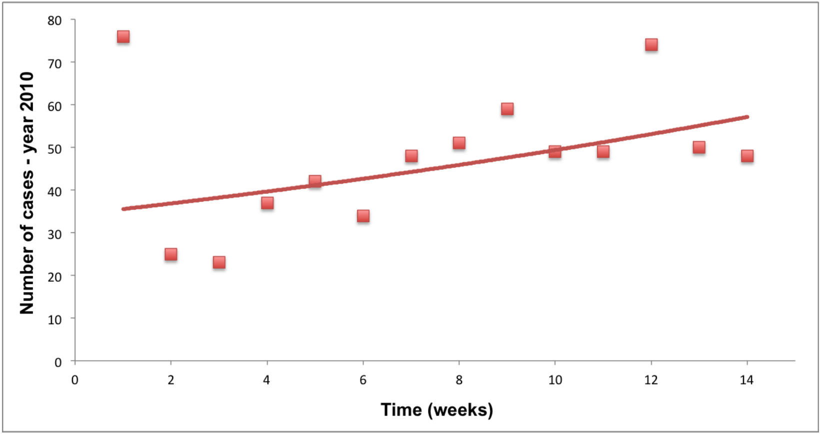

Figure: Number of weekly dengue cases for the first weeks of the year 2010 in Rio de Janeiro.

The fittings in the graphics give us $\lambda_{2008} = 0.022$ and $\lambda_{2010} = 0.0052$.
Applying $\pi = \left[1 - e^{-\lambda t}\right]$ we obtained the risk of a tourist to be infected in 2008 and the risk of a tourist to be infected in 2010:

$$\pi_{2008} = 26.96\%$$
$$\pi_{2010} = 7.04\%$$

Dividing the estimated risk for a resident by the risk estimated for a traveler, we obtained the correction factor.

The value of correction factor in 2008 and 2010

Underreporting	2008	2010
1 : 3	41,321	4,015
1 : 5	24,793	2,409
1 : 10	12,396	1,205

That means that in 2008, for underreporting 1:3, a tourist had a risk 41,321 times smaller to be infected than a resident of Rio de Janeiro, for example.

Finally, with the data presented above, we could determine the risk of a traveler acquiring dengue in 2013, for 14 days of stay in Rio de Janeiro.

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Finally, with the data presented above, we could determine the risk of a traveler acquiring dengue in 2013, for 14 days of stay in Rio de Janeiro.
We used t=14 days because this was the average time a tourist spent in the country during the FIFA Confederations Cup.

Risk in 2013 - Using the correction factor by year

Underreporting	*Risk using* *adjust*-2008	Cases x10, 000	*Risk using* year *adjust*-2010	Cases x10, 000
1 : 3	$8,74\text{x}10^{-6}$	0.087	$8,99\text{x}10^{-5}$	0.90
1 : 5	$1,46\text{x}10^{-5}$	0.146	$1,50\text{x}10^{-4}$	1.50
1 : 10	$2,91\text{x}10^{-5}$	0.291	$3,00\text{x}10^{-4}$	3.00

In the best scenario, the risk obtained was $8{,}74\text{x}10^{-6}$, ie less than one case per 10,000 tourists, and at worst, it was $3{,}00\text{x}10^{-4}$, ie 3 cases per 10,000 tourists.

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Until now we did not know of any confirmed case of dengue fever in tourists during the FIFA Confederations Cup 2013.

THANK YOU!

References

- E Massad and Ma Stefan and MN Burattini and et al, *Journal of Travel Medicine.* **25 (Issue 3)**, 147-155 (2008).
- World Health Organization. *http://www.who.int/denguecontrol/en/* (2013).
- World Health Organization. *http://www.who.int/topics/dengue/en/* (2013).
- T Jelinek , N Muhlberger, G Harms, et al. *Clin Infect Dis* **C35**, 1047 - 1052 (2002).
- A Lifson, *Mosquitos, models, and dengue. Lancet* **347**, 1161 - 8 (1996).
- A Wilder-Smith and E Schwartz, *N. Engl J Med.* **353**, 924-932 (2005).
- Secretaria Municipal de Saúde - Rio de Janeiro. Dengue: Dados epidemiológicos. *http://200.141.78.79/dlstatic/10112/2352733/DLFE-274958.htm/Dadosdengue2.4.0.6.1.3.SEM2.0.1.3..htm* (2013).
- E Massad and J. Rocklov and A. Wilder-Smith, *Epidemiol Infect.* **24**, 1-6 (2012).