

## Temporal analysis of the relationship between dengue and meteorological variables in the city of Rio de Janeiro, Brazil, 2001-2009

Análise temporal da relação entre dengue e variáveis meteorológicas na cidade do Rio de Janeiro, Brasil, no período de 2001 a 2009

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### Abstract

*Dengue, a reemerging disease, is one of the most important viral diseases transmitted by mosquitoes. Climate is considered an important factor in the temporal and spatial distribution of vector-transmitted diseases. This study examined the effect of seasonal factors and the relationship between climatic variables and dengue risk in the city of Rio de Janeiro, Brazil, from 2001 to 2009. Generalized linear models were used, with Poisson and negative binomial distributions. The best fitted model was the one with "minimum temperature" and "precipitation", both lagged by one month, controlled for "year". In that model, a 1°C increase in a month's minimum temperature led to a 45% increase in dengue cases in the following month, while a 10-millimeter rise in precipitation led to a 6% increase in dengue cases in the following month. Dengue transmission involves many factors: although still not fully understood, climate is a critical factor, since it facilitates analysis of the risk of epidemics.*

*Dengue; Climate; Temporal Distribution*

### Introduction

Dengue is an acute febrile disease caused by arboviruses (arthropod-borne viruses) of the Flaviviridae family, with female *Aedes aegypti* culicid mosquitoes as the vector. Tropical countries are the most heavily affected due to their environmental, climatic, and social conditions. Climate is an important factor in the temporal and spatial distribution of vector-transmitted diseases like dengue fever. Studies of climatic variables can improve knowledge and prediction of epidemic seasonality <sup>1</sup>, because the vector-climate relationship is just as important as vector-human interaction.

Several authors have investigated the relationship between climatic variables and dengue fever, often using time-series analysis to describe temporal trends, to identify patterns, and even to make predictions. The variables used in these studies have been temperature, precipitation, relative humidity, wind velocity, and El Niño Southern Oscillation (ENSO) <sup>2,3,4,5,6,7,8</sup>. Studies have also evaluated dengue's relationship with socio-demographic and environmental variables in the municipality of Rio de Janeiro, Brazil, with a view to examining the effect of seasonal and annual factors on increases and decreases in dengue cases, as well as to make predictions <sup>9,10,11,12</sup>.

Dengue incidence fluctuates with climatic conditions and is associated with increased tem-

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perature and rainfall<sup>13</sup>. Such conditions favor an increase in the number of available breeding sites, as well as the vector's development, and thereby increase the probability of vector-human (and consequently human-virus) interaction. According to various studies, temperature has an impact on the population size, maturation period, blood-sucking activity, and survival rate of *Ae. aegypti*<sup>14,15,16,17</sup>. The relationship to precipitation depends on local characteristics and whether breeding sites are maintained predominantly by rain<sup>3</sup>.

Dengue is expected to be an important public health problem for many years, due to population growth and movement, disorderly urban development, deficient water supply and inappropriate public waste disposal, proliferation of vector breeding sites, and lack of an effective vaccine<sup>18,19</sup>. Programs to prevent the disease concentrate on developing early intervention systems. Such systems require parameters that can predict the risk of epidemics. The climatic model offers advantages, as a low-cost system based on collecting meteorological data. The current study aimed to examine the effect of seasonal factors and how the climatic variables "temperature" and "precipitation" were related to dengue fever risk in the city of Rio de Janeiro from 2001 to 2009.

## Methodology

The study followed an analytical ecological design aimed at assessing the relationship between dengue risk and the climatic variables "temperature" and "precipitation" in the municipality of Rio de Janeiro. Rio de Janeiro is located in Southeast Brazil at 23°04'10" latitude South and 43°47'40" longitude West. The city has an estimated population of 6,093,472 and area of 1,224.56 km<sup>2</sup>. The climate is Atlantic Tropical, characterized by a mean annual temperature of 23°C and narrow temperature range. Average annual precipitation is about 1,000mm, with most rainfall from December to March.

Monthly notifications of dengue cases are available by neighborhood of residence on the portal of the Rio de Janeiro City Health Department (Secretaria Municipal de Saúde – SMS-RJ). Temperature data were obtained from the Weather Forecasting Center of the National Space Research Institute (Instituto Nacional de Pesquisas Espaciais – INPE), which draws its data from four monitoring stations, only one of which was used, since it offers complete data for the study period. Rainfall data, available on the portal of the Municipal Department of Public Works (Secretaria Municipal de Obras Públicas), were taken from

32 monitoring stations (Figure 1). For this study, cases were spatially aggregated, i.e., all cases in all neighborhoods were totaled by month from 2001 to 2009.

Exploratory data analysis was performed using boxplots, histograms, time series decomposition, and auto-correlation graphics. The outcome variable was the number of dengue cases, and the independent variables were the mean monthly precipitation at the 32 stations and the mean, low, and high monthly temperatures. After exploratory analysis, cutoff points for mean temperature were evaluated using generalized additive models<sup>20</sup>. Dengue risk was observed to increase up to 26°C. According to the literature, the mosquito's optimal temperature is from 22°C to 26°C, based on which the following variables were used: proportion of days in the month with mean temperature below 22°C, proportion of days in the month with mean temperature from 22°C to 26°C, and proportion of days in the month with mean temperature above 26°C.

The effect of climatic variables on the reported number of cases was evaluated using generalized linear models<sup>21</sup>, with a logarithmic link function for Poisson and negative binomial distribution. Time series are characterized by a sequence of data obtained at equal time intervals. The data used here refer to months, which do not have the same number of days, so that an offset was employed in multiplying the population by the number of days in the month. Model fit was evaluated by auto-correlation and normality test of residuals.

The analyses were performed using the R program, version 2.10.1 (The R Foundation for Statistical Computing, Vienna, Austria; <http://www.r-project.org>). The models were compared with the Akaike Information Criterion (AIC), which is widely used to compare nested and non-nested models. This criterion is calculated using the log-likelihood penalized by the number of parameters in the model. For models with the same dataset, the best model is the one with the lowest AIC<sup>22</sup>.

## Results

The only non-epidemic years during the study period were 2003 to 2005. The highest number of cases occurred during the 2001-2002 epidemic, reaching 52,861 in March 2002. Figure 2 shows the time series for the variables: number of dengue cases; mean, maximum, and minimum temperatures; precipitation; and proportions of days in the month with mean temperature below 22°C, from 22°C to 26°C, and above 26°C.

Figure 1

Map of the city of Rio de Janeiro, Brazil, showing rainfall monitoring stations (●) and temperature monitoring stations (■).



Analysis of case distribution showed that most cases were concentrated in the first half of the year, mainly in March, April, and May, underlining the known seasonality of dengue fever. Mean annual temperatures for the period were 24°C for monthly mean temperature, 21°C for monthly minimum temperature, and 29°C for monthly maximum temperature. Monthly accumulated precipitation in the period ranged from 6 to 371mm.

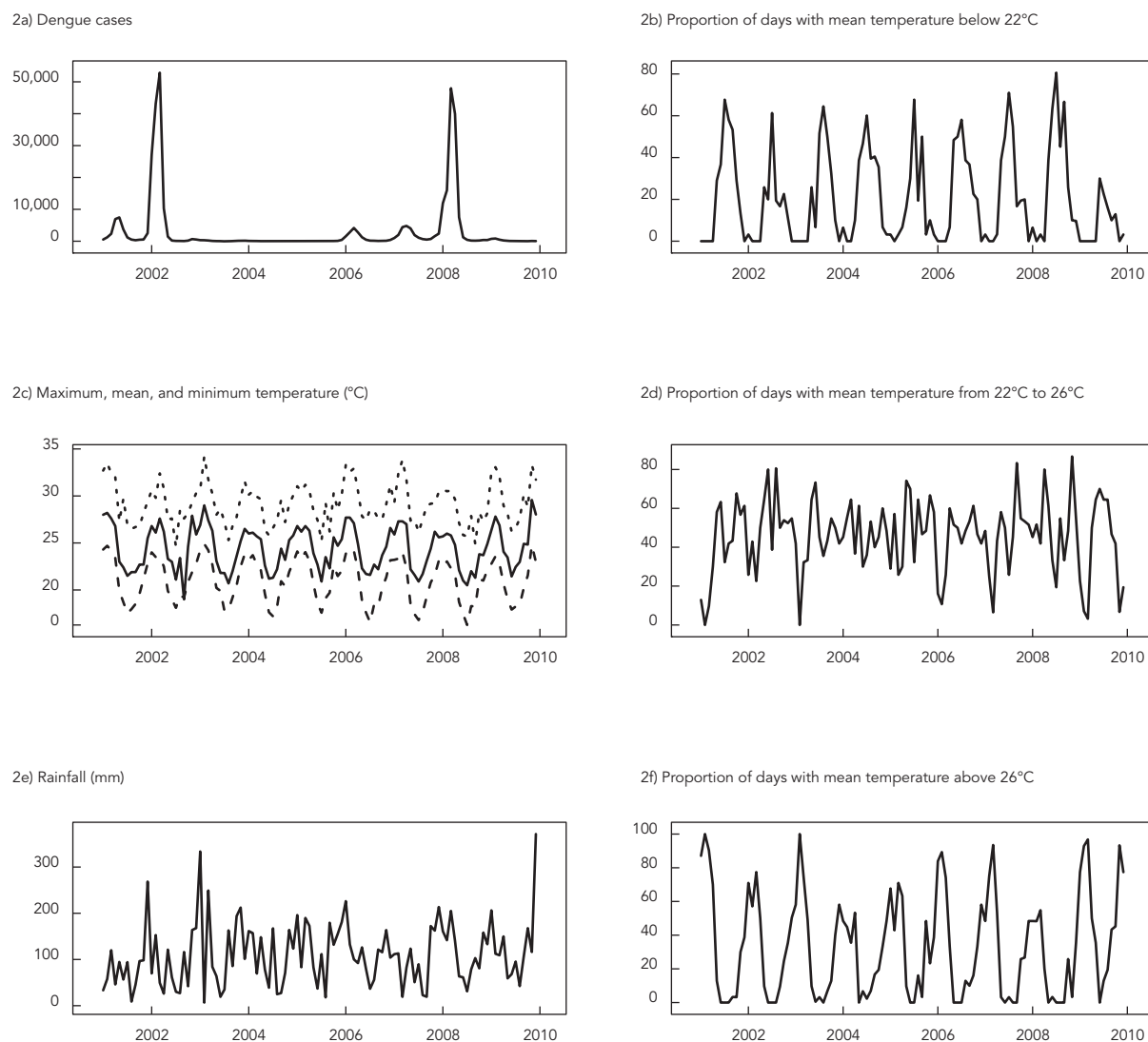
Since the data present over-dispersion (sample mean of 3,108 and sample variance of 84,695,150), comparison of the models' AIC showed that negative binomial distribution was a better choice than Poisson distribution. Models were initially fitted with only one variable; in these, the variable "proportion of days with temperature from 22°C to 26°C" was not significant, even when lagged, while precipitation was only significant in relation to the number of cases when lagged by one month. The other variables were significant with lags of up to two months.

On the basis of this initial analysis, all the models contained the variable precipitation, and then the inclusion of temperature-related variables was evaluated. Residuals analysis of the models showed that a time structure persisted; accordingly, an annual effect was incorporated into the model. Introduction of this variable improved both auto-correlation of residuals and model fit.

Table 1 shows the estimated relative risk (RR), 95% confidence intervals (95%CI), and AIC for the fitted models. The RR for the variable "precipitation" varies little between the models. Concerning the AIC criterion for comparing models, the model with the best fit was the one which (after controlling for the variable "year") used the variables "minimum temperature" and "precipitation", both lagged by one month. In that model, a one-degree rise in temperature in a month led to a 45% increase in dengue cases in the following month, while a 10mm increase in precipitation led to a 6% increase in dengue cases in the following month. Models with the variables "mean

Figure 2

Time series for number of dengue cases and meteorological variables in the city of Rio de Janeiro, Brazil, 2001-2009.



temperature” and “maximum temperature” presented similar results.

Figure 3 shows the coefficients for the variable “year” in Model 1: 2002 and 2008 were the only years in which the effect was greater than in 2001, which was taken as baseline. They were the years in the study period with the most cases, but this variable was not statistically significant. Figure 4 shows the time series for dengue cases and the series as estimated by Model 1, which managed to detect the epidemic years, although underestimating the major epidemics and over-

estimating the number of dengue cases in the following year.

## Discussion

Several studies have reported a positive association between minimum temperature lagged by one month and dengue incidence<sup>3,4,12,23,24</sup>. Minimum temperature is thus a critical limiting factor in the development and maintenance of the vector population. Replication of the virus

Table 1

Relative risk (RR), 95% confidence intervals (95%CI), and Akaike Information Criterion (AIC) of the proposed models for the relationship between dengue transmission and meteorological variables. Rio de Janeiro, Brazil, 2001-2009.

Models/Variables lagged by 1 month	RR	95%CI	AIC
1			
Minimum temperature	1.452	1.338-1.576	1,568
Precipitation	1.006	1.003-1.009	
2			
Proportion of days with temperature > 26°C	1.092	1.068-1.115	1,577
	1.008	1.005-1.011	
3			
Proportion of days with temperature < 22°C	0.894	0.867-0.921	1,584
Precipitation	1.007	1.003-1.010	

Note: all models were controlled for variables indicating the year.

Figure 3

Estimated coefficients of variables indicating the year in Model 1.

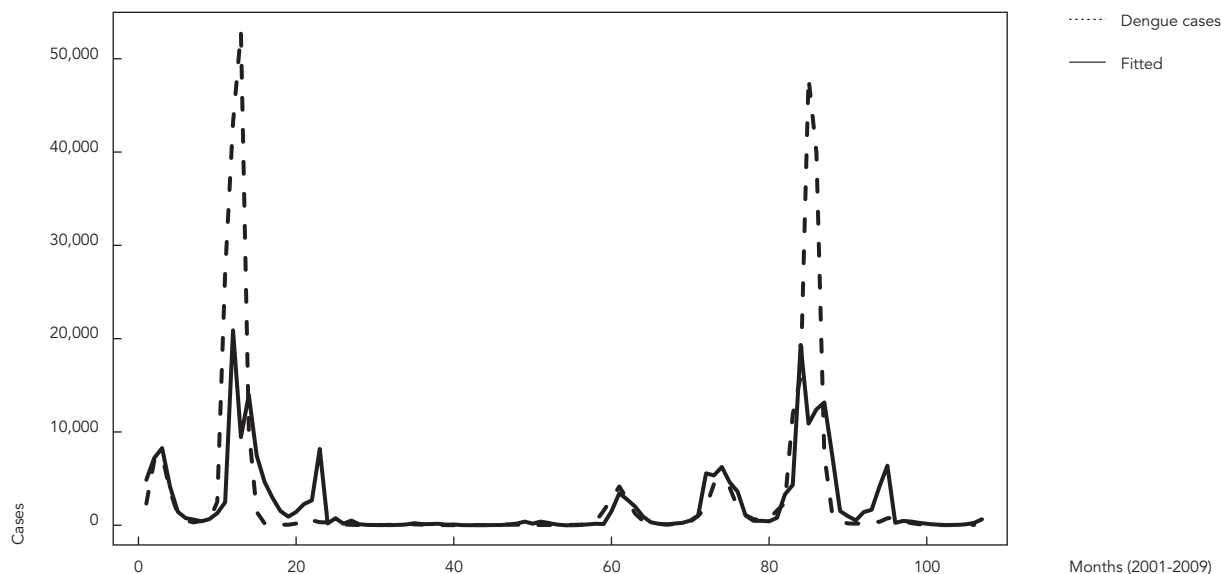


and maturation periods in the insect (extrinsic period) are shortened by increased temperature<sup>25,26,27</sup>, while decreased virus incubation time increases the likelihood that the vector will live long enough to transmit the virus, significantly boosting the magnitude of the epidemics. Studies have shown that *Ae. aegypti*, the vector for dengue in the Americas, ceases to feed when temperature falls below 17°C, and that the virus is not amplified in the vector when temperature falls below

18°C, while the threshold survival temperature for the dengue virus has been estimated at 11.9°C<sup>25,28,29</sup>. Thus, at very low temperatures the virus develops more slowly, and the mosquito does not live long enough to become infectious and transmit the virus<sup>30</sup>. Accordingly, analysis of minimum temperatures affords a better understanding of dengue epidemics. This study showed a small (but significant) coefficient for the relationship between dengue cases and precipitation. Studies

Figure 4

Time series of dengue cases and series estimated by Model 1.



in the literature on the correlation between rainfall and dengue are contradictory, because the relationship depends on local characteristics<sup>3,31</sup>.

Analysis of Model 3 shows that a unit increase in the proportion of days in the month when the mean temperature falls below 22°C led to an 11% decrease in the number of dengue cases in the following month, corroborating reports by other authors, because the vector's feeding rate declines at lower temperatures (as does the viral transmission rate, consequently)<sup>31,32</sup>.

A study by Honório et al.<sup>32</sup> in three neighborhoods in the city of Rio de Janeiro shows that air temperature from 22°C to 24°C has a positive impact on the development of *Ae. aegypti*, while temperatures above 24°C produce no evident effect. In the present study, that temperature range was incorporated into the variable "proportion of days in the month with mean temperature from 24°C to 26°C", which was not statistically significant.

According to Model 2, which incorporates temperature above 26°C, a unit increase in the proportion of days in the month when mean temperature is above 26°C leads to a 9.2% increase in dengue cases in the following month. That result was expected, because studies have found an association between dengue risk and temperatures above 26°C, with temperatures from 21°C

to 29°C favoring the development of *Ae. aegypti*, and from 22°C to 30°C, the longevity and fertility of the adults<sup>2,33</sup>.

The complexity of dengue transmission dynamics has prompted studies on various factors that contribute to circulation of the virus. Although the current study emphasizes the impact of climate, other approaches beyond socio-environmental conditions must be considered. One limitation of this study was the use of reported dengue cases, which fail to represent total dengue cases. These numbers may underestimate true incidence<sup>34,35</sup>. Another limitation was the lack of reliable information in each time period on the specific incidence rates for each serotype (among the circulating serotypes)<sup>36</sup>. Some authors claim that the entry of a new serotype into a non-immune population entails a risk of explosive epidemics, even while the succession of serotypes can result in epidemics with more severe cases<sup>10,18,37</sup>. The role of the exposed human populations, the effect of immunity to the virus in the at-risk population, and infestation by the mosquito vector are decisive factors in maintaining the virus in circulation.

## Conclusion

Dengue transmission involves numerous factors, including the impact of climate, whose role is still not fully understood. Elucidating the role of climate is critical, because it facilitates analysis of the risk of epidemics and assists preventive ef-

forts. This study proposed a model for examining the time series of dengue fever by which mean, maximum, and minimum temperature and precipitation were associated statistically with the number of cases, while one month-lagged minimum temperature proved to be the strongest explanatory factor for the number of dengue cases.

## Resumo

*A dengue é doença reemergente e uma das mais importantes doenças virais transmitida por mosquito. O clima é considerado um fator relevante na distribuição temporal e espacial das doenças transmitidas por vetores. O objetivo deste trabalho foi estudar o efeito de fatores sazonais e a relação entre as variáveis climáticas e o risco de dengue, na cidade do Rio de Janeiro, Brasil, entre 2001 e 2009. Foram utilizados modelos lineares generalizados, com distribuição Poisson e binomial negativa. O modelo com melhor ajuste foi o controlado por variáveis indicadoras do ano, que apresentou as variáveis temperatura mínima e precipitação, ambas com defasagem de um mês. Nesse modelo, o aumento de um grau na temperatura mínima em um mês leva ao aumento de 45% no número de casos de dengue no mês seguinte, enquanto o aumento em 10 milímetros na precipitação leva ao aumento de 6% no número de casos de dengue no mês seguinte. A transmissão da dengue está relacionada a muitos fatores; o impacto do clima, apesar de ainda não ser bem entendido, é apontado como crítico ao facilitar análise de risco de epidemias.*

*Dengue; Clima; Distribuição Temporal*

## Contributors

A. F. Gomes participated in the data analysis and interpretation and wrote the article. A. A. Nobre collaborated in the interpretation of the data and critical revision of the manuscript. O. G. Cruz contributed to the critical revision of the manuscript.

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