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ORIGINAL ARTICLE / *ARTIGO ORIGINAL*

Seasonal pattern of malaria cases and the relationship with hydrologic variability in the Amazonas State, Brazil

Padrão sazonal dos casos de malária e a relação com a variabilidade hidrológica no Estado do Amazonas, Brasil

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ABSTRACT: ***Introduction:*** Malaria is an infectious disease of high transmission in the Amazon region, but its dynamics and spatial distribution may vary depending on the interaction of environmental, socio-cultural, economic, political and health services factors. ***Objective:*** To verify the existence of malaria case patterns in consonance with the fluviometric regimes in Amazon basin. ***Method:*** Methods of descriptive and inferential statistics were used in malaria and water level data for 35 municipalities in the Amazonas State, in the period from 2003 to 2014. ***Results:*** The existence of a tendency to modulate the seasonality of malaria cases due to distinct periods of rivers flooding has been demonstrated. Differences were observed in the annual hydrological variability accompanied by different patterns of malaria cases, showing a trend of remodeling of the epidemiological profile as a function of the flood pulse. ***Conclusion:*** The study suggests the implementation of regional and local strategies considering the hydrological regimes of the Amazon basin, enabling municipal actions to attenuate the malaria in the Amazonas State.

Keywords: Hydrology, Malaria. Residence characteristics.

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RESUMO: ***Introdução:*** A malária é uma doença infecciosa de alta transmissão na região amazônica, porém sua dinâmica e distribuição espacial podem variar, dependendo da interação de fatores ambientais, socioculturais, econômicos e políticos e serviços de saúde. ***Objetivo*:** Verificar a existência de padrões de casos de malária em consonância com os regimes fluviométricos da bacia amazônica. ***Métodos*:** Foram utilizados métodos de estatística descritiva e inferencial nos dados de casos de malária e nível d'água para 35 municípios do estado do Amazonas, no período de 2003 a 2014. ***Resultados:*** A existência de uma tendência que module a sazonalidade dos casos de malária, devido a períodos distintos de inundação dos rios, foi demonstrada. Diferenças foram observadas na variabilidade hidrológica anual, acompanhada por diferentes padrões de casos de malária, mostrando uma tendência de remodelação do perfil epidemiológico em função do pulso de inundação. ***Conclusão:*** O estudo sugere a implementação de estratégias regionais e locais, considerando os regimes hidrológicos da Bacia Amazônica, possibilitando ações municipais de atenuação da malária no estado do Amazonas.

Palavras-chave: Hidrologia. Malária. Distribuição espacial.

INTRODUCTION

According to the World Health Organization (WHO), malaria is the main public health issue in many developing countries, with about 198 million cases, leading to 584,000 deaths per year[1].

In Brazil, malaria presents a high risk of transmission in the region of the Legal Amazon, whose climatic and environmental conditions are extremely favorable to its incidence[2,3]. In the Amazon, *Anopheles darlingi* is the main malaria vector, having great epidemiological importance due to its abundance, adaptive capacity, and wide geographical distribution[4-6].

Even within a region where the disease is deemed endemic, its dynamics of spatial transmission and distribution may vary depending on the interaction of environmental, sociocultural, economic, and political factors, in addition to the quality of healthcare services[7]. Moreover, different forms of land cover, distinct epidemiological situations, and landscape characteristics also contribute to this lack of homogeneity[8-10].

Interaction between factors that directly and indirectly collaborate with the maintenance of malaria represents a major obstacle to the control of the disease. Climatic variables, such as rain and air temperature, add a specific weight to the incidence and transmission of the disease[11]. The annual rainfall variability provides the aquatic environment for the life cycle phase of mosquitoes and contributes to the change in vector density. However, the effect of rainfall on malaria may differ depending on the circumstances of certain geographical regions[12].

The seasonal patterns of *A. darlingi* are closely related to the annual rainfall cycle and weather and hydrological variations[13,14]. According to Girod et al.[9], landscape characteristics may explain seasonal and regional fluctuations of *A. darlingi* that may or may not be related to rainfall and river levels. Rainfall and the water dynamics of Amazonian rivers greatly influence the vector fluctuation of malaria, ensuring the maintenance of permanent breeding sites[15,16].

With river overflows during floods, many areas in the Amazon become favorable to the reproduction of mosquitoes[17]. Some studies demonstrate the importance of considering river levels, especially in the overflow phase, and the proximity to residences[10,18].

Since environmental and climatic characteristics enable environments conducive to the persistence of this endemic disease[3], understanding the relationship between the river water level and its consequences for malaria cases is important for comprehending the heterogeneous epidemiological profile of the disease in the state of Amazonas.

Investigations addressing initiatives to clarify the dynamics of the disease at the municipal level, and which detail spatial differences, considering the hydrological variability of the basin, provide relevant data for implementing strategies for prevention and control based on distinct malaria patterns. Due to the unique influence of rainfall on each part of the basin, the hydrological regime presents distinct river regimes. Differentiated flood pulse regimes maintain the permanent breeding sites of mosquitoes and influence the seasonality of the incidence of malaria cases.

Thus, we aimed to verify the existence of patterns in the incidence of malaria cases in the state of Amazonas according to river regimes of the different sub-basins of the Amazon Basin.

METHODS

STUDY AREA

The state of Amazonas, located in the heart of the Amazon rainforest, in Northern Brazil, comprises 62 cities and covers an area of about 1,559,161,682 km^2. The region presents a humid equatorial climate, characterized by high temperatures and rainfall indices, and has well-defined seasons consisting of rainy period, drought, and transition months, directly influencing the period of hydrological variability of high and low water levels[19].

This state has the highest rate of malaria cases reported to notification systems, showing environmental and social characteristics relevant to determining epidemiological conditions[20]. Geographical and ecological aspects, such as territorial extension and predominance of river access routes, are key for determining vector proliferation sites[21].

DATA

The study was based on analyses of secondary data using descriptive and inferential statistical methods. We analyzed data on malaria cases and the water level of 35 municipalities in the state of Amazonas. The number of analyzed municipalities was associated with the quality of data on local hydrometric stations. Data covered different periods due to the integrality of the historical series of hydrometric stations.

Water level

Hydrological data from monitoring stations were gathered from the database of the National Water Agency (*Agência Nacional de Águas* – ANA) and the Observation Service for the geodynamical, hydrological and biogeochemical control of erosion/alteration and material transport in the Amazon, Orinoco and Congo basins (ORE-HYBAM), available at http://www.ore-hybam.org/. A total of 35 hydrometric stations from 6 distinct basins of the Negro, Japurá, Solimões/Amazonas, Juruá, Purus, and Madeira rivers were analyzed in the 2000-2010 period, on a monthly scale. Years prior to and after the assessed period lacked data of over three months, making it impossible to use the series.

Malaria cases

The survey on malaria cases was conducted by the processing of raw data, compressed in DBF files, made available in the database Information System for Epidemiological Surveillance of Malaria (*Sistema de Informação de Vigilância Epidemiológica da Malária* – SIVEP-MALARIA). We analyzed 35 municipalities (Figure 1) for the 2003-2014 period. Since SIVEP does not have records prior to 2003, the data assessed were from that year onwards.

DATA ANALYSIS AND PROCESSING

In order to obtain a higher quality of data on malaria cases, we excluded smear microscopy tests for cure verification (*lâminas de verificação de cura* – LVC – slides of the same person, whose data were duplicated), negative test results, and data cleaning, as described by Wiefels et al.[22]. We used filters for municipality, country, federative unit, and test result to select only allochthonous cases of infection. In order to display a standard behavior of 11 years, we analyzed data on a monthly scale by calculating monthly averages and dividing them by the interannual average.

Since the hydrological series of some hydrometric stations presented flaws or lack of records, a method to complement or replace data was used, as described by Santos et al.[23]. We adopted the simple linear regression technique for nearby stations based on the correlation between them. Criteria were defined according to:

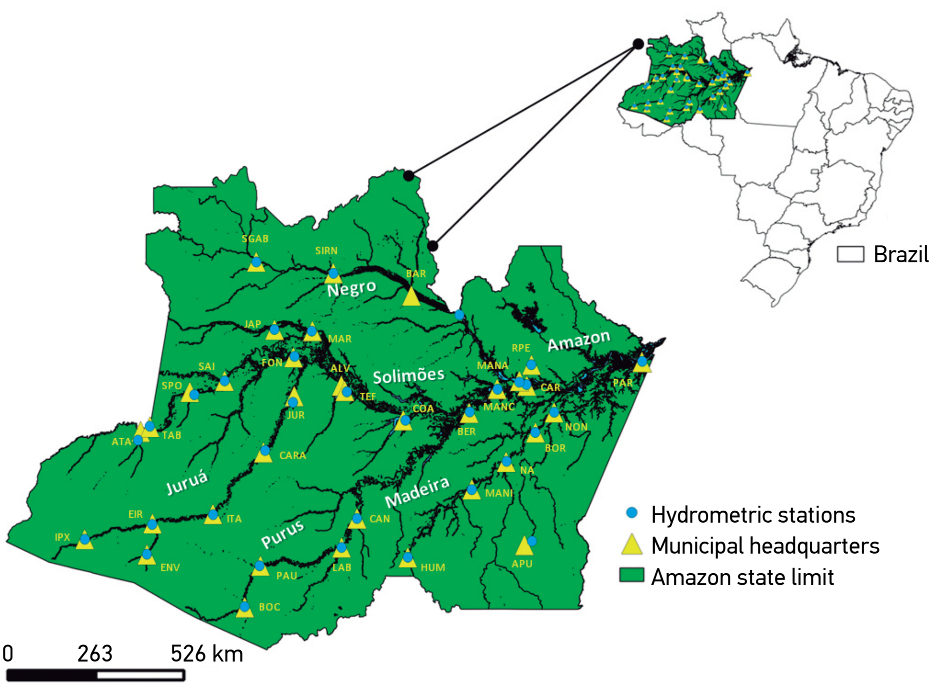
- data integrity and consistency;
- exclusion of years that lacked data for over three months;
- exclusion of stations presenting data gaps in several years;
- replacement of stations with lower data quality by other stations at the same municipality, with better conditions of use, based on the correlation coefficient.

Due to hydrometric stations not being referenced at sea level, but rather at a local datum (arbitrary reference plan), a normalization method commonly used in flow variables was adopted. River level normalization was calculated as the ratio of monthly averages of each month divided by the interannual average of each station[24].

We used the free software R statistical package, version 3.0, available at http://cran.r-project.org, and the Geographic Information System, free, QGIS 2.0, available at https://www.qgis.org/pt_BR/site/ to assist in data analysis and manipulation.

RESULTS

Regarding the hydrological regime, we detected differences in the annual variability of hydrometric stations located in the right and left banks and in the main canal of the Solimões river basin. As shown in Figures 2 and 3, stations located at the same basin presented distinct regimes according to their position, either further upstream or downstream.



ALV: Alvarães; ATA: Atalaia do Norte; APU: Apuí; BAR: Barcelos; BER: Beruri; BOC: Boca do Acre; BOR: Borba; CAN: Canutama; CAR: Careiro da Várzea; CARA: Carauari; COA: Coari; EIR: Eirunepé; ENV: Envira; FON: Fonte Boa; HUM: Humaitá; IPX: Ipixuna; ITA: Itamarati; JAP: Japurá; JUR: Juruá; LAB: Lábrea; MANC: Manacapurú; MANA: Manaus; MANI: Manicoré; MAR: Maraã; NA: Novo Aripuanã; NON: Nova Olinda do Norte; PAR: Parintins; PAU: Pauiní; RPE: Rio Preto da Eva; SAI: Santo Antônio do Içá; SGAB: São Gabriel da Cachoeira; SIRN: Santa Isabel do Rio Negro; SPO: São Paulo de Olivença; TAB: Tabatinga; e TEF: Tefé.

Figure 1. Location of the 35 analyzed municipalities and the hydrometric stations.

We identified that, in the Negro and Japurá rivers (left-bank tributaries of the Solimões river), the common trends relating to the period of maximum and minimum water level occurred between June and July and between October and November, respectively (Figures 2A and 2B). The Juruá, Purus, and Madeira rivers (right-bank tributaries of the Solimões river) showed similarities concerning the period of maximum water level between April and May, and the period of minimum water level in September (for the first two rivers) and October (for the third river) (Figures 3A, 3B, and 3C).

Hydrometric stations located at the main canal also presented specific regimes. The Alto Solimões stations (Atalaia do Norte, Tabatinga, São Paulo de Olivença, Santo Antônio do Içá, Fonte Boa, and Alvarães) revealed similar characteristics regarding the period of maximum water level in May, and minimum, in September (Figure 2C). In the Médio and Baixo Solimões/Amazonas stations (Tefé, Coari, Manacapuru, Careiro da Várzea, Rio Preto da Eva, and Parintins), the maximum water level occurred in June, and the minimum, in October (Figure 2D).

Stations near the confluence of the Solimões river presented a hydrological regime influenced by the backwater effect. The municipalities of Alvarães (Solimões river), Carauari and Juruá (Juruá river), Lábrea, Canutama, and Beruri (Purus river) presented lags between one and three months in relation to the regime of their main basin further upstream.

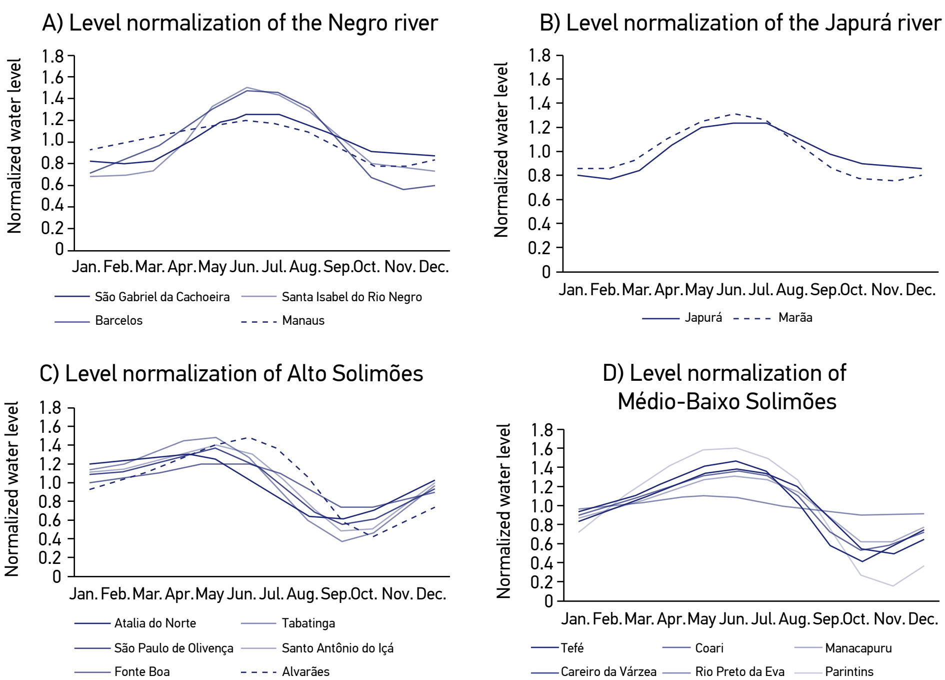


Figure 2. Data on the normalized water level at the (A) Negro, (B) Japurá, and (C and D) Solimões river stations. The stations represented by the black dotted line are under the influence of the backwater effect caused by the Solimões/Amazonas river.

PATTERNS OF MALARIA CASES AND THEIR RELATIONSHIP WITH HYDROLOGICAL VARIABILITY

Considering the importance of malaria dynamics in a given region, the descriptive analysis – of epidemiological and hydrological approach – demonstrated the existence of a trend in modulating the seasonality of malaria cases based on the flood wave movement of rivers. Figure 4 shows different patterns of variables according to their location in the basin. As differences in annual hydrological variability occurred, patterns of malaria cases became more distinct, displaying a trend in remodeling the epidemiological profile according to the flood pulse.

Concerning the municipalities located in the Negro river basin, malaria cases reached notification peaks in July, September, and October; in the Japurá basin, the peaks happened in August and October; in the Alto Solimões basin, in May and June; in the Médio and Baixo Solimões, especially in August; and in the Juruá and Purus basins, in June (Figure 5).

Variability in malaria cases relating to river levels presented three distinct patterns associated with the left and right banks and the main canal. We also found differences in the same basin, according to the location of the station.

In the left bank of the main basin, formed by the Negro and Japurá rivers, the interval between the maximum peak of water level and the maximum peak of malaria cases occurred, on average, from 1 to 4 months. The main canal (Alto, Médio, and Baixo Solimões/

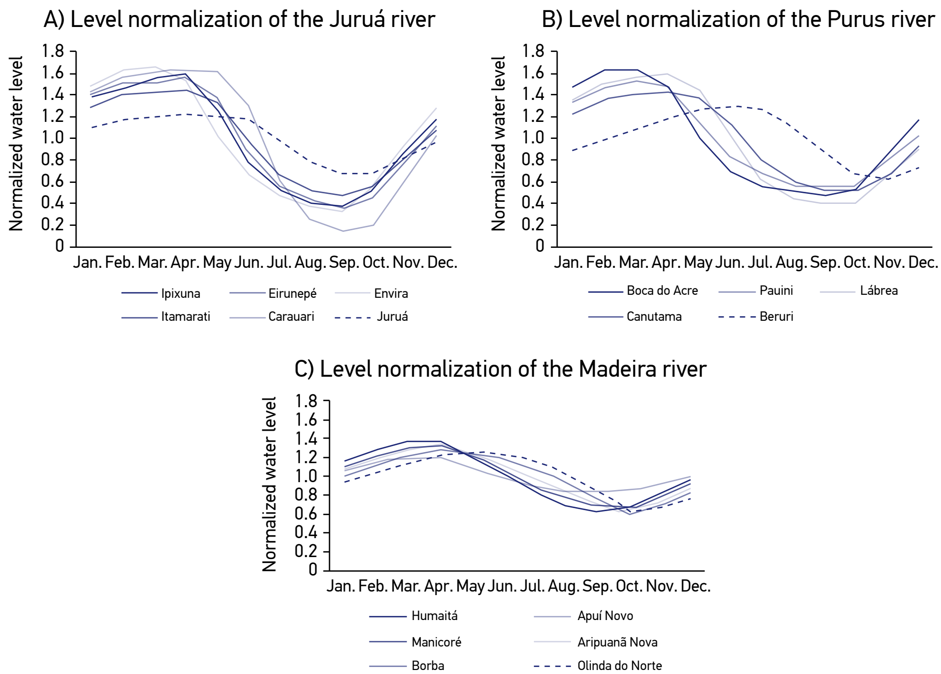


Figure 3. Normalized annual river regime index of stations that compose the basins of the (A) Juruá, (B) Purus, and (C) Madeira rivers. The stations represented by the black dotted line are under the influence of the backwater effect caused by the Solimões/Amazonas river.

Amazonas) had a delay of two months. In the right bank, consisting of the Juruá, Purus, and Madeira river basins, the delay ranged from 1 to 3 months.

The spatial variability of the hydrological regime, in response to differences in the seasonal distribution of rainfall, tends to characterize different behaviors of malaria cases based on the peak of water level of the river and according to the location of the hydrometric station.

Left-bank tributaries (Negro and Japurá rivers) coincided with the period of maximum water level, mainly in June, and demonstrated epidemiological patterns of malaria with incidences in the second half of the calendar year. As to right-bank tributaries (Juruá, Purus, and Madeira rivers), peaks of maximum water level showed epidemiological patterns at the end of the first half of the calendar year, especially in April.

In the course of the main canal (Solimões/Amazonas river), we detected variations regarding the period of maximum water level and patterns of malaria cases. We found that municipalities located at the Alto Solimões region tend to present peaks of malaria cases, particularly at the end of the first half of the calendar year, specifically between May and June. Municipalities located at Médio and Baixo Solimões/Amazonas regions showed peaks of malaria cases mainly at the beginning of the second half of the calendar year, precisely in August.

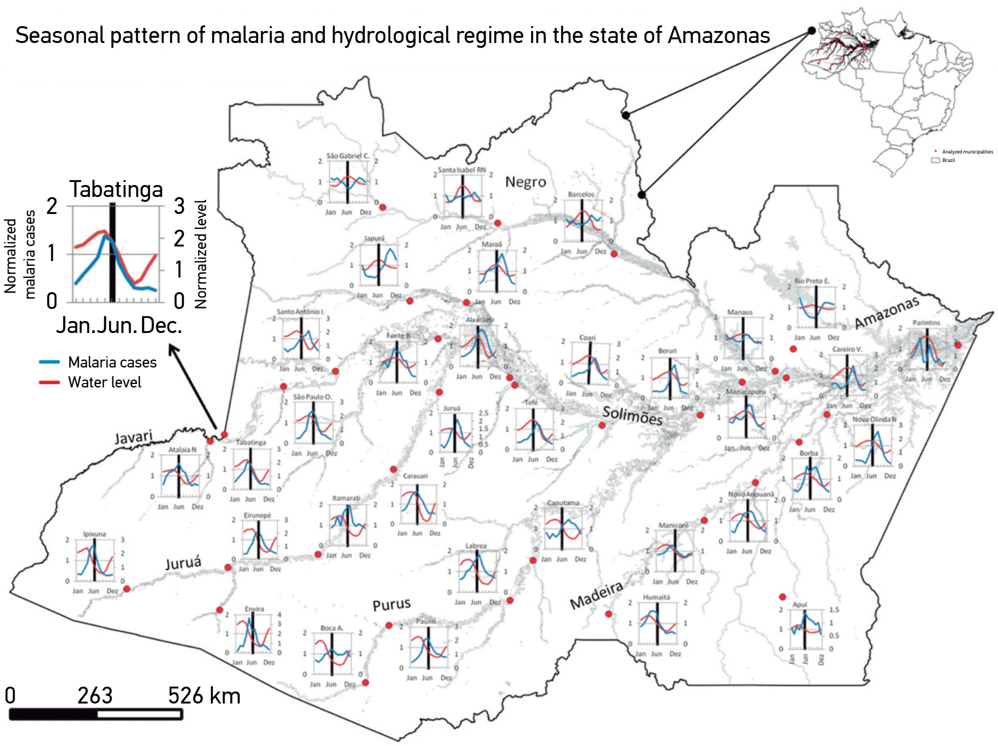


Figure 4. Seasonality of malaria cases and water levels in the analyzed municipalities. Graphs represent malaria cases (blue lines), variation in water levels (red lines), and the middle of the year (vertical black line).

DISCUSSION

Critical analysis of secondary data reveals care in the use of the available numbers and the problems included in their historical series. Errors and flaws in the hydrological data of some stations may lead to many of them becoming useless.

An alternative used to mitigate missing data problems from hydrometric stations is replacing them for data from a closer station and with more information in the water level records[23]. Discontinuous series, with lack of data, result from complications in issuing the record or are logistics-related, considering the difficult access to some stations by technical personnel, especially on rainy days.

The estimated water level values, found by linear regression, composed the studied historical series and were used to calculate interannual averages and river level normalization. The consistency criterion for hydrometric data keeps the interannual averages of water levels close to accurate values without changing the river behavior[24].

Although differences in the hydrological variability of the basin are more marked depending on the location of the station, we found common trends regarding the behavior of

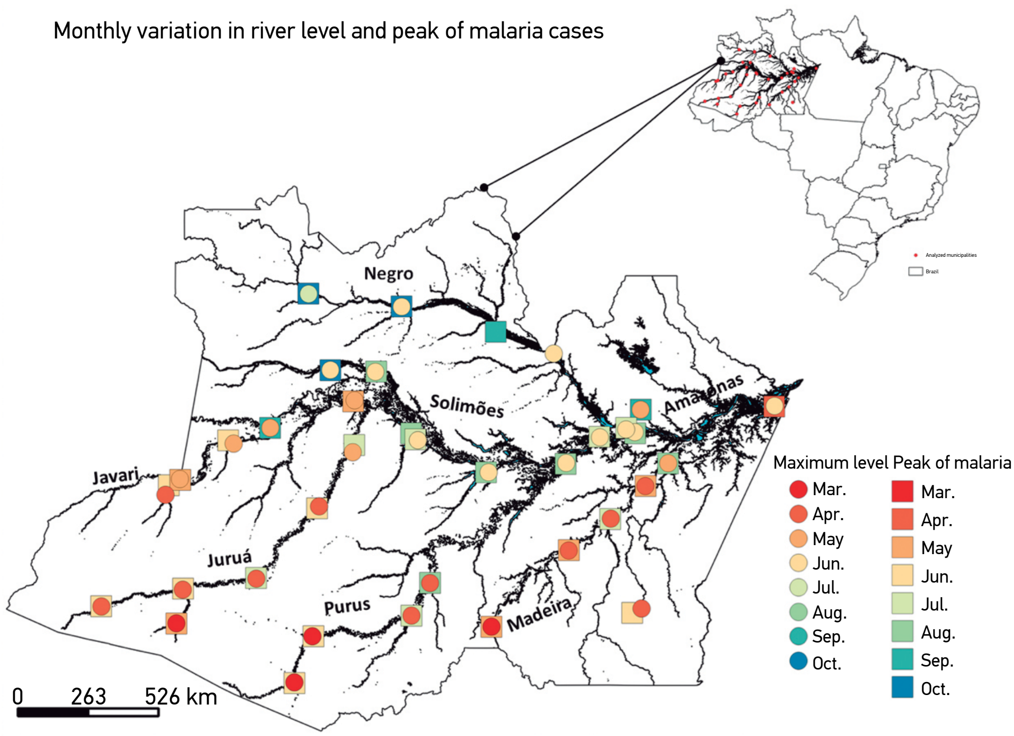


Figure 5. Spatial-temporal variation in peaks of malaria cases and river level. Lags according to maximum incidences.

hydrological dynamics, in the periods of flood and drought, between the Negro and Japurá rivers and among the Juruá, Purus, and Madeira rivers.

According to Meade et al.[25], the difference in the hydrological runoff model is attributed to the cooling of the water caused by the backwater effect and seasonal water storage in the floodplain. The distinct spatial rainfall regime reveals different lags in the tributary input and discharge peaks between parts of the basin, directly leading to periods of differentiated floods caused by variations in the time of rainfall onset.

Flood regimes coincided with an increase in malaria notifications, with peaks after the flood of rivers. Studies suggest that river overflows represent potential breeding sites of the vector in many areas throughout the Amazon[16-18].

The hydrological regime has been playing a key role in the dynamics of malaria cases. Seasonality and abundance of rainfall cause fluctuations in the water level, resulting from the overflow of the main river. Rains, in addition to environmental and social factors, are a determining environmental factor for the dynamics and proliferation of the malaria vector[26-28]; however, incidence rates and risk of transmission may vary throughout the basin[29].

In a study conducted in the municipalities of Coari, Codajás, Manacapuru, and Manaus, Wolfarth et al.[30] found maximum water levels in June. The authors proposed that malaria cases accounted for lags of 1 or 2 months after the floods of rivers, suggesting that they reflect the vector and transmission dynamics, which, despite the delay, follow the rise and fall of river levels. Xavier[31] found an association between malaria cases and the period of increase in the water level, with a two-month lag, in the municipality of Manaus.

Wolfarth-Couto et al.[32], based on statistical analyses, showed that malaria peaks are reached, on average, between 1 and 4 months after the peak of river levels. Moreover, the authors suggested that the relationship between the variables may represent local actions concerning time and space, and that variables, such as topography, favor a differentiated initiative for each municipality.

The results not only corroborated studies conducted in the state of Amazonas but also complemented spatial and descriptive aspects of the behavior of malaria cases as for distinct hydrological variabilities.

In the Amazon, malaria seasonality occurs between June and September, especially during the dry season. Studies reveal an increase in reports of malaria cases during the dry season, from August onwards[2,3,26,33]. Our study showed similar results; however, we identified that malaria peaks could also be reached before August if we consider the hydrological regime and the local rainfall.

The risk of contracting malaria in the state of Amazonas is high due to the existence of common permanent breeding sites in the region. This type of breeding site works as a habitat throughout the year, even in the dry season, favoring the continuous reproduction and transmission of malaria[34].

Although environmental and climate factors somehow influence malaria dynamics, surveillance, prevention, and control issues should not be disregarded. Healthcare actions implemented by the government might effectively work, masking possible relationships with hydrological/climatic conditions. Regardless of significant associations, the disease–climate relationship is complex and indirect, particularly when considering data on malaria cases instead of those on vectors. Despite this limitation, these cases are excellent health indicators and can measure the epidemiological surveillance in the region, in addition to supporting the planning, initiatives, and control in healthcare agencies[22].

CONCLUSION

According to the descriptive analyses of the hydrological regime, left- and right-bank tributaries and the main canal of the Solimões river are characterized by the regionalization of distinct flood periods. Another relevant finding was the response of flood peaks according to the location of the hydrometric station in the basin. Stations further upstream of the main stretch have early periods of maximum water level when compared with downstream stations and those close to the confluence of the Solimões river.

As we found differences in the movement of the floods of rivers, we noticed that the peak period of malaria cases was also dynamic. In this case, we believe that, as the rainfall regime modulates the river regime, overall, the latter significantly influences the different seasonal patterns of malaria cases, more specifically in periods of maximum incidence.

Since the spatial distribution of malaria is related to environmental and climatic characteristics of the region, analyzing the link between the disease and rainfall and water level variables is paramount for the local knowledge of the development of such relationships.

We suggest implementing regional strategies that consider local characteristics and behavior of the epidemiological profile, especially regarding trends in the peaks of malaria cases according to distinct hydrological regimes, as these policies could act as additional systems for monitoring the disease and supporting municipal initiatives to mitigate malaria in the state of Amazonas.

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