

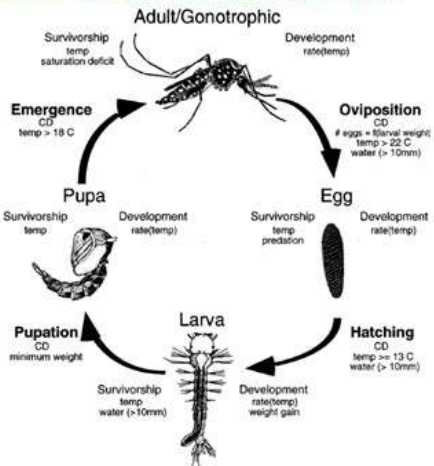
Summary

We quantify the historical relationship of dengue incidence with Minimum Temperature, Maximum Temperature, Rainfall and Water Availability based on observations of the Health Protection Authority of the Maldives Ministry of Health by region and season. Climate observations from the Maldivian Meteorological Service and Satellite based data sources. The seasonal variation, regional variation, monthly variation are shown here.

Introduction

Transmission of dengue involves the dengue parasite, vector (mosquito) and humans. The two types of dengue transmitting mosquito are *Ae. aegypti* and *Ae. Albopictus*. The dynamics of mosquito life-cycle is the most sensitive to climate. This cycle represented in four stages is captured below. Laboratory studies are used to obtain the sensitivity in each stage.

Climate Influence on Gonotrophic Cycle



Studies to understand mosquito development and survivorship are captured in the gonotrophic cycle shown. Environment factor includes temperature, water availability, and relative humidity. These influences vary in the four major stages of mosquito development. Temperature influences vector development rates, mortality, and behavior and controls viral replication within the mosquito. Variability in precipitation influences habitat availability for *Ae. aegypti* and *Ae. albopictus* larvae and pupae development and survivorship.

Source: Hopp and Foley (2001)

Dengue Incidence and Climate

The dengue incidence in the different provinces were estimated along with the rainfall, minimum and maximum temperature. The monthly climate is plotted against Dengue incidence below.

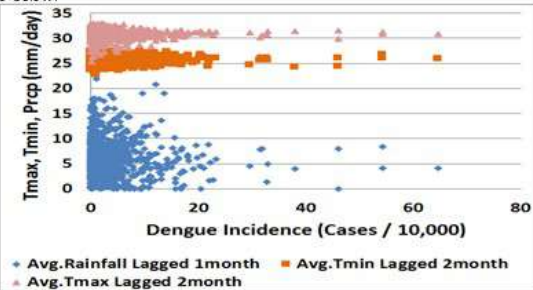


Figure2: Dengue Incidence Against Precipitation Lagged 1month and Tmin, Tmax Lagged 2month by Province. Source: Census Department, Maldivian Ministry of Health (MMOH) and Health Protection Agency(HPA), Maldivian Meteorological Service (MMS)

The lag between the climate and incidence is chosen based on the gonotrophic cycle. The graph shows that the months with the highest dengue incidence are closely clustered in temperature of 30-31 degrees C for maximum and 25-26 degrees for the minimum. There is a wider range of monthly rainfall averaging up to 9 mm/day. An analysis of climate sensitivity at daily or weekly time step may provide further insights on the rainfall.

Dengue Incidence and Rainfall by Province

The rainfall in different regions are shown in different colors below.

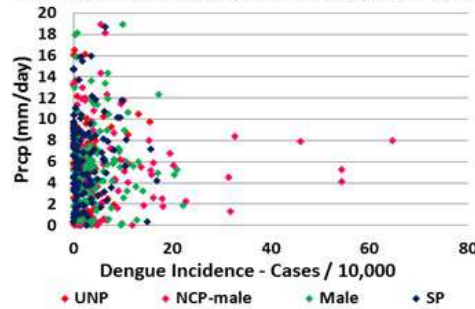


Figure 3: Precipitation Against Dengue Incidence by Provinces. Source: MMOH, HPA, MMS

High incidence of dengue is found regionally after a month between 2mm and 9mm. There is high incidence even for precipitation, rainfall up to 12mm per day. General rise in incidence can be observed in precipitation up to 0-10. More significantly in North Central Province (Excluding Male).

Dengue Incidence and Min/Max Temperature by Province

The range of temperature in which there shall be high survivorship in the four phases (different colors for the different phases of the gonotrophic cycle) as identified by laboratory studies is captured by the envelope of Tmin and Tmax shown below. We have superposed the observed rainfall and temperature below as seen in the first chart but here we identify the different regions by color of the data points.

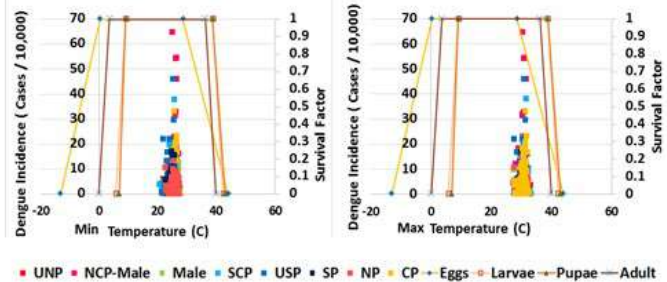


Figure 6: Minimum and Maximum Temperature Dependent Survivorship against Dengue Incidence Source: MMOH, HPA, MMS

What we see is that the temperature is more highly constrained in the Maldives and the sensitivity to climate is much more sensitive than may be understood from the laboratory studies.

Seasonality of Dengue and Climate

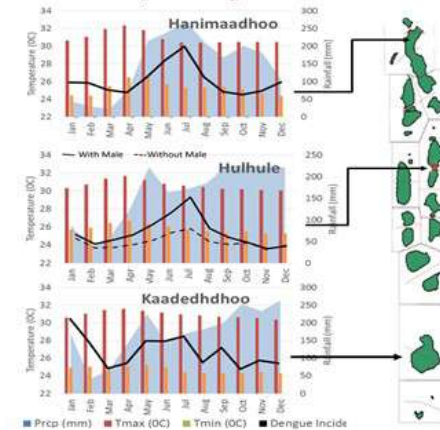


Figure 5: Seasonality of Dengue Incidence with Rainfall, Minimum and Maximum Temperature. Source: MMOH, HPA, MMS

The monthly average dengue incidence for three of the seven provinces is shown in the graph to the left as a black line. The graph on the top is for the Upper North Province where the Hanimaadhoo station is located. The monthly average for rainfall is shown as blue shading and minimum and maximum temperature is shown as bar graphs in red and yellow. Similar charts for North-Central Province with the Hulhule stations is shown in the middle panel. It is interesting to compare the NCP with and without Male. The lower graph is for the Upper South Province and the Kaadedhdhoo meteorological station. The dengue peaks are 1-2 months after the May rains. The lower dengue incidence in December/January are likely due to lower temperatures.

Time Series of Dengue Incidence and Water Availability

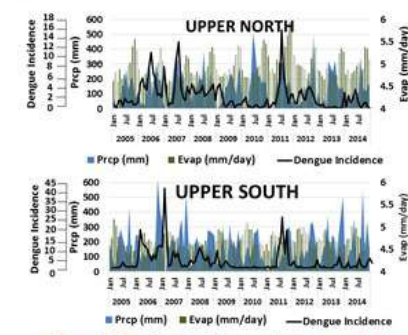


Figure4: Time Series of Dengue Incidence with the Precipitation and Evaporation from 2005 to 2014. Source: MMOH, HPA, MMS

The dengue incidence for the seven provinces as a time series along with daily rainfall, and evaporation were analyzed. The water availability is estimated as the difference between monthly rainfall and evaporation for dengue as breeding takes place in artificial receptacles.

The data for two provinces are shown on the left shows the time lag between the rainfall and dengue peaks. There is very clear relationship.

Future work shall provide the difference between rainfall and evaporation at different time steps.

Conclusions

There is clear evidences of climate drivers of dengue seasonality and epidemic events based on analysis of the climate and incidence data. Rainfall and temperature relationships with dengue remain in different regions even while the seasonality changes. Epidemics have occurred when the minimum and maximum temperatures is between 25-26C and 30-31 C. These relationships are much more sensitive than may be understood from laboratory studies. The relationships are consistent across regions and seasons. We need further analysis at shorter time steps to nail down relationships with rainfall which we are following up now.

