Assessing the Impact of Climate Factors on Dengue Outbreaks in Puerto Rico

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ABSTRACT

Dengue fever affects 50-100 million people worldwide, with symptoms ranging from unaffected to a 50% mortality rate. Unfortunately, no specific medical treatment or vaccine is available. Dengue is transmitted in the Caribbean primarily through a mosquito vector called Aedes aegypti. Past studies have found that climate factors such as higher temperatures and increased precipitation affect the lifecycle and habitat of these mosquitoes. Likewise, changes in the Aedes lifecycle cause changes in dengue transmissions. Therefore, a thorough analysis of those climate factors would aid in understanding dengue transmissions.

This study focused on how air temperature, humidity, precipitation, and sea-surface temperature (SST) affected the dengue epidemics of 1994 and 1998. Each climate factor was correlated with dengue outbreaks on a weekly basis. Precipitation, air temperature, and humidity showed weak relationships with dengue outbreaks. SST, however, showed an exponential relationship. A good exponential model was found for 1994, but was not appropriate for 1998. Instead, a regression tree was used to analyze 1998 SST and air temperature thresholds. The thresholds were around 27-30°C, which agreed with past studies. Qualitative analyses of tropical storm systems showed that storms did not have a strong impact on dengue transmissions. In general, the results demonstrated that except for SST, climate factors did not have a large effect on dengue transmissions, rather key social factors could be at play. Thus, for dengue prevention, the public health infrastructures should focus more on social problems and less on climate factors.
Introduction

Dengue fever, also known as “bone crusher’s disease,” is a significant topic for research in the public health community. The dengue virus affects 50-100 million people worldwide (Pinheiro and Chuit 1998); this year, 2.5 billion people are living in at risk areas as opposed to only as 66,000 in 1980 (WHO 2005, Rigau-Perez et al 1998). Many factors likely contributed to this immense growth. Some of them include societal factors such as urbanization and crowded living conditions (Gubler 1998). Other factors are more climatic, such as increase in global temperature. All of these factors could have great impacts on dengue transmissions around the world.

In the United States, dengue fever has been transmitted indigenously in Texas, the Virgin Islands, and Puerto Rico. The symptoms range from asymptomatic to a 44% mortality rate (Rigau-Perez et al. 1998). In terms of treatment, dengue can be clinically confused with other diseases such as yellow fever (PAHO 1997). There is no specific medical treatment and no vaccine is available. As a result, dengue is a serious disease for the at risk public.

Dengue fever is caused by a virus with four different strains called serotypes (Dengue 1, 2, 3, and 4). Infection from one serotype only provides temporary immunity against the other three. The first infection is often mild or asymptomatic and referred to as “Classical Dengue Fever.” Symptoms include high fever, coughing, vomiting, headache, and severe pain in the joints and eye orbits (Rigau-Perez et al. 1998). A second infection can lead to dengue hemorrhagic fever (DHF), which is characterized by bleeding from the nose, gums and internal organs with a possible 20% mortality rate (Ostronoff et al. 2003). About 33% of DHF patients will develop circulatory failure, also known as dengue shock syndrome (DSS), which has a mortality rate of 12%-44% (Meltzer et al 1998). There are many people who carry the virus without symptoms, and often do not know about it until a second infection resulting in DHF or DSS (PAHO 1997).

The dengue virus is transmitted in the Caribbean primarily through the mosquito vector Aedes aegypti. It is a small tropical mosquito, only 3-4 mm long, with a life span of a few months. Only the female of the species is responsible for transmission because she needs protein from vertebrate blood to develop and lay eggs. The virus can be passed from adult to egg and resides in the salivary glands of the mosquito. The dengue virus is transmitted to humans when the female mosquito bites a host and injects saliva into the wound (Mortimer 1998). For the most part, there is little human-to-human transmission of dengue through blood products and breast milk. In 2001, the World Health Organization (WHO) considered the dengue virus to be the most common and widespread arbovirus (arthropod-borne virus, arthropod being the mosquito) known to humans (WHO 2001).

The Aedes aegypti habitat is primarily in the tropics because its survival rate is highest between 20 and 30 ºC and drops down around 15 ºC (Rueda et al. 1990). However, global warming could increase the areas in which Aedes aegypti would present and even cause them to be more active (Shope 1994). The rise in temperature allows the mosquito to move northward, expanding the geographic range of the vector and potentially increasing the transmission of dengue. Elevated temperatures can also shorten both larval development of Aedes aegypti, and
the period for dengue virus replication (extrinsic incubation period) in the mosquito. In the first case, the mosquito larvae would mature faster and become transmitting adults earlier in the season (Shope 1991). In the second case, the extrinsic incubation period, which is temperature dependent, is shortened. Both cases lead to increased transmission of dengue in the at risk areas. Therefore, to better understand dengue transmission and epidemics, a thorough analysis of climatic factors that affect the Aedes aegypti population and life cycle is needed.

Some past studies have investigated the influence of climate on dengue. In a dengue surveillance report from 1986 to 1992, three serotypes were found in the U.S. Virgin Islands and Puerto Rico. The disease transmission had a cyclical pattern that peaked during the months with higher temperatures and humidity (Rigau-Perez 1994). Similarly, in 2001, the Intergovernmental Panel on Climate Change (IPCC), The National Research Council (NRC), and the United States Global Change Research Program (USGCRP), each published a report relating dengue incidence with climate change. There was general consensus among the three teams that transmission and incidence will increase with temperature (Jaenisch 2002). In a medical study conducted in 2004, the rate of virus replication in Aedes aegypti mosquitoes increased directly with temperature in the lab. Biological models were developed to evaluate the influence of projected temperature change on dengue incidence. The models suggested that small increases in temperature may increase the potential for epidemics (Haines 2004). However, another model that predicts the abundance of Aedes aegypti in Puerto Rico using climate data showed that temperature was not a good indicator of larvae abundance. Rather, the amount of precipitation was a more effective predictor (Moore 1985).

Furthermore, precipitation can have varying effects on the mosquito population. The female mosquito lays her eggs above the water line where they grow and develop for a few days. The eggs then need to be submerged in water to hatch. If the ambient air is warm and humid, Aedes aegypti eggs can survive for over a year while waiting for water to hatch. After a hard rain, all the eggs laid during dry periods hatch at the same time, which can lead to numerous dengue outbreaks (Myhre 2002). In contrast, some tropical storms and hurricanes can wash out mosquito eggs, significantly reducing the population and disease transmission. During dry periods or droughts, people in the developing world tend to store water in containers which are perfect mosquito breeding sites. In this case, mosquito populations could climax even without rain.

From these past studies, the precise impact of climate factors on dengue transmission is unclear and seems to vary with different cases. This study focuses on clearing up those confusions for the dengue epidemics in Puerto Rico in the 1990s. The factors to be investigated include relative humidity, precipitation, air temperature, sea-surface temperature, and tropical cyclones. The general hypothesis is that high air temperatures and SSTs will produce high dengue transmissions; high precipitation, relative humidity, and strong tropical cyclones following dry periods will have the same effect. The results of this study will be beneficial for climatology, epidemiology, and the at risk public.
Methodology

Data Sources

In studying the relationship between climate factors and dengue outbreaks in Puerto Rico, health and meteorological data from the dengue epidemics are needed. In the 1990s, two severe epidemics occurred, one in 1994, and one in 1998 (see figure 1 below). Weekly health data for those two years were not available from one source, so a number of different published sources were consulted.

Figure 1. Dengue outbreaks in the 1990s (CDC 2000).

For the year 1994, weekly outbreaks were obtained from an article investigating the relationship between transmission and sanitary conditions in certain Puerto Rican cities (Perez et al. 2001). No definite conclusions were made but the data showed a higher percentage of patients less than 30 years of age and an even distribution of the disease between genders. The 1998 weekly dengue outbreaks were provided by a report that studied the sudden emergence of Dengue 3 in Puerto Rico after a twenty year absence (Perez et al 2002). The report gave a spatial analysis of Dengue 3’s transmissions; outbreaks were recorded by two sentinel clinics located in Ponce and San Juan. All the recorded outbreaks were laboratory confirmed using a combination of direct and indirect enzyme-linked immunosorbent assay (ELISA).

Daily air temperature and precipitation data from 1994 and 1998 were collected by the National Climatic Data Center at two stations in Puerto Rico, San Juan and Ponce (NCAR database). Relative humidity data were available on a daily basis from San Juan only. Weekly sea surface temperature (SST) data in the 1990s were obtained from the Reynolds Optimally Interpolated Sea Surface Temperature Observations. There are six stations located around Puerto
Rico on a one degree by one degree grid. The data are interpolated by both in-situ SSTs and satellite derived SSTs from the National Oceanic and Atmospheric Administration (NOAA) and Advanced Very High Resolution Radiometer (AVHRR). The overall intrinsic spatial resolution of the SST data is 1.1 km. El Nino oscillations and tropical cyclone data from 1960-1998 were acquired from the National Weather Service.

**Data Selection and Analyses**

For the epidemics in 1994 and 1998, health data were available in weekly form so the precipitation and air temperature data needed to be processed to show weekly averages with variances. In the case of 1994, San Juan’s climate data were used; weekly averages of precipitation, relative humidity, and maximum daily temperatures were plotted against the weekly dengue outbreaks. The same was done for 1998 with air temperature and precipitation data from Ponce. All the available SST data were already in weekly form so no further calculations were necessary. Of the six stations around the island, the closest and thus most relevant one is station five, located off the coast of San Juan. Dengue outbreaks in 1994 and 1998 were plotted against the respective station five SST data.

Then, bivariate correlations were performed in the statistical program R for each climate factor against dengue outbreaks in 1994 and 1998. Next, to better understand the relationship between SST and dengue outbreaks, a few statistical tests were performed in the statistical program R. For 1994, the nonlinear graph was transformed to show a linear relationship using the log function for the dependent variable. The new linear relationship was analyzed using linear regression with Pearson’s coefficient and t-test. The 1998 data could not be successfully linearized or analyzed with one model, so a threshold analysis was more appropriate. A regression tree that established nodes and grouped data by minimal variances was used. Weekly SST values over an eleven year interval was plotted to see how those values varied between epidemic years and non-epidemic years. In addition, SST is related to air temperature so bivariate correlation analyses of the two variables were performed for 1994 and 1998. Air temperature thresholds for dengue outbreaks were evaluated using the regression tree in R. Finally, a general look at tropical cyclones and El Nino oscillations before and during those two years of epidemics helped evaluate further relationships between climate and dengue outbreaks.

**Results**

**Statistical Analyses**

First, a general visualization of how dengue relates to each climate factor is needed. Figures 2 and 3 show that some of the climate factors have positive correlations with the dengue outbreaks. The only one that shows a strong correlation was dengue outbreaks versus SST.
Figure 2. a, b, c, and d. 1994 weekly dengue outbreaks plotted against each climate factor.
In looking for relationships between climate factors and dengue outbreaks, bivariate correlations were performed in R (see below). The correlation numbers range from zero to one; zero means no correlation and one means perfect correlation.

**TABLE 1. Bivariate Correlations of Each Climate Factor vs. Dengue Outbreaks**

<table>
<thead>
<tr>
<th>Climate Factors</th>
<th>1994</th>
<th>1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0.22</td>
<td>0.46</td>
</tr>
<tr>
<td>Precipitation</td>
<td>0.40</td>
<td>0.36</td>
</tr>
<tr>
<td>Humidity</td>
<td>0.45</td>
<td>0.53</td>
</tr>
<tr>
<td>SST</td>
<td>0.65</td>
<td>0.62</td>
</tr>
</tbody>
</table>

In 1994, the correlations are weak for temperature, precipitation, and humidity. In 1998, the correlation is weak for precipitation, but a little stronger for air temperature and humidity. In both years, SST has the strongest correlation with dengue. With this in mind, additional statistical analyses were made to analyze the relationship between SST and dengue. To further explore that relationship, some simple modeling was done. For the case in 1994, the dengue versus SST graph looked exponential. Therefore, using a log transformation, a linear regression was performed (see figure 4).
The regression has a very good $r^2$ of 0.6592 for this type of analysis. The t-statistics for slope and intercept of the regression line were both significant at the 0.001 level. A similar procedure was done for SST versus dengue in 1998, but the linear regression did not fit the data at all. A polynomial fit was done instead (see figure 5).

This fit yields a good $r^2$ of 0.5957, but because it is a second degree polynomial, it curves up at the lower SST values, which disagrees with past studies that found dengue numbers to increase with SST. A threshold analysis for this graph is more suitable, so a regression tree was used.
performed in the statistical software R. A regression tree splits the data such that the sum of the squared deviations from the mean in the separate groups or nodes is minimized. In other words, the data is broken up into groups with similar values. That portioning process is then applied to each of the new branches until the groups reach a certain size.

From figure 6b, the first threshold (outlined in red) makes a clean division of the data, showing that the points to the left of the red line have low dengue outbreaks, and the points to the right are very high. Of the two subdivisions (blue vertical bars), the first one is reasonable, but the second makes it seem that there are more dengue outbreaks in the region where SST is between 29.15 °C and 29.35 °C than in the region where SST is above 29.35 °C. For example, looking at the right side of the tree, for SST < 29.35 °C, the average number of dengue cases is 756, but for SST > 29.35 °C, the average number of dengue cases is approximately 580.

To understand if SST has an impact on dengue, a look at SST seasonal cycles of several years is helpful. Figure 7 displays weekly SST values over an interval of eleven years. 1994 and 1998 were the two years with the epidemics; the other years had fairly small numbers of dengue cases. Compared to the non-epidemic years, 1994’s SSTs are not at all extreme. SSTs in 1998 are rather extreme and maybe related to tropical cyclones.
In dealing with correlations between climate factors and dengue outbreaks, there is the possibility that climate factors may have correlations with each other. Since Puerto Rico is a small island, SSTs are related to air temperatures and both of them may have a synergistic effect on dengue transmission. Hence, a bivariate correlation analysis of SST and air temperatures is performed in R. In 1994, the air temperature-SST correlation was 0.74, and in 1998, it was 0.84. These correlations are very strong and suggest that the relation between dengue outbreaks and air temperature could be strong, too. Looking back upon the graph of dengue versus temperature (figure 2a and figure 3a), the approximate relationship between them is positive, but with a lot of noise where temperature is around 30 and 31°C. Figure 8 displays the graphs with some of that noise removed.
Both relationships look approximately exponential, but the exponential model does not fit either graph very well. Regression tree analysis for thresholds is performed instead.

In figure 9b, the primary threshold for 1994 looks like it is too far to the left. The second subdivision is a much better threshold of the data. In figure 10b, the primary division for the 1998 data is a good threshold; the points are cleanly divided into high and low dengue outbreaks.
Discussion

From the bivariate correlations in Table 1, three of the four climate factors (air temperature, precipitation, and humidity) had somewhat weak relationships with dengue outbreaks. The weak correlation with humidity could be accredited to humidity’s small variations throughout the years (See figure 12).

![1994 Humidity](a) ![1998 Humidity](b)

Figure 12a and b. Humidity remains constant in 1994 and 1998.

From these graphs, the humidity varied between 76% and 100%, which would not have a big impact on the *Aedes* lifecycle. So even though dengue transmissions generally peak during months with higher humidity, it is fairly constant here, making it an unimportant factor in dengue transmissions in Puerto Rico.

There was also a weak correlation between dengue transmissions and precipitation. In theory, high precipitation can help mosquito eggs hatch, and increase their population. However, in most of Puerto Rico, there are many water-filled artificial containers such as tires that serve as mosquito breeding sites. This makes the mosquito population independent of precipitation (Moore 1978).

On the contrary, sea surface temperatures had a strong and positive relationship with dengue transmissions. In 1994, the logarithmic transformation produced a good linear fit with an $r^2$ of 0.66. The final equation for the data is:

$$y = (3.03^x) \div (61090000000) \quad y = \text{dengue outbreaks} \quad x = \text{SST in degree C}$$

The linear model for the logarithmic data worked well because the residual plot had no distinct pattern, and the t-statistic was significant at the 0.1% level. This means that there is less than one
percent chance that this relationship between SST and dengue happened by chance. Before causation can be established, it is helpful to look at how well the model predicts the data (see figure 13).

**1994 Dengue transmissions predicted and actual**

![Figure 13](image1.png)

Figure 13. Predicted and actual dengue outbreaks based on the exponential model.

The exponential model fits the data well, with the exception of a few noisy points. To see if this model could really predict dengue outbreaks from SST, it is interpolated against the 1998 data in figure 14.

**1998 Predicted and Actual dengue from 1994's model**

![Figure 14](image2.png)
Figure 14 shows that the 1994 exponential model does not work well for 1998’s data. Perhaps when the SST was below 27.5 °C, the model could fit, but anything higher than that, the model cannot do an accurate prediction of dengue outbreaks. The 1998 dengue versus SST graph did look similar to that of 1994, but the data did not fit the exponential model, so a polynomial model was used instead (fig. 5). That model provided a good fit with an $r^2$ of 0.595, but the quadratic model is a parabola that gives high dengue values for low SST values. This does not agree with the data or theory from the IPCC report that claimed the transmissions would increase with temperature. Low temperatures are supposed to discourage mosquito reproduction and increase virus incubation time. If this model were to be implemented, it would only be useful for SSTs above 27.5°C. In seeing this, perhaps the exponential and polynomial models could used together, one for predicting dengue below 27.5°C and one for above 27.5°C. However, all this shows that there is still no universal model that can predict dengue from SST.

Turning now to a different type of analysis, the regression tree shown in figure 6 was a way of finding an SST threshold for dengue outbreaks. The primary division at 29.15°C is the most useful; it provides a good threshold for when the dengue outbreaks would hit extreme values. In addition, air temperature is strongly related to SST from the bivariate correlations, so their thresholds must also be considered. In both years, the main air temperature threshold was about 30°C. These results agree with a past study on the effects of temperature and *Aedes aegypti* survival rates that found the maximum survival rates to be between 20 and 30 °C (Tun-Lin 2000). The observed threshold may imply that at around 30 °C, mosquito populations are peaking and virus replication is faster than usual. In one study, there were approximately 45% more female mosquitoes at 30 °C than at 26 °C. Also, females that incubate the dengue virus at higher temperatures like 32 °C are 2.64 times more likely to infect humans (Focks et al. 2000). From a social perspective, higher temperatures could mean that people wear short clothing, giving the mosquitoes more opportunities to spread the dengue virus. All this demonstrates that the higher temperatures lead to higher transmissions and outbreaks.

In looking at the weekly SST time series in figure 7, 1994’s SST was not much higher than SST from non-epidemic years. 1994 was an El Nino year in which the Pacific basin warms, causing the Atlantic basin to cool, resulting in lower SSTs (NWS 2005). In 1998, the year started out as El Nino and then transitioned sharply to La Nina (NWS 2005). This event probably caused the high SSTs in September of 1998. In general, 1994 had the bigger epidemic but 1998 had the more extreme SST. Hence, higher SSTs may not necessarily cause more dengue outbreaks. Instead, the increase in dengue cases with SSTs in both years maybe more of a seasonal phenomenon.

The bivariate correlations showed that temperature and SST have strong correlations, but temperature and dengue outbreaks do not. This does not make the temperature thresholds meaningless, but in the case of Puerto Rico, temperature may not be a good indicator of dengue outbreaks. In a study that looked at dengue outbreaks and global climate change, the conclusion was that global warming would cause an increase in average temperatures. From this, the largest change in the *Aedes aegypti* population and dengue epidemic potential would occur in temperate
regions, while the tropical and subtropical regions would experience little or no change (Patz 1998). This is probably because there’s little temperature variability in the tropics. So, since Puerto Rico is in the tropics, it is understandable to see that increased temperatures do not have a strong effect on dengue transmissions.

A few weather events took place before and during 1994 and 1998 that may have contributed to the epidemics. In August of 1993, Tropical Storm Cindy passed about 2 degree latitude of Puerto Rico from the southeast to the northwest (National Weather Service 2004). No hurricanes or tropical storms came close to Puerto Rico in 1994. This is probably because 1994 was an El Nino year. El Nino causes warm waters to flow to the Eastern Pacific, triggering hurricanes and rain. Most of the storm activity moves to the Pacific, leaving the Atlantic much less active. Therefore, the large epidemic with no storm activity in 1994 seems to indicate that tropical storms do not have a predictable impact on dengue cases.

In September of 1997, Hurricane Erika passed by Puerto Rico from the northeast and hit a maximum of 110 knots (National Weather Service 2004, Lawrence 1997). Erika was a category three hurricane and caused large waves and swells off the coast of Puerto Rico. Two deaths were reported and the rest of the island had minor wind damage at high altitudes (Lawrence 1997). Interestingly, one month later, the dengue epidemics started increasing in Puerto Rico, reaching a climax in August of 1998 (CDC 2000). A few weeks later, Georges, a category 4 hurricane, hit the island and caused a brief interruption in dengue reporting, shown in figure 11 (Rigau-Perez et al. 2002).

![Number of weekly dengue cases in 1998; Hurricane Georges caused an interruption in reporting (Rigau-Perez et al. 2002).](image)
Hurricane Georges made landfall in southeast Puerto Rico with a wind speed of 100 knots, and produced 24.62 inches of rain, as opposed to the island’s usual 3-6 inches (Guiney 1999). Georges happened right after the height of the dengue outbreaks. Dengue reporting was briefly interrupted for a week and then returned to above average levels. In theory, hurricanes can cause significant reductions in transmission because it washes out mosquito eggs. In contrast, hurricanes can cause increases in transmission because there’s more opportunities for mosquitoes when people are living in shelters with poor sanitary conditions. In this case, for uncertain reasons, Geroges produced no significant effects on dengue outbreaks (Rigau-Perez et al. 2002).

There were many social factors involved in 1994 that could have impacted the outbreaks. The first is the closure of 61 municipal sanitary landfills due to Environmental Protection Agency’s (EPA) regulations. The EPA made stricter rules and imposed higher fees for discarding old tires and kitchen appliances in the landfills. This led to numerous illegal dumpings on roadways and other public property. Those dumpings may have served as breeding sites for mosquitoes once rainwater begins to collect. Then from May to October, more breeding sites became available when residents stored water in containers around their homes and work places because water service was interrupted due to drought (Rigau-Perez et al. 2001). All these factors may have contributed to the large dengue epidemic that broke out later that year.

From the present data, SST is the only one out of five climate factors to show strong correlations with dengue transmissions. However, even that relationship varied between 1994 and 1998. Now turning away from climate factors and their uncertainties, social factors could be of equal or more importance in predicting dengue outbreaks in Puerto Rico. Some of the social factors involved were general population growth that led to crowded living conditions, lack of effective mosquito control, and increased air-travel. In 1994, 40 million people left the United States by plane and more than half of them traveled to places where dengue is endemic (Rigau-Perez et al. 2001). This means that the travelers could be returning to U.S. territory with the virus and transmitting it to others through the mosquito vector. Tourism is a likely factor in determining the number of dengue outbreaks. It is difficult to determine how great of a role social factors play, but it is evident that both social and climate factors, especially SST, can contribute to the increase in dengue transmissions.

Conclusion

This study of two dengue outbreaks in Puerto Rico showed weak relationships between dengue and the climate factors: precipitation and air temperature. Relative humidity had slightly better correlations, but not enough to prove causation. SST had a somewhat exponential relationship with dengue, and both SST and air temperature showed promising thresholds around 30 ºC that agreed with past studies on how temperatures affect mosquito survival rates. A few models were attempted for SST as a possible precursor of dengue; however, the models are different between 1994 and 1998. Thus, the definite type of relationship between SST and dengue could not be concluded.
A lack of detailed health data limited the scope of this project. Interpolating health data from past-published research is strenuous and leaves a large margin of error. Future studies could benefit by obtaining health data that gives the geographic region where the outbreaks occurred, along with which dengue strain had caused the outbreaks. This would allow research to focus on a few social factors involved in dengue transmission as well as benefit the climate factor analysis. As a result of this study, it is apparent that both climate and social factors contribute to dengue outbreaks and are likely intertwined.

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References


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