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# The use of Predictive Models as a Tool to Fight Dengue and to Improve Public Health

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***Abstract*** *- Dengue has become a global concern due to the number of populations threatened by the disease, especially in countries with tropical climates, and the ease of adaptation of the transmitting mosquito to new environments. Thus, the objective of this work is to demonstrate a predictive model based on meteorological and dengue data mining organized in an Excel spreadsheet. Organized data allow for the generation of association and classification rules through the CBA software so that public administrations can plan preventive actions to control disease outbreaks. Based on the association and classification rules, it was possible to prepare a forecast of the occurrence of dengue of up to 10 weeks, as proposed in the research.*

## I. INTRODUCTION

Dengue is a disease at a global level with disastrous consequences for health, especially in tropical and subtropical countries where *Aedes aegypti* has found easy adaptation. Its adaptability to new environments has caused the mosquito that transmits dengue to spread across nearly the entire globe [1]. With climate change, this vector is trending toward regions that previously had no problems with this insect. With the spread of the mosquito and the increase in the threat of the disease, authorities linked to the Public Administration must act preventively to control and combat dengue [2]. Thus, this research aims to present a predictive model for the occurrence of dengue with a forecast of up to 10 weeks so that public managers can plan and develop actions to face possible disease outbreaks in cities. The predictive model used meteorological and dengue data from January 2010 to August 2020. These data were organized in an Excel spreadsheet, and the association and classification rules were extracted using the CBA software. Morrinhos, located in the interior of Brazil and constantly facing problems with dengue, was chosen as a model.

## II. THEORETICAL REFERENCES

2.1. Dengue: adaptation and advances of the disease in the world

Dengue has recently become one of the most epidemiological diseases with global relevance, transforming it into a worldwide public health problem, with outbreaks occurring in Latin America every three or five years since the 17th century [3]. Climate change has contributed to the geographic distribution of *Aedes aegypti* on a global scale, including in areas where there were no reports of the mosquito before, as is the case in southern Buenos Aires Province and Eastern Patagonia (low temperatures, 16.5º to 11º C) [4]. In addition, climate change may affect the range of *Aedes aegypti* within the United States of America in areas with a temperate climate, which indicates that this mosquito has the potential to spread throughout North America [5].

The adaptability of the mosquito that transmits dengue is related to its ecophysiological (genetic and environmental) plasticity—that is, the ability of a species to survive in different habitats. The more ecophysiological plasticity the *Aedes aegypti* displays in environments of extreme temperatures (cold winters or periods of heat), the greater the distribution limits of this vector, which increases the risk of the disease arising [1].

The spread of *Aedes aegypti* is influenced by the population's susceptibility and exacerbated by human migration, whether within the country or between countries, including over large distances [6]. An infected female mosquito can transmit the virus to a population throughout her life [7]. Moreover, at the end of the 20th century, dengue spread throughout tropical countries. It threatened a third of the world's population, even more so because *Aedes aegypti* can transmit four different viruses (serotypes).

According to serotypes, the first dengue epidemic confirmed in the laboratory occurred in Brazil in 1981 and 1982 in Boa Vista, the capital of Roraima (serotypes DENV-1 and DENV-4). In 1990, the DENV-2 serotype was detected in Rio de Janeiro, while the DENV-3 serotype appeared in 1999 in Amapá, Pará, Roraima, and the Tocantins [8]. However, the first dengue epidemic in Brazil was recorded in 1845 in Rio de Janeiro. Brazil is responsible for more than 50% of dengue cases in the Americas. The Central-West region (formed by Goiás, Mato Grosso, and Mato Grosso do Sul) has the highest dengue cases per capita [9].

Many Brazilian cities need running water or garbage collection services. Therefore, they can provide conditions for mosquito breeding in waste thrown in backyards and water stored for consumption [10]. The mosquito's behavior is anthropophilic, and it prefers to lay eggs in containers with water (artificial pools), which favors its adaptation to the urban environment.

As evaluated by these same authors, the mosquito that transmits dengue can be introduced into ecosystems where it did not exist. The life cycle of *Aedes aegypti* spans four phases: egg, larva, pupa, and adult. The females deposit the eggs on the edge of water containers, and embryonic development takes an average of 48 hours. However, the eggs can subsist for more than a year without water. Humans can transport it in containers for long distances (and, in some cases, even by animals) [11].

Dengue viruses are transmitted to humans through a contaminated female mosquito bite. The disease can present symptoms from mild fever to more severe cases, such as hemorrhage and shock. The transmission from mosquito to man and man to mosquito is called horizontal transmission. However, recent studies also consider vertical transmission (or transovarial transmission), in which female mosquitoes transfer the virus to their offspring [12].

The seasonality of the occurrence of dengue in the hottest months of the year is related to the dynamics of the reproductive cycle of *Aedes aegypti*. However, even when cases decrease in the colder months, it is not enough to stop transmission [13]. Since 1998, Brazil has made it mandatory to record dengue cases in a national computerized system created in 1993 (SINAN - Information System for Notifiable Diseases). All municipalities, states, and the Federal District must report disease cases [14].

SINAN intends to record the occurrence of outbreaks and epidemics, measure the magnitude of epidemiological diseases (including dengue), and use it as a tool in public health planning in Brazil [14]. In the late 2000s, due to the increase in dengue cases in Brazil, new challenges were created in the disease control and prevention systems. Health resources should be adequate to achieve the expected effectiveness and efficiency [15].

In the state of Goiás, according to research by Santos et al. [15], there is much difficulty among municipal coordinators of Epidemiological Surveillance to prevent the most severe cases of dengue and, in addition, most do not know if their municipality has a contingency plan against the dengue epidemic. In Goiânia (capital of the state of Goiás), as of 2008, dengue epidemics were observed for three consecutive years, and in 2013 the worst occurred with 58,024 confirmed cases, of which 89.5% occurred in the interval between December 30, 2012, and June 29, 2013 [16].

It is recommended to use mathematical and statistical models for predicting dengue outbreaks to determine the realistic nature of the disease. According to Nascimento et al. [16], monitoring severe disease cases through information integration tools becomes an essential strategy in controlling dengue epidemics to reduce lethality, allowing adequate decision-making for the planning and organization of health services. Erandi et al. [17] developed a predictive model of dengue for the city of Colombo (Sri Lanka) based on the classic compartmental model that was reduced to a simpler quasi-equilibrium Infection/Recovery model to try to understand the dynamics of disease transmission. The development of more promising predictive models for dengue must consider the external variables. Of these, the ones that presented the best results were climatic factors such as precipitation, temperature, and humidity, but it was impossible to use these variables in their studies [17].

### 2.2. Public administration and dengue

Improvements cannot match the expectation that developing countries' urban growth rates will double by 2050. Furthermore, the increase in arbovirus cases was practically due to urbanization, environmental deterioration, poverty, and social inequality. When the Public Administration makes the interventions without the direct participation of the community, the effect will not have the desired impact, nor will it be a sustainable action. A positive example of community intervention was recorded on the Kenyan coast, where environmental education and cleaning campaigns contributed to reducing malaria and diseases caused by *Aedes*. Improving housing that favors a more sustainably built environment also helps fight vector-borne diseases [2].

Pandemics (and their consequences) should lead cities to review their concepts of how they provide services and rethink how they plan their space. When thinking about the city of the future, which is expected to be more ecologically and economically resilient with healthier and more livable neighborhoods (available and accessible to all people), improvement in the quality of life of local communities should arise from Public Administration that promotes inclusion, equity, urban accessibility, and sustainability, in addition to community-based services. In other words, when Public Administration begins to understand the need for change, it should develop integrated planning for public services based on the community and implement solutions that connect local governments, associations, communities, and the population [18].

The ability to promote the safety of essential household utilities, such as energy, water, and accessibility to health infrastructure, is directly related to Public Administration interventions in health policies and how vulnerable families bear the disease burden. This is mainly because inequality in access to public policy resources (public services, medical care, Etc.) and health intervention policies make it more difficult for the low-income population to protect themselves from pandemics [19]. It is necessary to create strategies to mitigate the effects of a pandemic on low-income families (vulnerable population), given that economic vulnerability, difficulty in accessing public policies, and low spending capacity on health can interfere with the city's ability to react with policies to deal with disease outbreaks.

## III. RESEARCH METHOD

Initially, it was necessary to carry out a bibliographic survey on dengue and the importance (or need) of seeking a way to collaborate with public health in the fight against this disease by reading several articles that address the subject, especially in the Americas and in Brazil.

The development of research involving data mining generally presupposes the establishment of three phases: a) the data collection, b) data preparation, and c) modeling [20].

### 3.1. Data collection

In data mining, the collection phase may require specialized hardware or manual work in the search for documents on the Web. This research phase works with meteorological and dengue data in Morrinhos, state of Goiás, Brazil, from January 2010 to August 2020. The meteorological data were obtained from the National Institute of Meteorology (INMET), linked to the Ministry of Agriculture, Livestock and Supply. INMET has a meteorological station in Morrinhos, in Goiás, latitude -17.745066, longitude -49.101698, altitude 751.09 m, installation date: May 24, 2001, code from station: A003.

Ideal climatic conditions, such as temperature, rainfall intensity, and other climatic events, can affect the reproduction and survival of *Aedes aegypti* and influence the rate of human morbidity [21]. As for dengue data, they were obtained from the Notifiable Diseases Information System (SINAN) by the Dengue Notification/Investigation Bulletin - Frequency per Epidemiological Week Notification and Classification (Dengue) and Frequency per Epidemiological Week Notification and Evolution (Deaths) in the Integrated Monitoring System Aedes Zero of the State Department of Health of the State of Goiás.

The Federal Government defines the epidemiological weeks of each year on the SINAN website (available at http://www.portalsinan.saude.gov.br/calendario-epidemiologico), and the Epidemiological Surveillance Centers of the municipalities, states, and the Federal District provides the records of notifications and investigations based on the Epidemiological Calendar. The intention of collecting meteorological and dengue data is to verify, by cross-analyzing these data, whether there is a pattern in the occurrence of disease cases concerning climatological data.

Meteorological data comprise essential variables that affect the behavior of the *Aedes aegypti* mosquito, such as temperature, relative humidity, precipitation, drought, atmospheric pressure, wind speed, and solar radiation, among others, according to Erandi et al. [17]. However, the data on dengue is weekly (epidemiological week), and the meteorological data are daily. It was necessary to calculate the weekly average of the meteorological data, following the same seven-day periods, except for the variable "precipitation" since it is essential to know the total volume of rainfall each week and not the average.

### 3.2. Data Preparation

The second phase, data pre-processing, is the most crucial part of data mining. Still, it is sometimes given little importance, as the focus is usually on the analytical aspects of this method [20]. However, as Aggarwal [20] points out, data preparation begins soon after data collection and consists of the following:

a) resource extraction - the researcher, can extract the essential characteristics of the research data for a specific application;

b) data cleaning – aims to eliminate unnecessary records and work on missing entries and, if necessary, eliminate inconsistencies; and

c) feature selection and transformation – taking out worthless features or transforming current features into a new range of data more accessible for analysis.

Regarding the dengue data obtained from SINAN, it was possible to create a new variable, in a row with dengue, to verify the existence of the correlation between accumulated rainfall and cases of the disease. New variables were created and added from the meteorological information existing in the INMET data, such as precipitation accumulated in two weeks, four weeks, eight weeks, and ten weeks, and also weeks followed by rain, since the saturation of the soil by rainwater tends to increase the number of breeding sites for *Aedes aegypti* [11].

3.3. Modeling

Four aspects are essential in data mining (grouping, classification, association, and outlier detection) for scientists to understand the nature of the relationships between data. It is considered, then, a multidimensional database "D"; with "n" records and "d" attributes. This database can be represented by the matrix "D n x d"; each row refers to a record, and each column relates to a dimension. The relationships between data items can be "relationships between columns" – it establishes positive or negative association, used to predict the value of a column, and is known as 'data classification'; or "relationship between lines" – favors the identification of clusters and anomalies (outlier analysis) [20].

In this research, data mining involves a bank of variables with 572 lines and 26 columns organized and worked on in an Excel spreadsheet, considering meteorological and dengue data. The data mining technique from meteorological and dengue data from Morrinhos, state of Goiás, Brazil, prepared in an Excel spreadsheet, proposes a multivariate analysis and the generation of rules for association and classification of data through the CBA software (quantitative model). Association rules with high support and confidence can help predict dengue outbreaks and are of the "IF (X), THEN (Y)" type; that is, it is an easy-to-understand model when relating cause and effect (IF /THEN) [22]. Such rules can facilitate prediction and are considered classification rules.

Consider "A" and "B" as variables in this case. Rule A => B is satisfactory in 'support' if the level of 'confidence' satisfies concomitantly: a) the support of the set of variables "A" is at least 's' and b) the confidence of A => B is in the minimum 'c' [20]. The present research intends to present the forecast of dengue cases of up to 10 (ten) weeks so that those responsible for the city's health can plan and anticipate actions so that disease outbreaks can be prevented.

## IV. RESULTS AND DISCUSSION

The creation of a predictive model presupposes the analysis of several variables that maintain a direct (or, sometimes, indirect) correlation with the phenomenon studied. In the case of small cities, where the absolute numbers of the variables are low, it is proposed to look at the variables in relative numbers [17]. In addition, a predictive model that can predict the occurrence of a pandemic (or even an outbreak) significantly corresponds with the management of the city, particularly with the authorities linked to the area of Health [14 - 15].

In the case of Morrinhos, with an estimated population of 46,955 [23], the absolute number of dengue cases and deaths from the disease in the period under analysis (2010 to 2020) is low. As the contamination potential of the transmitting mosquito is high, it becomes a concern for the local community [6 - 21]. Thus, the predictive model considered the calculation of the morbidity level of the disease in Morrinhos (GO) and separated the data into tertiles (three parts) - low, medium, and high, built from classification rules through the CBA software [11 - 21].

When processing the classification rules, the software checks the entire data set (weather variables, disease morbidity, and death variables) until it finds many highly supportive rules at the intersection of input and output variables. Subsequently, in the model validation phase, the algorithm builds a set of rules to elaborate the disease occurrence level [11 - 20 - 21].

The software confirms the classification rules in a confusion matrix in which the main diagonal demonstrates the correct model classification while the incorrect classification appears outside this diagonal [22]. Fig. 1 illustrates the confusion matrix for the first week (s1) of future disease prediction for Morrinhos (GO).

```
Overall Error : 15.25%
Confusion Matrix On Training:

(1)   (2)   (3)    <--- Classified As
----  ----  ----
271   27    8      (1): dengue_s1_<_1
21    35    13     (2): 1_<_dengue_s1_<_4
4     11    161    (3): dengue_s1_>_4
```

*Fig. 1: Confusion matrix to predict disease occurrence in Week 1 (s1).*

The first line refers to the first tertile (dengue cases less than 1), the second line to the second tertile (dengue cases between 1 and 4), and the third line to the third tertile (dengue cases more significant than 4), related to the epidemiological weeks from 2010 to 2020 entered into the model. It is observed that the model's accuracy for Week 1 (the first week of the predictive model) is 84.75% (that is, 100% - 15.25% of general error). To better understand how the software calculates accuracy, add the values of the main matrix (271 + 35 + 161 = 467) and divide by the total number of samples (551) and multiply by 100 to find the percentage (467 ÷ 551 x 100 = 84.75%) [22].

The predictive model was applied for the ten coming weeks with the accuracies shown in Fig. 2. Ideally, the accuracy should be 100% or present a value close to this maximum accuracy [20]. However, given the low absolute numbers of dengue in Morrinhos, the comparative data are significant due to the concern about the spread of the disease [13 - 16].

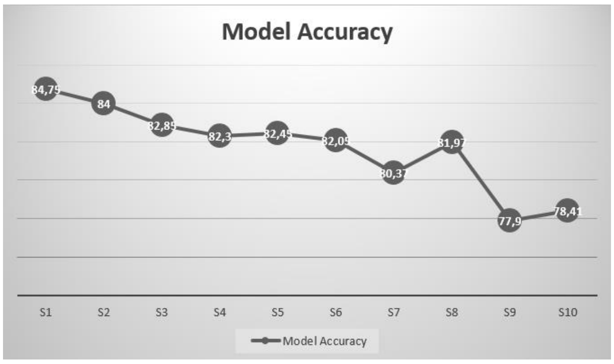


*Fig. 2: Model accuracy – weeks: s1 to s10.*

It should be clarified that the CBA software generated the following number of classification rules for each week of the prediction: s1 – 108; s2 - 91; s3 - 92; s4 - 95; s5 - 81; s6 - 82; s7 - 97; s8 - 103; s9 – 98 and s10 – 95. Moreover, it was possible to analyze those that presented 100% reliability from the rules generated in the classification. Thus, attention was drawn to the model that it did not relate the meteorological variables 'precipitation' and 'temperature' with the occurrence of dengue cases, as in Rule 5 of Week 2 (s2) and Rule 8 of Week 7 (s7) (and the pattern was also repeated in the other weeks):

Rule 5:

sem_com_dengue_<_0 = Y

precip_acum_s+8_>_310 = Y

temp_med_>_25 = Y

-> Class = dengue_s2_<_1

(7.273% 100.000% 40 40 7.273%)

Rule 8:

temp_min_>_19 = Y

sem_com_chuva_>_5 = Y

temp_med_>_25 = Y

rad_sol_>_20 = Y

-> Class = dengue_s7_<_1

(5.321% 100.000% 29 29 5.321%)

As can be seen in rule 5 (s2), with support of the rule at 7.273% and reliability of 100%, even with rains accumulated in 8 consecutive weeks with more than 310 mm and temperature above 25º C, the fact of not having dengue at present, the model indicates that cases of the disease in the second following week will be less than 1 (i.e., none). The same occurs in rule 8 (s7), with rule support at 5.321% and 100% reliability, minimum temperature above 19º C, with more than five weeks of accumulated rainfall, average temperature above 25º C, and solar radiation more significant than 20, the model does not predict dengue cases for the next seven weeks.

On the other hand, in the rules where dengue cases appeared in the input variables, the model presents a dengue forecast for the following weeks, regardless of climatic factors, as shown in rule 3 (s2), rule support at 8.727 % and 100% reliability. Atmospheric pressure is more significant than 933 hPa, and rainfall accumulated in the last ten weeks is less than 85 mm. Still, with more than six consecutive weeks of dengue cases, the model predicts that for the second week (s2), the occurrence of the disease is more significant than four cases (dengue_s2_>_4).

Rule 1 (s8) supports the 7.537% rule and 100% reliability, even with accumulated rainfall of less than 65 mm in the last eight weeks and minimum temperature below 15º C, the fact of having more than six weeks in a row with cases of dengue, the model predicts that dengue will occur in the eighth week (s8) of more than four cases (dengue_s8_>_4).

Rule 3:

p_atm_max_>_933 = Y

precip_acum_s+10_<_85 = Y

sem_com_dengue_>_6 = Y

-> Class = dengue_s2_>_4

(8.727% 100.000% 48 48 8.727%)

Rule 1:

precip_acum_s+8_<_65 = Y

sem_com_dengue_>_6 = Y

temp_min_<_15 = Y

-> Class = dengue_s8_>_4

(7.537% 100.000% 41 41 7.537%)

However, it should be noted that a milder temperature does not impede the proliferation of the arbovirus, given the vector's ability to adapt to new environments and temperatures [4].

## V. FINAL CONSIDERATIONS

Future prediction models for the occurrence of diseases aim to collaborate with city managers to organize resources, plan actions, and effectively control endemic diseases so that the impact on the local community is as small as possible [5 - 3]. According to the results found in the classification rules to develop a predictive model for dengue in Morrinhos, it was proved that the disease occurrence is more related to existing cases in the city than to meteorological issues, such as precipitation and temperature.

Although the meteorological data show little rain in recent weeks and low temperatures (rule 1, s8), the rules generated by the model indicate that even with prolonged periods of rain and high temperatures. It is not enough to determine that a dengue epidemic, as shown in the results of rules 5 (s2) and 8 (s7), had a similar pattern in the other weeks. Likewise, rules 3 (s2) and 1 (s8) present dengue cases with more than four occurrences in the respective weeks. The disease has been present for more than six weeks in both cases.

The state government provides monthly mosquito incidence data. However, this is data that contributes little to a predictive model on a weekly scale. The lack of daily or weekly data from the city hall on the incidence of the mosquito that transmits dengue in Morrinhos, mapped by street and neighborhood, makes it challenging to create a predictive model. As data are collected daily by agents fighting endemic diseases, they should also be made available in daily data or, at most, per epidemiological week, which would increase the efficiency and effectiveness of the predictive model.

## VI. RECOMMENDATIONS FOR FUTURE STUDIES

It is known that transmission occurs when *Aedes aegypti* bites an individual with dengue and then bites another healthy individual(s). In this case, the more mosquitoes there are in a given region, the greater the chances of an epidemic [1 -12]. Because of the results found in this research, it would be interesting to study the levels of infestation of the *Aedes aegypti* mosquito in cities. The model can better relate meteorological issues (precipitation, temperature, relative humidity, Etc.) to the proliferation of this dengue vector.

The risk of having *Aedes aegypti* in the city is already a cause for concern since if any infected individual arrives, it could promote an explosion of cases [8 - 10]. Faced with this possibility, a new predictive study would be healthy and necessary, one that would seek to relate the meteorological variables with the infestation variables of the mosquito that transmits dengue.

In addition, studies indicate that this arbovirus is also related to the incidence of greater poverty [7 - 9], which deserves a predictive model allowing Public Administration to follow up with vulnerable families in advance.

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