ISSN 1870-4069

# Conceptual Model of Mosquito Life Cycle Aedes Aegypti to Describe the Behavior of Dengue Virus

Laura Valentina Bocanegra-Villegas[1], Sandra Patricia Usaquén-Perilla[2], Cuauhtémoc Sánchez-Ramírez[1], Tomas Muñoz-Guerrero[3]

[1] Instituto Tecnológico de Orizaba,
División de Investigación y Estudios de Posgrado,
México

[2] Universidad Militar Nueva Granada,
Programa de Ingeniería Biomédica,
Colombia

[3] Hospital General Regional 1 del IMSS,
Clinica Hospital ISSSTE, Epidemiología,
Mexico

{laura.bocanegra, sandra.usaquen}@correounivalle.edu.com,
csanchezr@ito-depi.edu.mx, doctortmg@yahoo.com.mx

**Abstract.** Mosquitoes of the species Aedes (Ae. aegypti or Ae. albopictus) can transmit Dengue, Chikungunya, Zika and Yellow Fever. For the people's mobility and increasing population density, diseases as the Dengue have been an epidemic in recent years, being a globally important health problem. Those responsible for creating vector control campaigns and medical staff are interested in identifying tools to predict the seasonal peak of the dengue outbreak and identify related climate factors that contribute to the increase in the number of mosquitoes. The main variables entered are precipitation, temperature, and epidemiological week. The model is the first phase of a project that aims to provide a tool for simulating outbreaks of dengue with system dynamics, a basis for predicting the spread of the dengue outbreak in Orizaba, Veracruz, Mexico.

**Keywords:** System dynamics (SD), simulation, dengue virus, aedes aegypti.

## 1 Introduction

The Aedes Aegypti mosquito goes through four distinct stages during the life cycle: egg, larvae, chrysalis and adult [1]. They can live in urban areas with altitudes below 2200 meters above sea level, lay their eggs in clean water tanks such as swimming pools, vases, aquatic plants, tires, buckets of water and any container that is outdoors and can store water [2]. Studies on the flight radius indicate that most females can spend their entire lives inside or around the houses in which they have become adults, and that they usually fly about 400 meters on average [3].

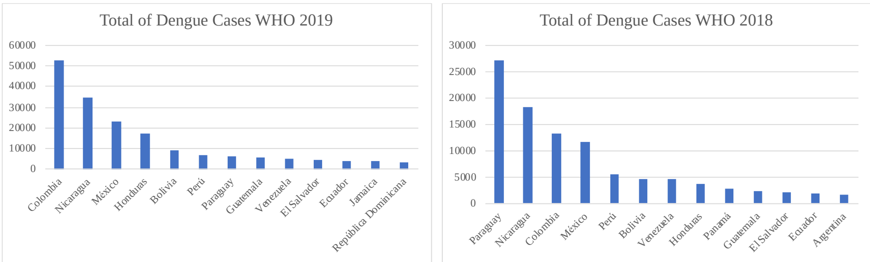


**Fig. 1.** Total of Dengue Cases, year 2019-2018.

Dengue is considered to be the most important mosquito-borne viral disease, about half of the world's population lives in countries endemic, causing it to spread rapidly, with a lethality exceeding 2% per year [4, 5], in more than 100 countries [6, 7].

The virus is transmitted to humans through the bites of infected female mosquitoes, mainly of the species Aedes Aegypti. After incubation of the virus (4 to 10 days), an infected mosquito can transmit the virus for the rest of its life. Mosquitoes usually acquire the virus while feeding on the blood of infected humans (symptomatic or asymptomatic), with humans being the only source of the virus for uninfected mosquitoes [8].

## 2 Background and State of the Art

Up until 1970, only nine countries had experienced severe dengue epidemics, currently endemic in more than 100 countries in WHO regions, accounting for approximately 70% of the global burden of disease. An estimate indicates that 390 million infections occur dengue per year (credible interval of 95%: 284 to 528 million), of which 96 million (67 to 136 million) manifest themselves clinically (with any severity of the disease). And an estimated 3.9 billion people are at risk of contracting the dengue virus [9].

The WHO collects information from ministries of health, which groups information from the Americas in six groups, on the continent a 662% increase between 2018-2019. Mexico is in the " Isthmus " group Central America and Mexico" together with Belize, Panama, El Salvador, Costa Rica, Guatemala, Honduras and Nicaragua, in the years of study, Mexico has been in second place (28%.26% respectively) of the cases reported in the group; Figure 1 shows the growth of Dengue and the relevance to Mexico and the impact on the continent (to facilitate the analysis, Brazil is excluded, which is in first place with a wide difference) [10].

The average economic cost of dengue in Mexico was $170 million in 2013, including direct and indirect costs associated with dengue. The cost associated with inpatients was $25 million, while outpatient and fatal dengue episodes account for $54 million and $8 million per year, respectively.

In addition, the monitoring cost and vectors control account for 48.9% of the total economic burden of dengue in the country, equivalent to $83 million per year [4]. In particular, average annual spending estimated for insecticide products per household

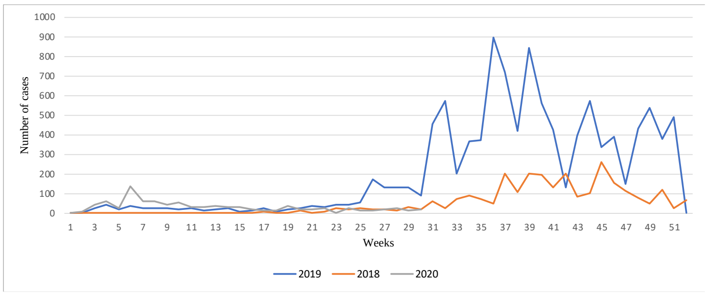


**Fig. 2.** Cases reported by the Health Department of Mexico between 2018-2020.

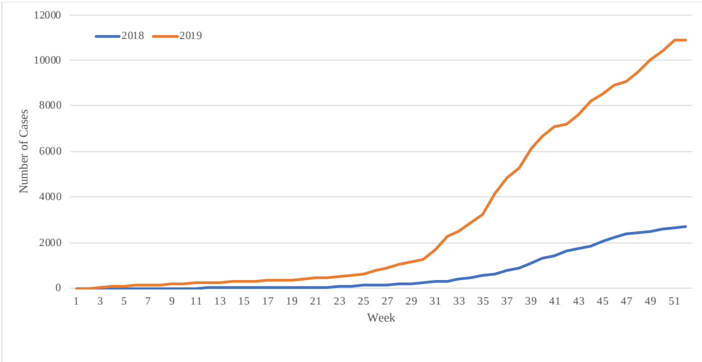


**Fig. 3.** Cases reported by the Secretary of Health of Mexico in Veracruz.

was $31 million [11]. However, vector control is partially successful in reducing the burden of dengue disease, increasing the importance of prevention [6].

The incidence has increased 303% in Mexico between 2018-2019 (see Figure 2) [12], although cases reported up to epidemiological week 30 of 2020 are shown, were not taken into account for the analysis due to irregularity caused by the SARS- CoV- 2 infection.

Having tools that allow patient estimations to be treated, make it easy the design of public vector control policies, to determine the economic impact, to build health policies in the Health Care Institution, and to prepare them for the attention of this population in terms of technology, availability of laboratory tests and human resources, Figure 3 shows the growth of the disease in the state of Veracruz.

Figure 4 shows the results of technology surveillance conducted with the keywords "Dengue model AND Simulation" in the databases ScienceDirect, Scopus, Web of Science and IEEE, finding 4034 articles, of which 327 were duplicated and 3659 were excluded for not complying with inclusion criteria (refer to aspects of care, treatment or ecology not included in the research). Therefore, only 48 articles were evaluated in full text for fulfilling the objective of the investigation, identifying that 11 of these used SD which is the proposed technique because allows to analyze and understand the underlying causes of the system studied in different scenarios, without modifying the actual system, however, of the 48 evaluated articles, were only taken 7 as a reference

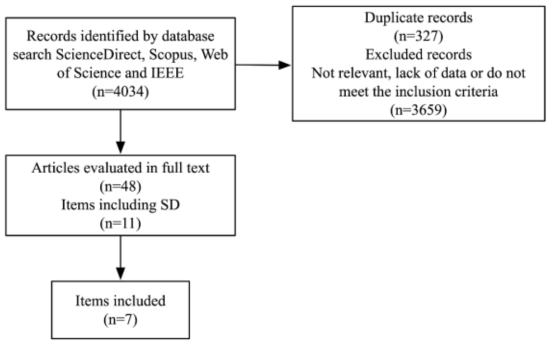


**Fig. 4.** Bibliometric analysis.

**Table 1.** Identification of variables for causal diagram design.

| Authors | Variables | Description |
| --- | --- | --- |
| [1, 16–19] | Temperature<br>Rainfall | Temperature in Celsius degrees in Orizaba, Veracruz. Climate fluctuation contributes to the seasonal dynamics of infectious diseases because it affects pathogen transmission rates. |
| [1, 8, 16, 18, 20] | Predators | Rate of predators decreasing the population of Mosquitoes. |
| | Food | Amount of food available. |
| | Number of eggs | Number of eggs, starts with 1000. |
| | Egg mortality rate | Egg death rate per natural causes. |
| | Larvae | Number of larvae, starts with a 0. |
| | Larvae mortality rate | Death rate of larvae from natural causes. |
| | Pupas | Number of pupae, starts with a 0. |
| | Pupas mortality rate | Death rate of pupae from natural causes. |
| | Female mosquitoes | Number of female mosquitoes, 50% of the total population is assumed. |
| [16, 20] | Diapause eggs | Eggs in inactivity due to low temperatures. |
| | Egg mortality rate in diapause | Egg death rate in diapause for natural causes |

for this investigation, because they allowed identify the key variables required in the development of the causal diagram.

There are different models of transmission of infectious diseases focused on Aedes Aegypti mosquitoes, it was found that from 2015 to 2020, 135 publications have been made with the keywords "Dengue model AND Simulation", four of which have been made in Mexico, concerning the risk matrix of vector-borne diseases [13], antibodies against dengue in three urban environments in Yucatan [14] and projected impact of the vaccine against dengue in Yucatan [15]. The seasonality equations in the Aedes aegypti mosquito life cycle, were taken as basis for this model [16], because they study the effects of temperature and precipitation for eight Mexican regions and the diapause role of in seasonality shoots in conjunction with [1] to complement some parameters not detailed in the previous [16], because of the similarity between the case-of-study regions and specificity of information.

## 3 Model Formulation

The growing need to control dengue has driven the development of research to shape mosquito behavior. System dynamics allows to model different variables of propagation, control and attention that impact the behavior of the disease.

Table 1 presents the authors (first column) who have identified key variables in their investigations, which will be used with the names listed (second column) and corresponding descriptions (third column). The model is developed based on [21] for the creation of dynamic system simulation models, first the key variables are selected, the information collected allowed to identify the variables (Table 1) that represent the different interactions between the stages of the life cycle and meteorology.

The second step, which is the Formulation, different mathematics techniques that include the seasonality of the life cycle were identified, such as: Vector Modeling, Multiple Staged Regression Analysis and Analysis [1, 18, 16, 19, 20]. Some authors have used System Dynamics [17, 22], to structure the elements and programming required in Stella® software. To simulate temperature and precipitation behavior, the information available at NASA [23] over the past five years was used, the data were analyzed and with a 95% confidence level the normal distinction is adjusted, normal log, exponential and logistics.

Once the variables were identified, the Causal Diagram was developed (Figure 5), in which the main variables and the feedback loops between them are identified. The red interactions represent the stages of the life cycle, grouped into mosquito biology (egg, larvae, pupa and adult) and meteorology (temperature and precipitation), is contextualized with preventive and corrective control strategies identified in green, although these are not within the scope of the document.

The loops in the Causal Diagram are described below:

- B1: The swing loop B1, is made up of female mosquitoes, number of eggs, larvae and pupas, if the larvae increase, then there will be more female mosquitoes and each of the above variables, conditions that are conserve as long as there are no temperature changes or there are control strategies.
- B2: The B2 rolling loop, composed of Preventive control and vector surveillance and control, reflects the indirect relationship between these variables.
- B3: The swing loop B3, vector surveillance and control and corrective control and preventive control shows how when the vector surveillance and control decrease corrective control.

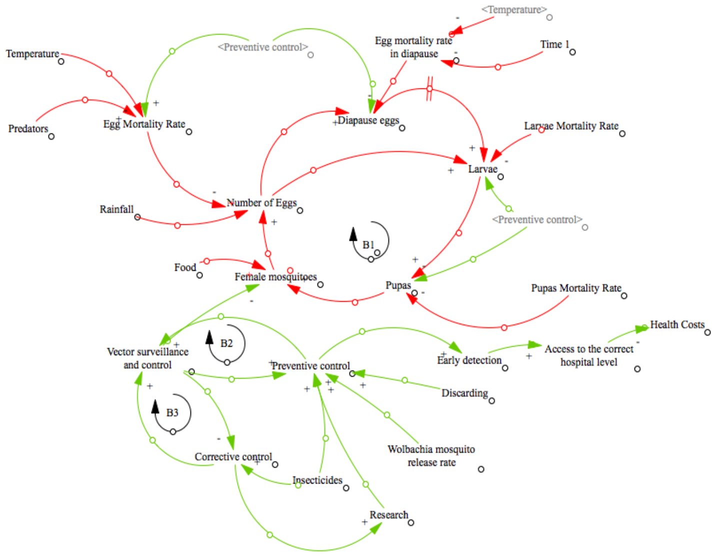


**Fig. 5.** Causal loop diagram.

The overall analysis of the causal loop diagram shows that the temperature and precipitation are key variables that influence the life cycle of mosquitoes, mortality, and diapause. If at least one is outside the life-friendly values, the number of mosquitoes at each stage will be severely affected and their future will be compromised.

Validation is intended to determine whether the structure and behavior are consistent with the cases of dengue recorded by the Secretary of Health of Mexico until the results are satisfactory. The purpose of this research is to simulate the behavior of the mosquito population with system dynamics.

For simulation, it is important the precipitation, temperature, and the total number of dengue cases per week to predict the behavior of dengue-transmitting mosquitoes. This is an archetype that can be used in other countries for any period of time if fed with information from the region to be studied.

## 4 Conclusions and Future Work

A deterministic model can be used to understand the dynamics of disease transmission, particularly for large populations. Using the dynamic system approach and causal loop diagram, this research proposes a conceptual model that analyzes the biological process of mosquito reproduction, taking into account death rates related to environmental factors, which allows future analysis of biological, chemical or mechanical control activities and how this relates to the dynamics of Dengue.

This model can be complemented by integrating diagnostic stages, the capacity of the health care institution, days of disease evolution when going to a medical service, the available equipment, among others. This will provide a better understanding and a more complete vision to find opportunities for improvement. Vector control and health care processes continue to be investigated in Orizaba, Veracruz, Mexico.

## References


1. Traoré, B., Koutou, O., Sangaré, B.: A Global Mathematical Model of Malaria Transmission Dynamics with Structured Mosquito Population and Temperature Variations. Nonlinear Analysis: Real World Applications, 53 (2020) doi: 10.1016/j.nonrwa.2019.103081.
2. Ministerio de Salud y Protección Social: Dengue (2020) https://www.minsalud.gov.co/salud/publica/PET/Paginas/dengue.aspx.
3. Organización Mundial de la Salud (OMS): El mosquito (2020) https://www.who.int/denguecontrol/mosquito/es/.
4. Shepard, D.S., Undurraga, E.A., Halasa, Y.A.: The Global Economic Burden of Dengue: A Systematic Analysis. The Lancet Infectious Diseases, 16(8), pp. 935–941 (2016) doi: 10.1016/S1473-3099(16)00146-8.
5. Padilla, C., Rojas, D., Sáenz-Gómez, R.: Dengue en Colombia, epidemiología de la reemergencia a la hiperendemia. pp. 1–249 (2012) doi: 10.18270/rsb.v5i1.186.
6. Schwartz, L.M., Halloran, M.E., Durbin, A.P.: The Dengue Vaccine Pipeline: Implications for The Future of Dengue Control. Vaccine, 33(29), pp. 3293–3298 (2015) doi: 10.1016/j.vaccine.2015.05.010.
7. Constenla, D., Garcia, C., Lefcourt, N.: Assessing the Economics of Dengue: Results from A Systematic Review of The Literature and Expert Survey. Pharmacoeconomics, 33(11), pp. 1107–1135 (2015) doi: 10.1007/s40273-015-0294-7.
8. Páez Chávez, J., Götz, T., Siegmund, S.: An SIR-Dengue Transmission Model with Seasonal Effects and Impulsive Control. Mathematical Biosciences, 289, pp. 29–39 (2017) doi: 10.1016/j.mbs.2017.04.005.
9. Organización Mundial de la Salud: Dengue y dengue grave (2020) https://www.who.int/es/news-room/fact-sheets/detail/dengue-and-severe-dengue.
10. PAHO, WHO: Muertes y letalidad de dengue (2020) http://www.paho.org/data/index.php/es/temas/indicadores-dengue/dengue-subnacional/520-mex-egi-muertes-letalidad-es.html.
11. Loroño-Pino, M.A.: Household Use of Insecticide Consumer Products in A Dengue-Endemic Area in Mexico. Tropical Medicine and International Health, 19(10), pp. 1267–1275 (2014) doi: 10.1111/tmi.12364.
12. Panorama epidemiológico: Dengue, 1 (2019)
13. Anzo-Hernández, A., Bonilla-Capilla, B., Velázquez-Castro, J.: The Risk Matrix of Vector-Borne Diseases in Metapopulation Networks and Its Relation With Local and Global. Communications in Nonlinear Science and Numerical Simulation, 68, pp. 1–14 (2019) doi: 10.1016/j.cnsns.2018.06.006.
14. Pavía-Ruz, N.: Seroprevalence of Dengue Antibodies in Three Urban Settings in Yucatan, Mexico. American Journal of Tropical Medicine and Hygiene, 98(4), pp. 1202–1208 (2018) doi: 10.4269/ajtmh.17-0382.

15. Hladish, T.J.: Projected Impact of Dengue Vaccination in Yucatán, Mexico. PLOS, 10(5) (2016) doi: 10.1371/journal.pntd.0004661.
16. Pliego Pliego, E., Velázquez-Castro, J., Fraguela Collar, A.: Seasonality on the Life Cycle of Aedes Aegypti Mosquito and Its Statistical Relation with Dengue Outbreaks. Applied Mathematical Modelling, 50, pp. 484–496 (2017) doi: 10.1016/j.apm.2017.06.003.
17. Jaafar, I., Abidin, N., Jamil, J.: Modelling the Prediction of Dengue Outbreak Using System Dynamics Approach, 1, pp. 1–6 (2015) doi: 10.11113/jt.v78.8984.
18. Taghikhani, R., Gumel, A.B.: Mathematics of Dengue Transmission Dynamics: Roles of Vector Vertical Transmission and Temperature Fluctuations. Infectious Disease Modelling, 3, pp. 266–292 (2018) doi: 10.1016/j.idm.2018.09.003.
19. Laureano-Rosario, A.E., Garcia-Rejon, J.E., Gomez-Carro, S.: Modelling Dengue Fever Risk in the State of Yucatan, Mexico Using Regional-Scale Satellite-Derived Sea Surface Temperature. Acta Tropica, 172, pp. 50–57 (2017) doi: 10.1016/j.actatropica.2017.04.017.
20. Ewing, D.A., Cobbold, C.A., Purse, B.V.: Modelling the Effect of Temperature on the Seasonal Population Dynamics of Temperate Mosquitoes. The Journal of Theoretical Biology, 400, pp. 65–79 (2016) doi: 10.1016/j.jtbi.2016.04.008
21. Cedillo M., Sánchez, C.: Análisis dinámico de sistemas industriales (2008)
22. Brailsford, S.C., Berchi R.: System Dynamics Models to Assess the Risk of Mosquito-Borne Diseases and to Evaluate Control Policies. In: International System Dynamics Conference, 1979, pp. 1–10 (2007)
23. NASA: POWER Data Access Viewer (2020) https://power.larc.nasa.gov/data-access-viewer/.