A DETERMINISTIC MODEL APPROACH OF LEPTOSPIROSIS OUTBREAKS IN RELATION TO CLIMATIC VARIABLES

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1) INTRODUCTION

Leptospirosis is a zoonosis found worldwide and it is a major public health issue in many rural and urban surroundings in temperate and tropical climates. This vector disease is present especially in many countries of Latin America and South-East Asia. The reported yearly incidence usually ranges from 0.1 to 1 per 100,000 inhabitants in temperate climates and is higher than 10 per 100,000 inhabitants in tropical regions (Haake et al., 2015). The animal reservoir includes mostly rodents, they excrete leptospires in their urine and thus contaminate hydric environment, transmitting the disease to other animals or to humans (McBride et al., 2005).

Outbreaks of leptospirosis in the northeast of Argentina occurred in months with moderate temperatures (late summer, early autumn) mainly coincident with El Niño event periods, characterized by flooding events caused by rivers levels increases or by abundant precipitation (López et al., 2016; 2019). This region accounts for the highest annual number of cases and deaths due to leptospirosis, being a top priority health issue at a regional level (Moral et al., 2014; López et al., 2019). The most affected cities were those with the largest population within each province.

Susceptible-Infectious-Recovered Epidemiological Model (SIR) has been used to describe the transmission dynamics of many infectious diseases, included leptospirosis. In this work we proposed a SIR model for leptospirosis outbreaks but incorporating hydroclimatic variables that influence the disease transmission in the northeast of Argentina, fitting the model to the actual data reported in outbreak events, in the three most populated cities in the area, Santa Fe, Rosario and Paraná, which have latitudinal and topographic differences. Each of these cities has experienced at least one outbreak since 2009.

2) METHODOLOGY

This study is carried out for the cities of Santa Fe, Paraná and Rosario that reported leptospirosis outbreaks in recent years. National System of Epidemiological Surveillance by Laboratories of Argentina (SIVILA) was implemented in 2009, and since then the notification of leptospirosis is mandatory in Argentina. Prior to this year, the registration of cases was not mandatory in health centers, nor was it systematized or standardized, so there are no reliable records in the region

We consider only the confirmed cases according to the information provided by the Directorate for Health Promotion and Prevention, Ministry of Health of the Santa Fe province and the Epidemiology Division of the Entre Ríos province. The total number of confirmed leptospirosis cases between 2009 and 2018 was 263; 94 for Santa Fe, 97 for Rosario and 72 for Paraná. This study does not analyze probable cases neither nor suspected or unconfirmed cases.

The adopted model is based on the work of Triampo et al. (2007), which described the transmission dynamics of leptospirosis in Thailand (Asia) through a SIR model where the infection rate varies in relation to precipitation, since in such zone there is a strong rainy season determined by the Monsoon regimes. The Ordinary Differential Equations (ODE) system implemented and a schematic diagram of the proposed SIR model could be seen in Gómez et al. (2022). Among the parameters of the model we must mention a very relevant one, Infection Rate β_H which particularly considers the hydroclimatic variables and it is defined as:

$$\beta_H\,(t) = \,k\Gamma(t, a, loc)\Delta FA(t) \quad \textbf{(1)}$$

where k is a scale parameter; $\Gamma(t, a, loc)$ is a gamma distribution of precipitation and $\Delta FA(t)$ is a function of variation of flooded area.

Raw precipitation data cannot be directly used into the structure of the differential equations of the SIR model, but rather a mathematical function of few parameters is usually used to simplify programming. Based on the methodology of Triampo et al. (2007), the monthly distribution of precipitation of each year is modelled with a Gamma probability distribution function and incorporated into the SIR model. The $\Gamma\,(t, a, loc)$ distribution is defined using non-linear least squares to fit the function to data of precipitation, where t is the time, a is the shape parameter, and loc is the location parameter. Monthly precipitation is divided by the annual precipitation in each city, in order to normalize it and obtain comparable values in the three studied cities.

Finally, in order to determine the function $\Delta FA(t)$ in each city, Landsat images TM5 and 8/OLI (approximate error of 30 m, one pixel) were analyzed using the Quantum Gis software. A buffer of 6 km^2 was defined around the hydrometer of each city to calculate the flooded area in three situations: minimum hydrometric level (year 2009), average hydrometric level (year 2015) and maximum hydrometric level (year 2016). Once the flooded areas were obtained according to each hydrometric level (h), the mathematical function of the variation of the flooded area (**Δ**FA) was determined for each city (**Δ**FA = f(h,t)).

The performance of the model was assessed by the Root Mean Square Error, according to equation **(2)**, where x is the number of leptospirosis cases at time *i*, and *n* is the total number of time steps at which the model is evaluated.

$$RMSE = \sqrt{\left(\frac{1}{n}\right)\sum_{i=1}^{n}(x_{observed} - x_{modeled})^2} \quad \textbf{(2)}$$

The RMSE is always positive and has the same units as the variable, so is a good measure of the goodness of fit to real values, with the smaller RMSE the better fit of the model.

3) RESULTS

The time series of leptospirosis cases shows an important outbreak in 2010 in the three cities (López et. al, 2019), so that the model is evaluated in that particular year. Figure 1 shows registered cases of leptospirosis in the three cities, as well as the SIR model results for 2010. The model is able to reproduce the peak behavior in Santa Fe, Rosario and Paraná, as can be observed in Figure 1a, 1b and 1c respectively.

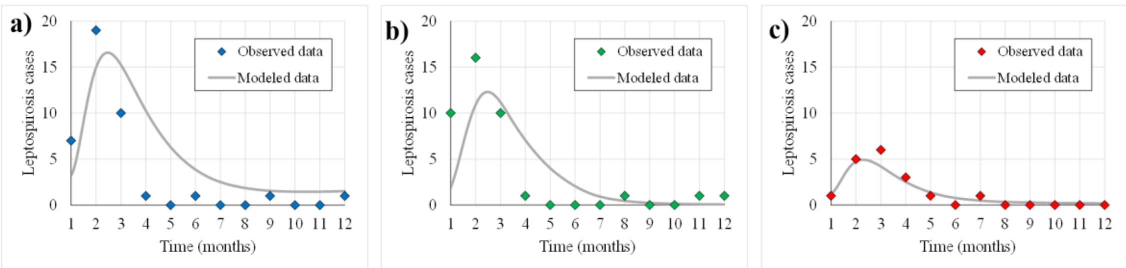

Figure 1: SIR model results and registered cases for the leptospirosis outbreaks in 2010 in a) Santa Fe, b) Rosario and c) Paraná.

The Santa Fe city outbreak lasted only three months, from January to March 2010, with a maximum peak of 19 cases in February and 40 confirmed cases in total. In the same year, Rosario city presented 40 confirmed cases, also concentrated between January and March with its peak of 16 cases in February, and Paraná city had 17 cases in total with an outbreak peak of 6 cases in March. In the three cities it can be observed some isolated cases during the winter months which may be associated with the specific activities of affected people (rural environment or in contact with contaminated water). The number of cases of leptospirosis infections obtained in the three cities by solving the proposed SIR model for 2010 are in good agreement with the actual data.

Calculated RMSE are 4.1; 3.5 and 0.6 cases, for Santa Fe, Rosario and Paraná cities, respectively. The higher values in the first two cases may be due to the fact that the actual number of cases at the peak of the outbreak is relatively greater and the model needs a longer tail to decrease that peak, so that it overestimates the number of cases during the subsequent months. Its means the model is no capable of reproducing the duration of the outbreak throughout the year, especially in Santa Fe and Rosario cities. Even in Santa Fe, the model never return values of zero cases in the last months of the year. Triampo et al (2007) obtained a similar result when they simulate at the state level which allows to infer that this behavior could be due to the rigid structure of the coupled differential equations used. Certainly, this constitutes a limitation of the model to take into account at the time of take preventive actions.

4) CONCLUSIONS

The development of a model like the proposed in this study could be a public health management tool to improve the preparation for eventual leptospirosis outbreaks. The influence of climatic variables, such as precipitation and the extent of flooded areas are important variables that directly affect the infection rate of the susceptible human population. The model presented in this work confirmed mathematically that outbreaks of leptospirosis occurred in months mainly coincident with El Niño event periods.

The dynamic modeling of infectious diseases considering hydroclimatic variables constitutes a climatic service for the public health system, not yet available in Argentina. Since climatic conditions vary in each region, its relevance on the transmission of leptospirosis should be evaluated for each one and this work aims to contribute in that direction.

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