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Climate variability and hospitalizations due to infectious diarrheal diseases in a municipality of the Western Brazilian Amazon Region

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Abstract *Morbimortality due to infectious diarrheal diseases still is a serious health issue in Brazil and is highly related to factors such as weather, environment, and people's life conditions. This study aimed to analyze the relationship between hospitalization rates due to infectious diarrheal diseases among the population of the municipality of Rio Branco (AC), Brazil and precipitation, river level, humidity and temperature between 2000 and 2013. Data were retrieved from the Hospital Information System of the SUS (Unified Health System), the National Institute of Meteorology and the National Water Agency. Multiple Poisson and negative binomial regression models were adjusted. Results showed that there is a positive association between hospitalization due to infectious diarrheal diseases and the level of the Acre river (RR: 1.07; CI 95%: 1.04 to 1.1); these hospitalization rates fell 14% between 2000 and 2013 (RR: 0.86; CI 95%: 0.85 to 0.87). The most vulnerable group was the age group of less than 1 year of age. This study showed the vulnerability of an Amazonian city to climate variability and its respective epidemiological influence on the incidence of hospitalizations due to infectious diarrheal diseases.*

Key words *Diarrhea, Floods, Climate, Climate change, Amazonian ecosystem*

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Introduction

Infectious diarrheal diseases are caused by pathogens such as viruses, bacteria and protozoa, and their main physiological effects are dehydration and malnutrition[1-3]. These diseases affect individuals of all age groups, but children are more vulnerable and susceptible to nutritional deficiencies that impair their growth, weight gain, intellectual development and even their survival[2,4-8]. Diarrhea is among the leading causes of death in children under 5 years of age in poor countries, along with respiratory diseases. Morbimortality due to diarrhea is a public health problem in several regions of the world and is conditioned by several causes, but poverty, poor sanitation and climatic and environmental conditions favoring the transmission of pathogens are critical in the modulation, frequency and severity of this disease[1-3,7-9].

Deaths from diarrheal diseases remain high in Brazil, especially in children under 1 year of age and in the North and Northeast of the country[2,8,10]. Brazil has great demographic, economic, social, cultural and health diversity across its different regions. The North region comprises most of the Brazilian Amazon. In this vast region of humid tropical climate, climatic swings are intensified annually by floods that usually occur between October and April, which are favorable conditions for the spread of infectious diarrheal diseases[2,11-15]. With the prospect of global climate change and the possibility of increased extreme weather events, special attention should be paid to the consequences to the health of this population, especially as the poor local urbanization conditions associated with the few advances in basic sanitation contribute to a typical vulnerability framework[16-22].

Thus, this ecological study aimed to analyze the association of hospitalization rates due to infectious diarrheal diseases in the population of the municipality of Rio Branco, capital of the state of Acre, with climatic variables such as precipitation, Acre River's level, humidity and temperature in the period 2000-2013. This type of study is fundamental for the region, as it contributes to a better knowledge about the climate-health relationship and may subsidize the elaboration of public policies aimed at improving the indicators of this health problem and the quality of life of the population in general. We also sought to study the behavior of these hospitalization rates in terms of their temporal trend and in different age groups, in order to increase the epidemiological knowledge of these diseases at the local level.

Methodology

The study area was the municipality of Rio Branco, capital of the state of Acre, located in the Western Amazon region of northern Brazil. According to IBGE (2016), the municipality has a population of approximately 370 thousand inhabitants and a predominantly hot and humid tropical climate; temperatures remain around 25-30°C all year round, with short cooling periods, where temperatures usually drop to around 14°C. The adjusted mean relative humidity remains higher than most other regions of the country throughout the year, with percentages usually above 65%[11,14,23].

The municipality developed on the banks of the Acre River, one of the largest rivers in the North, which springs from Peru and flows into Brazil across the state. In rainy periods, which usually occur between the months of October and April, the river level rises and most often exceeds its alert level for overflow (13.5 meters), which causes the flooding of much of the city[11,14]. The seasonal pattern of rainfall in the state is regular. High floods in the Amazonian winter are predictable, but the disordered occupation of the flood plains favors the occurrence of flooding. According to a study carried out by Duarte[24], urban settlements were located in the flood plains of the Acre River in the municipalities of Rio Branco, Assis Brasil, Brasileia and Xapuri. The study also points out that 79.1% of the population growth in the state has been converted into socially vulnerable residents who are exposed to the environment of waters along riverbanks, streams and sewage pipes[24].

In addition, the state of Acre is described in the literature as one with the worst sanitation indicators in Brazil[2,25]. In 2014, Rio Branco was among the 15 largest municipalities in the country with the worst sanitation, with more than 78% of the population without access to sewage collection and just over half of the population covered by the water supply system[25]. The capital also has high percentage of indigenous population living in rural areas and with less access to these services[2,6,26,27]. It is important to emphasize that the North is the second poorest region of the country and has one of the highest incidence rates of diarrheal diseases in children under 5 years of age, after the Northeast[28].

For this study, we used data on the number of monthly hospitalizations due to infectious diarrheal diseases, categorized by age group, obtained between January 1, 2000 and December 31, 2013.

This information was extracted from the Hospital Information System of the Unified Health System (SIH/SUS), available on the website of the Department of Information Technology of the SUS maintained by the Brazilian Ministry of Health[29]. Hospitalization case records were used under codes A03 (Shigellosis), A06 (Amebiasis), A09 (Infectious gastroenteritis and colitis, unspecified), A00 (Cholera), A01 (Typhoid and paratyphoid fevers) and Z22.1 (Carrier of other intestinal infectious diseases) of the 10th Review of the International Classification of Diseases (ICD-10).

The climatic variables used for the association studies were monthly average of total precipitation (in mm); average monthly maximum temperature (in °C); average monthly adjusted temperature (in °C); average monthly minimum temperature (in °C); mean monthly average relative humidity (in %); and monthly average of the Acre River's level (in meters). These data were extracted from the information database available on the website of the National Institute of Meteorology[23] and from the hydrological information system available on the website of the National Water Agency[30].

All data from this research were retrieved from open access secondary sources, waiving the Research Ethics Committee's scrutiny and approval. This information was tabulated and organized into Microsoft Excel spreadsheets. The mean monthly hospitalization rates due to infectious diarrheal diseases per 100,000 inhabitants and their variance were calculated, which were stratified according to year and age group. The population estimates for the years of the analysis period (2000-2013) were obtained from the Brazilian Institute of Geography and Statistics Foundation[26].

Generalized Linear Models (GLM) were used to estimate the association between climatic and environmental variables and the rate of hospitalizations due to diarrheal diseases. The analyzes were performed using the Stata statistical software (Data Analysis and Statistical Software) version 13.0[31] (permission of use granted to the Faculty of Public Health of the University of São Paulo).

The rate ratios (RR) were calculated, which were initially adjusted using the Poisson regression and the negative binomial (NB) regression model, both estimated by maximum likelihood, as the alternative[32-34]. Adjustments of the models obtained with BN regression were evaluated by analyzing the statistical significance of the alpha (α) value. When the value obtained was significantly different from zero, then the multiple BN regression model was adopted to obtain the adjusted estimates, considering overdispersed data[32-34].

When choosing variables, we considered the statistical significance of the parameters, the McFadden's pseudo-R^2 increase and the confidence intervals for the significance level of 5%[32-34]. Variables whose parameters were not statistically different from zero at the significance level of 5% were discarded from the analyses using the stepwise procedure that, in several modeling software, has the property of automatically excluding the explanatory variables whose parameters are not statistically different from zero[33]. This procedure was also used to correct the multicollinearity between the explanatory variables[33].

The final model was evaluated using the deviance and Pearson's statistical tests for the goodness-of-fit[33,35] and contains all parameters statistically different from zero at the significance level of 5%, with the highest adjusted R^2 value and with less amplitude of the confidence intervals. The quality of fit was measured by the Chi-square test (X^2) to compare the two curves and the lack of statistically significant differences between predicted and observed values[32-34].

Results

In these 14 years, 8,080 hospitalizations due to infectious diarrheal diseases in the population of the city of Rio Branco were recorded in the DATASUS database, and 1,153 hospitalizations were recorded in 2006 alone. Rates monthly average were 16.5 hospitalizations and variance of 147.9.

Due to the large difference between the mean and variance values, we decided to adopt the negative binomial regression model for the analyses.[33] Furthermore, the fit quality of data obtained with the Poisson distribution showed significant differences between the observed and predicted values ($p < 0.001$). On the other hand, the alpha (α) term value of the model with negative binomial distribution was significantly different from zero (Table 1), which indicated that this is the most adequate model for analysis, considering overdispersed data[33].

Variables whose parameters were not statistically different from zero at the significance level of 5%, after the application of the stepwise procedure[33] were discarded from the analysis, leav-

ing out the following variables: river's level, mean relative humidity, year and age group.

The results of this study show that there is a significant positive association between hospitalization rates due to infectious diarrheal diseases and the Rio Acre level, with a 7% increase in these rates for each meter of river level increase (RR: 1.07; 95% CI: 1.04 to 1.1). In addition, there is a negative relationship between hospitalization rates and years, with a general decline of 14% in hospitalization rates due to these diseases between the years 2000 and 2013 (RR: 0.86, 95% CI: 0.85-0.87), as well as a negative association between hospitalization rates and adjusted mean relative humidity (RR: 0.97; 95% CI: 0.96 to 0.99), (Table 1).

The Graph 1 shows that, over the years, in general, hospitalization rates have decreased in the period 2000-2013. However, some increases were recorded during this period in specific years. At first, rates fell between 2000 and 2004. From then on, a sudden upswing was recorded until 2006, when the highest rates of hospitalizations due to diarrheal diseases of the period were recorded. In the following years, rates declined progressively until 2009, when a slight elevation was recorded. Thereafter, rates declined steadily until 2013, when the lowest rates of hospitalizations due to infectious diarrheal diseases of the period studied were recorded.

The age group with the highest hospitalization rates includes children under 1 year of age followed by children 1 to 4 years of age. High hospitalization rates were also found in the elderly group, especially for those over 70 years of age (Chart 2).

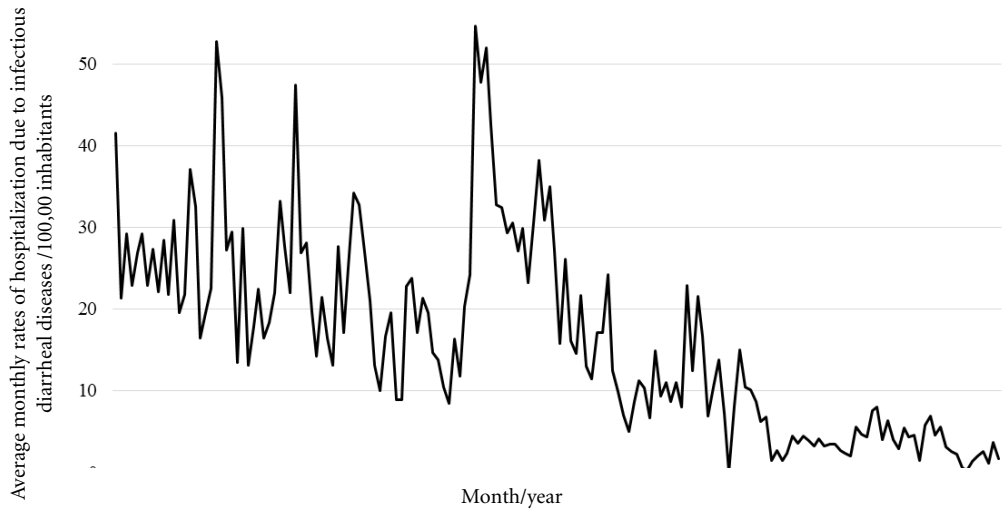
Discussion

Results obtained in this study evidenced a significant association between the rates of hospitalization due to diarrheal diseases and the Acre River level, year, adjusted mean relative humidity and age group. Poisson Regression[33,36] is usually adopted as a standard for analyses containing this data type. However, this model assumes equality between mean and variance, which does not always occur in series with overdispersion or excess of zeros. In these cases, the use of Poisson regression may lead to an underestimation of coefficient standard errors, very narrow confidence intervals and small p-values[32,33]. The negative binomial distribution has a modified variance function that makes its dispersion parameter facilitate the accommodation of an extra variation and bypass the issue[33,34]. Once this last model has been tested, the alpha value found shows an overdispersion that must be taken into account and, thus, this was the analytical model adopted in this research[33].

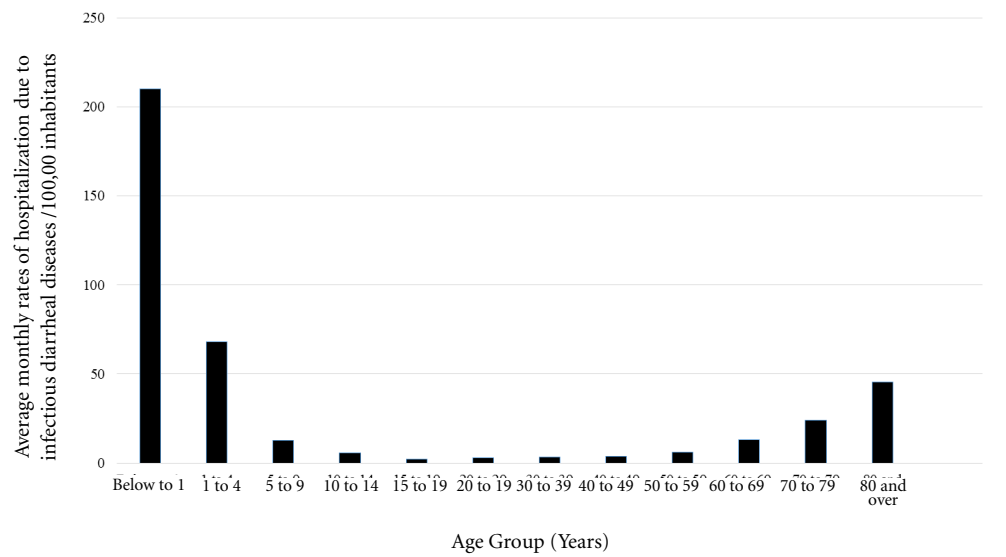
Table 1. Variables associated with hospitalization rates due to infectious diarrhea.

Variable	RR (CI95%)	Negative binomial regression model*	
		Adjusted RR (CI95%)	p-value
River level (m)	1.07 (1.06 to 1.10)	1.07 (1.04 to 1.10)	<0.001
Relative humidity (%)	0.97 (0.96 to 0.98)	0.97 (0.96 to 0.99)	<0.001
Year	0.86 (0.86 to 0.87)	0.86 (0.85 to 0.87)	<0.001
Age group			
< 1	Reference	Reference	
1 to 4	0.32 (0.30 to 0.33)	0.33 (0.29 to 0.38)	<0.001
5 to 9	0.06 (0.05 to 0.06)	0.07 (0.06 to 0.08)	<0.001
10 to 14	0.02 (0.02 to 0.03)	0.04 (0.03 to 0.04)	<0.001
15 to 19	0.01 (0.00 to 0.01)	0.01 (0.00 to 0.02)	<0.001
20 to 29	0.01 (0.01 to 0.01)	0.02 (0.01 to 0.02)	<0.001
30 to 39	0.01 (0.01 to 0.02)	0.02 (0.02 to 0.03)	<0.001
40 to 49	0.01 (0.01 to 0.02)	0.02 (0.02 to 0.03)	<0.001
50 to 59	0.03 (0.02 to 0.03)	0.04 (0.03 to 0.04)	<0.001
60 to 69	0.06 (0.05 to 0.07)	0.08 (0.06 to 0.09)	<0.001
70 to 79	0.12 (0.10 to 0.14)	0.14 (0.11 to 0.16)	<0.001
> 80	0.23 (0.20 to 0.26)	0.26 (0.20 to 0.30)	<0.001

* Alpha of the Negative binomial regression model = 0.29 (95% CI: 0.25-0.33, $p < 0.001$). Each estimate is adjusted by the other variables listed in the table.



Graph 1. Time series of the average monthly rates of hospitalization due to infectious diarrheal diseases from 2000 to 2013, in Rio Branco (AC), Brazil.



Graph 2. Average monthly rates of hospitalization due to infectious diarrheal diseases, by age group, from 2000 to 2013, in Rio Branco (AC), Brazil.

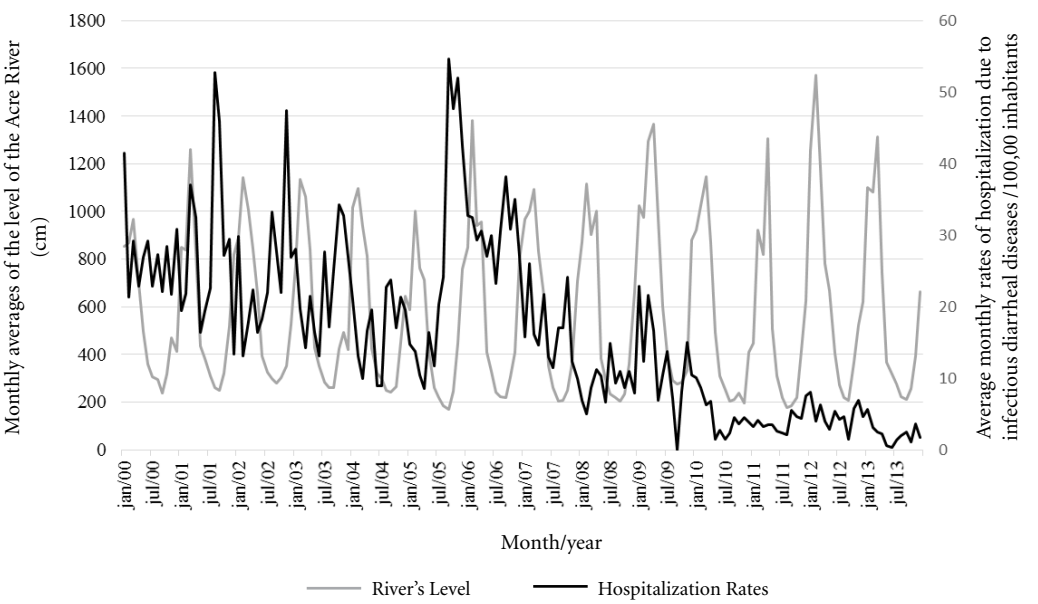
The results obtained with the analyses of this study show, for the first time in this municipality, how the river level can interfere in the monthly hospitalization rates due to infectious diarrheal diseases. The model shows that each meter increase in the monthly average of the Acre River level can contribute to a 7% hike in these rates. This variable is an indicator for the prediction of trends in the occurrence of this disease in this municipality and in the other municipalities of the Amazon region, as they share similar climatic and environmental features[28]. Graph 3 shows the time series of these variables during the study period.

Outbreaks of diarrhea associated with extreme weather events have occurred worldwide, especially after flooding events and inundations[9,28,36-41]. However, until then, no one knew how much these factors could contribute to the occurrence of infectious diarrheal diseases in this municipality with potential to cause hospitalization. In Rio Branco, this situation is now a matter of great concern, because Acre River's floods occur practically every year, lead to seasonal flooding of the lowland areas characteristic of the Amazonian geography and inundate a large part of the city, which may contribute to transmission and contagion by these diseases[24,43].

In Rio Branco, Acre River's flooding almost always occur in the February-April period, putting thousands of families at risk in several cities. In 2006, some 29,000 people were affected by one of the river's major floods. In March 2010, more than 4,000 buildings were affected, with more than 350 displaced and homeless families. In 2012, more than 6,000 people were left homeless, and this was the second largest flood since the beginning of the Acre River's level measurements. In 2015, the largest flood ever recorded in state history left more than 9,000 people homeless[28,43].

During floods, the water distribution network for human consumption may be affected, compromising the supply system for homes and health services, resulting in lack of drinking water or distribution of water contaminated by infectious agents[36,38,43-47]. Food stored in homes or markets may be contaminated by biological agents and by chemical products of industrial, commercial and/or residential origin. In these periods, other urban and basic sanitation services, such as sewage collection and waste disposal are also affected, favoring conditions for the emergence and spread of diseases[28,39,47-50].

Another consequence of floods and inundations is change in the reproductive cycles of vectors, hosts and reservoirs of diseases due to the proliferation of wastewater, garbage and decomposing materials on the streets, leading to an increased number of mosquitoes, flies, rats, and fecal environmental contamination by parasites. Thus, the sources of exposure to the risk of diseases increase, especially for those who are displaced or become homeless[46,50-52].



Graph 3. Time series of the average monthly rates of hospitalization due to infectious diarrheal diseases compared to the time series of the monthly averages of the level of Acre River, from 2000 to 2013, in Rio Branco (AC), Brazil.

Massive population displacement, crowding in shelters and the accelerated and poor urbanization process also create conditions for the spread of communicable diseases[28]. When this process tends to occur with improper planning, the construction of water supply networks and sewage collection, for example, is adopted as a measure of adaptation and develops for domestic supply, but these improvements are vulnerable to environmental changes due to the easy contamination and also by inadequate water treatment and distribution capacity[8,15,22].

In fact, the intense urbanization of the Brazilian Amazon region has been under pressure in recent decades due to the increased migration, which has aggravated the situation of poverty in the region. In Rio Branco, for example, as in other cities in the region, urban settlements are common in rivers' flood plains because of this process. This results in increased socially and environmentally vulnerable population that is exposed to various flood damages[15,22,24].

Such environmental conditions have also contributed to the occurrence of other diseases in the region, especially dengue and leptospirosis, which have accounted for an elevated number of victims in the region, with increasingly severe symptoms[1,29]. In Rio Branco, in the same period, more than 80,000 cases of dengue have been reported and confirmed by the Epidemiological Surveillance Department of the Municipal Health Secretariat[29]. In addition, respiratory diseases have also generated increasing concern at the local level, since they mainly involve children, similarly to infectious diarrheal diseases[1,15,29].

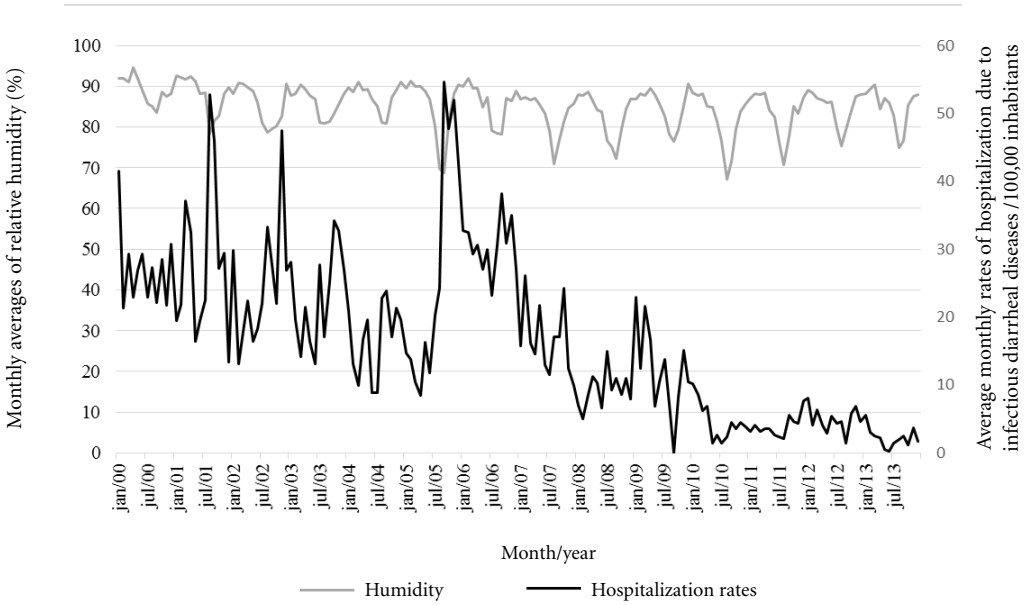
In addition, with the prospect of global climate change, it is believed that the risk of extreme events may become more frequent in the future. Climatic models designed for the Amazon rainforest point to increasingly elevated temperature, which may influence the rainfall regime and floods events in the region[28,53,54]. The great Amazonian floods in this century resulted from unusually strong precipitations in northern Brazil and were generally associated with higher than normal surface temperatures of the Tropical South Atlantic Ocean[53-56].

Interestingly, the results of this study showed a negative, albeit small association between the monthly average of the adjusted mean relative humidity and rates of hospitalization due to infectious diarrheal diseases. However, this result may have been achieved to the detriment of peculiarities of the climate of this region, which is quite hot and humid. The lowest value for the monthly average of relative humidity obtained in the city during the study period was 67.25%, while the highest value was 92.30%, which reflects the high humidity and the small variation[23]. Thus, periods of marked increases or decreases in the rate of hospitalization due to infectious diarrheal diseases were not accompanied by such sharp increases or decreases in relative humidity, which is measured as a percentage (Graph 4). Therefore, this variable was not considered adequate for this type of study.

Regarding the behavior of rates of hospitalization due to diarrheal diseases over time in this municipality, the statistical model showed a declining trend, especially after 2006. One of the main explanations for this result refers to the introduction of the rotavirus vaccine in the SUS vaccination calendar. Since 2006, Brazil has immunized children in the first two years of life against this pathogen by an attenuated oral vaccine[5,9]. In the literature, rotavirus has been highlighted as one of the most prevalent pathogens causing severe diarrhea with severe dehydration and need for hospitalization after floods[5,38,39]. Thus, immunization against rotavirus and universal coverage were an important contribution in the reduction of severe forms, in the number of hospitalizations and in the risk of death from this disease, as shown by some studies carried out in Brazil and in other countries[3,5,9,57,58].

Other factors contributing to this situation include improvements in sanitation conditions, water quality, campaigns to encourage total and exclusive breastfeeding duration, reduced prevalence of malnutrition and improved access to health care with increased vaccination coverage against measles and the use of oral rehydration[20,21,59]. The expanded Family Health Strategy (ESF) and the establishment of social programs, such as the Bolsa Família and the Mais Médicos Program, for example, contributed in recent years to a substantial increase in access to PHC and quality of life of the population[59-61].

However, despite advances, infectious diarrheal diseases are still a serious public health problem in Brazil and generate high hospitalization rates, especially in children under 1 year, as shown in the results of this study and in several other studies[2,8,61]. In addition, childhood diarrhea appears as a disease that evidences health inequity in the Brazilian territory. Health indicators show the highest rates of morbimortality in the North and Northeast regions, which have the worst conditions of poverty and basic sanitation in Brazil[2,8,61].



Graph 4. Time series of the average monthly rates of hospitalization due to infectious diarrheal diseases compared to the time series of the monthly averages of relative humidity, from 2000 to 2013, in Rio Branco (AC), Brazil.

We should also consider that more information about the distribution of these diseases is scarce in the country. SUS Hospital Information Systems only provide hospitalization or mortality data, that is, they are limited only to the most severe cases of diarrheal diseases that lead to death or hospital admissions and do not allow us to distinguish whether different hospitalizations are from the same patient or different patients. New cases and less serious cases are not properly recorded and made available. Thus, there may be biases in the data that may lead to underestimating cases and diverting the focus from the problem and measures aimed at its prevention, such as improving basic sanitation, for example[62]. This lack of information was one of the main limitations of this study.

Other limitations include the use of secondary health data, which rely on records and may not reproduce reality very accurately. Likewise, the number of meteorological stations and data quality in the Amazon region of the country are very limited[28]. The results of this study, when considering monthly hospitalization data for the general population of the entire municipality of Rio Branco, without considering major characteristics of this population, such as socioeconomic factors, for example, and their geographic delimitations does not allow us to characterize the population groups most vulnerable to infectious diarrheal diseases.

However, this study provided information on how and how much climate can influence the distribution of these diseases in this region and allowed the identification of factors that warrant further investigation. Expanded knowledge on the relationship between climate and health at the regional level is fundamental for the implementation of precautionary, prevention and impact-mitigating actions, especially for the most exposed population[1,15]. A next step would be to study the socio-environmental vulnerability areas in association with socioeconomic factors in the municipality so that the different local realities are identified.

Conclusion

Even with the sharp decline of deaths and hospitalizations due to infectious diarrheal diseases in the last decades, these are still a serious pub-

lic health problem in Brazil, together with other infectious diseases, mainly because Brazil is undergoing a rapid and poor urbanization process. The Brazilian Amazon region has a typical and favorable setting for the permanence, expansion and distribution of these diseases. Advances occurred in relation to the coverage of water supply and sanitary sewage in the country. However, there are still inequalities related to these services, which shows the importance of diarrheal diseases in the Brazilian epidemiological setting[8]. In addition, since it mainly involves the poorest people, this disease draws much less attention than most other diseases[1,2].

Thus, this study focuses on the impact of these diseases in this population and provides a model where the river's level can be used as a trend predicting indicator of infectious diarrheal diseases events with potential to generate hospitalizations. This type of study is instrumental to increased knowledge about how the region's climate can change and interfere with the occurrence of these diseases, especially considering the Amazon region as being at great risk of extreme climatic events, vulnerable to the occurrence of floods and where the rates of morbimortality from infectious diarrheal diseases are still quite high.

Collaborations

JL Duarte worked on the writing of the scientific article in all phases: idealization of the study, collection and analysis of the data, bibliographic survey, discussion of the results and writing of the work. FA Diaz-Quijano contributed to the analysis of the data, with the discussion of the results and with the final revision of the article. AC Batista, and AF Duarte contributed to the idealization of the work, with the data collection and with the final revision of the article. LAK Melchior collaborated with the bibliographical survey, with the discussion of the results and with the final revision of the article. LL Giatti has worked on guiding the work from its idealization to its final review and approval.

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