# Identification System based on Fuzzy Logic for epidemiological control of dengue in the metropolitan region of São Luís - MA

Hyngrid H. de C. Coelho[1], Matheus S. Pestana[2], Danúbia S. Pires[3], Orlando D. R. Filho[4]

*Dept. de Eletroeletrônica, Instituto Federal do Maranhão*
*Av. Getúlio Vargas, 65025-001, São Luís - MA, Brazil*
[1]*hyngridhevilyn@hotmail.com*
[2]*matheus.pestana@acad.ifma.edu.br*
[3]*danubiapires@ifma.edu.br*
[4]*orlando.rocha@ifma.edu.br*

**Abstract.** Dengue, as a highly prevalent disease in Brazil, impairs the population's well-being, affecting public health costs, so it is necessary to take measures to help prevent the onset of the disease. Thus, predicting the number of cases of the disease in a given region helps in planning and decision-making by Public Agencies. For this reason, it is extremely important that such forecasts are accurate, although this process has errors, since the factors that serve to obtain the diagnosis of cases have a behavior that depends on numerous parameters, such as precipitation rate and ambient temperature . Therefore, fuzzy logic presents itself as a good alternative for modeling a dengue case prediction system, as well as the development of low-cost technologies for this purpose. For that, a Takagi-Sugeno (TS) type MISO system (multiple inputs and one output) is proposed, capable of providing a forecast of the number of dengue cases in the city of São Luís - MA, based on the collection of epidemiological data from dengue in the municipality, which were related to the input variables of the system, obtaining linear submodels through a fuzzy clustering algorithm. The model obtained, with two input variables (rainfall rate and average temperature), obtained good computational results.

**Keywords:** Dengue; Fuzzy logic; System.

## 1 Introduction

According to the Pan American Health Organization [1], more than 1.6 million cases of dengue were reported in the Americas in the first five months of 2020, most cases were reported in Brazil, more precisely 1,040,481 cases, a figure that represents 65% of the total.

As reported by the Ministry of Health [2], the Brazil adopted in 2014 a new classification of dengue, which became a single, systemic and dynamic disease of broad clinical spectrum in symptomatic dengue, that is, the infection can evolve to an improvement or worsening, as well as to death, so caution is recommended with any symptoms presented, so that due care is adopted promptly, in the search for the reduction of severe cases and deaths.

Because of the hot and humid climate, according to Brazil [3], factors that facilitate the proliferation of the virus, the infected dengue mosquito is found in all regions of Brazil, which causes a great need for research and studies aimed at the prevention of this epidemic, in addition to favorable environmental conditions with significant influence on the distribution of the vector.

An increase in the use of techniques involving predictions of future facts in the branch of epidemiology was observed recently, such as a system based on epidemiological data in which Silva et al. [4] concludes that factors such as: rainfall, air temperature and relative humidity of the air, from 2016 to 2019 in the city of Quixadá - CE, presented themselves as favorable for the proliferation of A. aegypti and, consequently, the occurrences of infections, a result obtained through a model based on fuzzy logic. According to the author, the system achieved was very satisfactory for the inference of classes and approximation of the quantitative cases of occurrences of arboviroses in the study region.

Therefore, the fuzzy logic presents itself as a good alternative for modeling a forecasting system of prevalence and incidence of dengue cases, since one of its strongest features is the treatment of uncertainty that certain information has, accordind to Pires; Serra [5].

The MISO (Multiple Input, Single Output) fuzzy system proposed in this project analyzes two inputs (rainfall level, average temperature) - which directly influence the emergence of dengue cases, which vary in a non-linear manner - the interaction between these variables and the degree of influence of each on the future state (system output) of the disease. The proposed model allows the measurement of the prevalence and incidence of dengue cases in the city of São Luís - MA, through fuzzy logic with Takagi-Sugeno inference, in order to assist in the decision-making of the competent bodies.

## 2 Theoretical foundation

According to Machado et al. [6], dengue is considered a serious public health problem, since sociocultural factors and social inequality contribute to its proliferation. Dengue virus (DENV), the etiological agent of dengue fever and dengue hemorrhagic fever, is considered the most important arbovirus that affects humans worldwide. DENV is transmitted by the bite of arthropod vectors, mosquitoes belonging to the genus Aedes, with the species Aedes aegypti, the main vector in Brazil, proven in studies like Murray et al. [7].

In the area of epidemiology, in Sette [8] the climate is the main aspect of the physical environment studied, because it is the result of several characteristic meteorological phenomena, which express the average situation of the atmosphere in a delimited region of the earth's surface. Climate, as well as other factors, can lead to the manifestation of certain health diseases through its characteristics (temperature, air humidity, rainfall, atmospheric pressure), which interfere with people's well-being.

Studies such as Monteiro; Braz [9] and Viana; Ignotti [10] show the influence of meteorological factors such as temperature, relative humidity, and rainfall on the dynamics of disease transmission, in addition to the peaks of disease epidemics in Brazil, regardless of the climatic compartment. This worsening occurs mainly in the first half of each year, as this is the period of highest rainfall and temperature in most of the country, which contributes to an increase in the number of breeding sites and, consequently, of dengue cases.

Conforming to Monteiro; Braz [9], the Aedes Aegypti mosquito finds ideal breeding conditions in high temperatures and high humidity, which makes dengue a common disease in the tropics. The author also concludes that in the Northeast region, precipitation has a positive effect on the number of dengue cases

As stated in Cavalcante et al. [11], temperature influences the development of the mosquito cycle (which is between 5 to 7 days), as long as they are in the range of 25 to 29°C. Below these temperatures, the development time becomes slower and at temperatures below 12°C, the larvae do not transform into pupa.

A control action is defined by a set of fuzzy rules, a given rule (Ri) can be defined as a relation between antecedent and consequent linguistic variables, for both classical approaches (Mamdani and Takagi-Sugeno), contained universes of speech, thus the fuzzy rules algorithm is considered as a following equation:

$$Ri : If \quad x \quad is \quad Ai \quad and \quad y \quad is \quad Bi, \quad then \quad z \quad is \quad Ci, \quad i = 1, 2, 3, ..., K \tag{1}$$

Where x and y are the background variables, which represent the input to the fuzzy system, z is a consequent variable, which represents the output, Ai, Bi and Ci are the fuzzy sets of x, y and z. (Babushka and H.B.Verbruggen [12])

The system's qualitative information is transformed into quantitative information, according to its membership function defined by the operator. The inverse process is provided at the output, that is, the quantitative is transformed into qualitative, a process called defuzzification. In Takagi-Sugeno systems, the consequent of the rule is not a fuzzy set (Kadkhodaie-Ilkhchi et al. [13], Babushka and H.B.Verbruggen [12]).

The set of rules relate the variables through connectives and, or not, thus it is possible to correlate more than one input and more than one output for a given fuzzy system, from this concept that are generated as SISO, MISO and MIMO classifications. A system is considered SISO when it has a single input and a single output, a MISO system has multiple inputs and a single output while a MIMO system is one with multiple inputs and multiples that exist cloudy (Kadkhodaie-Ilkhchiet al. [13], Babushka and HB Verbruggen [12]).

Fuzzy systems provide a good treatment of data in forecasting systems, pioneering work such as Tanaka; Sugeno [14] showed that the fuzzy control of TS models can be made in a rigorous manner, following methodologies that can be reproduced in a systematic way, ensuring beyond the stability several performance criteria in closed loop.

Takagi-Sugeno systems are capable of representing, approximately or exactly, any nonlinear dynamics as a combination of locally valid linear models. In general, they are less complex than other classes of fuzzy models, as stated in Johansen et al [15], making identification and modeling aspects easier.

In Zadeh [16], the mathematical foundation of fuzzy logic is in the theory of fuzzy sets, which states that given a particular element that belongs to a domain, is verified the degree of relevance of the element in relation to the set. The degree of relevance serves as a reference to verify how possible" this element belongs to the set. The degree is calculated through a certain pertinence function that returns a real value ranging from 0 to 1, where 0 indicates that it does not belong to the set, and 1 indicates that it totally belongs.

In Silveira [17] was presented a system based on epidemiological data through a study of the risk of dengue in the city of Sorocaba - SP based on Fuzzy Logic and a two-dimensional model of Takagi-Sugeno type, where the consequence of each fuzzy rule is a partial differential equation - PDE, the research results showed that an effective action to reduce the risk of dengue is to severely combat the possible breeding sites of mosquitoes.

## 3 Methodology

The fuzzy model was implemented using the Matlab simulation and modeling platform, from which the system variables (mean temperature and precipitation) were defined and the epidemiological data of the chosen variables were collected on the platform of the Ministry of Health and the National Institute of Meteorology (INMET). Then, using the modeling and simulation platform, a behavioral analysis of the MISO system was carried out in the context of the study presented, from which it was possible to identify the inputs and how they influence the output, as well as an analysis of the system suggested from the survey of the data obtained.

## 4 Computacional results

Using the MatLab modeling and simulation platform, the implemented system included two variables: precipitation index and average temperature of the environment, defined according to Baracho et. al [18] in his study "The climatic influence on the proliferation of dengue in the city of Areia, Paraíba", whose author observed that climatic factors were paramount for the appearance of infection, in the years 2007, 2008 and 2011 in the municipality under study, when it reached a high number of cases. In addition, in the first semesters of the years studied, weather conditions had their highest rates, which favored the proliferation of the dengue virus, an event that correlates these factors with the appearance of cases of the disease. In the second half of the year, these weather conditions decreased, which led to a decrease in the number of episodes of the pathology under study.

In the development of the cloudy system, the two variables mentioned (precipitation index and average ambient temperature) were used, acquired through the portal of the National Institute of Meteorology (INMET) and related to probable cases of dengue (output of the system), information acquired by the Ministry of Health's Online Notification System (SINAN) platform. The creation of the system consists of using data from the years 2017 and 2018. The 2020 data were not in the SINAN platform, so the most recent year was used for validation of the system, which in this case was 2019. It was possible to obtain the fuzzy sets for each variable, as shown in Figure 1. From these sets, a set with 8 fuzzy rules was obtained, see table 1, responsible for the correlation between the variables of input with the output of the system.

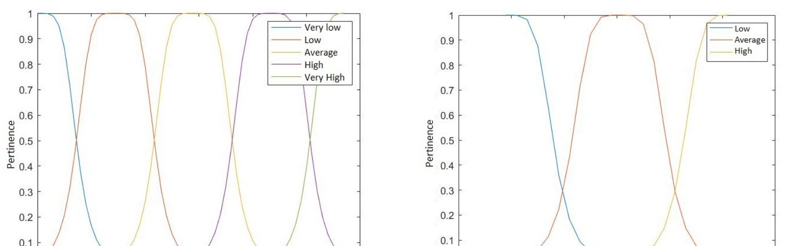



Figure 1. Fuzzy set of rainfall and temperature for the year 2019. Source: Author.

The graphical representation of the surface generated by the developed system, figure 2, is interpreted as follows: cases are more frequent when the rainy season presents average precipitation values between 200 and 400 mm per month and average temperature between 26 ° C to 27 ° C, factors such as those that favor the development and proliferation of Aedes Aegypti and, consequently, of the cases of the disease in São Luís.

Table 1. Fuzzy set for probable cases of the year 2019. Source: Author.

| |
|---|
| 1. If the temperature is **high** and rain is **medium** then the probable cases are **low**; |
| 2. If the temperature is **medium** and rainfall is **medium** then probable cases is **low**; |
| 3. If the temperature is **medium** and the rain is **very high** then probable cases are **low**; |
| 4. If temperature is **low** and rain is **very high** then probable cases are **medium**; |
| 5. If temperature is **low** and rain is **high** then probable cases are **high**; |
| 6. If temperature is **medium** and rain is **low** then probable cases is **high**; |
| 7. If the temperature is **medium** and the rain is **very low** then probable cases are **medium**; |
| 8. If the temperature is **high** and rain is **very low** then probable cases are **low**; |

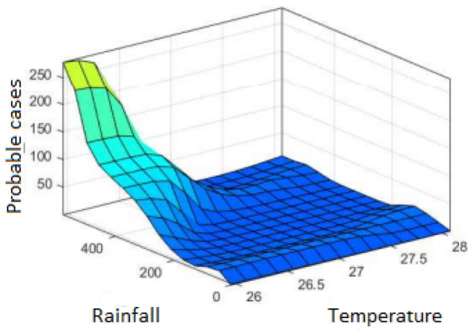
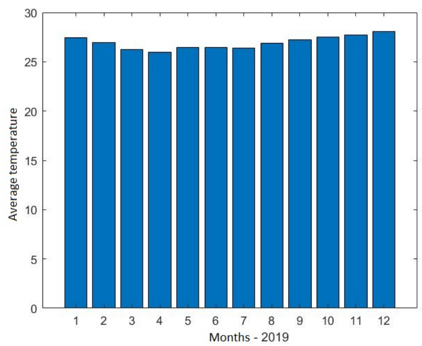
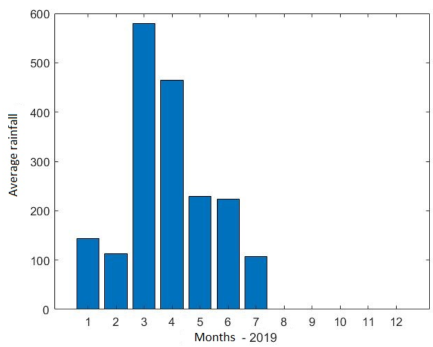



Figure 2. Surface graph representing probable cases, rainfall and temperature in the year 2019. Source: Author.

The region comprising the city, being a coastal area influenced by the tropical climate, has an average temperature almost constant throughout the year, as shown in Figure 3a, for this reason the temperature variation ends up not having a great influence on the growth or decrease of new cases of the disease, as it is always in the range considered ideal for the mosquito's life cycle, as mentioned in Cavalcante [11].




((a)) Average temperature.




((b)) Average rainfall.

Figure 3. Average temperature and rainfall graphs for the year 2019. Source: Author.

Added to this, in the first seven months of the year there is rainfall, but the periods of highest rainfall in the city correspond to the months of March to June, Figure 3b, which leads to an increase in cases of the disease in this period, but this increase does not it is sudden, since the peak of cases occurred in May, see figure 4, as in Czuy, Baldo et al [19] and Souza, Vianna and Moraes [20], the need for statistics The analysis relating variables is demonstrated climate,it's necessary to consider a lag period in the occurrence of Dengue, since the disease takes some time to follow the change after the meteorological variations of an environment. This is due to the life cycle time of the vector plus the incubation period in mosquitoes and humans, and only then can the case be notified in hospitals.

In addition, it can be observed that when there is no rain, the cases decrease, but are not null, this situation coincides with the end of the rainy season, it is in this period when the proliferation of dengue is continued due to the accumulation of rainwater in puddles, swamps, tires and in waste improperly disposed of in homes and on the

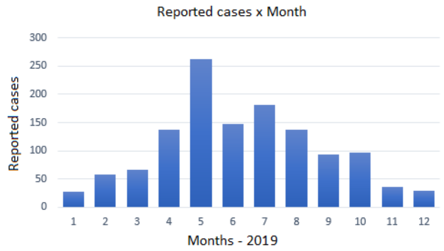



Figure 4. Reported cases in the year 2019 by the Ministry of Health. Source: Author.

street that serve as breeding grounds for the transmitting mosquito, conforming in Silva et. al [21].

It can be seen that, although the proposed system has only two inputs (rainfall rate and average ambient temperature), the prediction of possible cases of the disease in the municipality of São Luís, represented in Figure 5, obtained a result very similar to the cases reported by the responsible agency , since the accuracy rate between the notified cases and the cases foreseen in the system was 67%, that is, the platform considered a good performance when taking into account the nature of the factors influencing the input and output variables they have nonlinear behavior, that is, your data can vary over the same time span from one analysis to another.

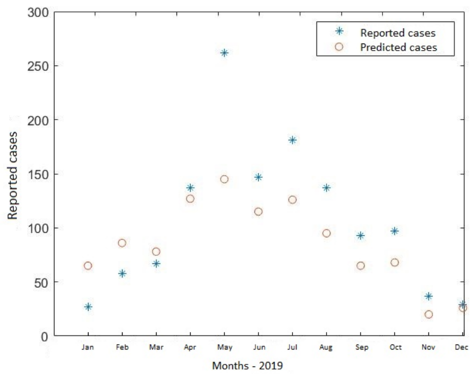



Figure 5. Relation between reported dengue cases (notified by the Ministry of Health) and cases predicted by the fuzzy system, year 2019. Source: Author

From this, it is possible to observe that the results of the proposed epidemiological system present themselves as an efficient methodology, since the input data obtained in the simulation demonstrate a nice relationship with the probable cases of dengue, see figure 6, which offers reliability and agility for the decision making of agencies responsible for health in Brazil in the field of epidemiology. The system still under study has as a future stage the inclusion of more variables to improve its performance, reducing forecast errors.

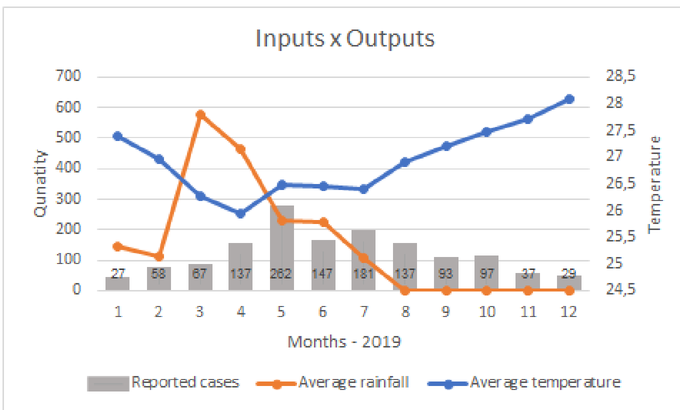



Figure 6. Relation between the inputs and output of the fuzzy system in the year 2019. Source: Author.

## 5 Conclusions

This article is presented as a procedure that seeks a tool to assist in decision making of the competent health agencies regarding the probable cases of dengue in the city under study. The data obtained via virtual simulation show the accuracy and convergence of input variables with the output of the system, thus the tests of the simulations show the efficiency of fuzzy logic for treatment of non-linear situations, such as dengue. The results achieved are already promising in the field of epidemiology, added to this, the next steps of the work will include more variables in order to increase the accuracy of the system under study.

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**Authorship statement.**The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

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