CSP **CADERNOS DE SAÚDE PÚBLICA**
REPORTS IN PUBLIC HEALTH

ARTIGO
ARTICLE

Variability in malaria cases and the association with rainfall and rivers water levels in Amazonas State, Brazil

Variabilidade dos casos de malária e sua relação com a precipitação e nível d'água dos rios no Estado do Amazonas, Brasil

Variabilidad de los casos de malaria y su relación con las precipitaciones y nivel del agua de los ríos en el estado del Amazonas, Brasil

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doi: 10.1590/0102-311X00020218

Abstract

Understanding the relations between rainfall and river water levels and malaria cases can provide important clues on modulation of the disease in the context of local climatic variability. In order to demonstrate how these relations can vary in the same endemic space, a coherence and wavelet phase analysis was performed between environmental and epidemiological variables from 2003 to 2010 for 8 municipalities (counties) in the state of Amazonas, Brazil (Barcelos, Borba, Canutama, Carauari, Coari, Eirunepé, Humaitá, and São Gabriel da Cachoeira). The results suggest significant coherences, mainly on the scale of annual variability, but scales of less than 1 year and of 2 years were also found. The analyses show that malaria cases display a peak at approximately 1 and a half months before or after peak rainfall and on average 1-4 months after peak river water levels in most of the municipalities studied. Each environmental variable displayed distinct local behavior in time and in space, suggesting that other local variables (e.g. topography) may control environmental conditions, favoring different patterns in each municipality. However, when the analyses were performed jointly it was possible to show a non-random order in these relations. Although environmental and climatic factors indicate a certain influence on malaria dynamics, surveillance, prevention, and control issues should not be overlooked, meaning that government public health interventions can mask possible relations with local hydrological and climatic conditions.

Malaria; Atmospheric Precipitation; Hydrology

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Introduction

Malaria, a serious infectious disease, places a huge burden on the population's health and social and economic development. In Brazil, especially in the Legal Amazon, the disease is considered a serious public health problem, with widespread incidence and debilitating effects due mainly to the favorable environmental conditions for maintenance of the disease [1,2].

Although environmental and social conditions are important for malaria's endemic levels, factors such as health services access and quality can affect the disease dynamics [3,4]. The interaction between these factors favors the variations in case reporting, and many such factors are associated with weaknesses in epidemiological surveillance activities, responsible for delays in diagnosis and treatment of the disease and conditions of population vulnerability [5,6,7].

Many factors (e.g. climatic, ecological, and environmental) can be responsible for the vector's seasonal characteristics [8]. Research has constantly suggested the influence of climatic factors on the occurrence of vector-borne diseases [9,10,11]. Environmental variables such as temperature, humidity, and land use and vegetation patterns affect the life cycle of various diseases, especially vector-borne ones [12].

Seasonality patterns in the malaria vector's presence are closely related to the annual rainfall cycle and meteorological and hydrological variations [13,14]. The annual variability in rainfall contributes to altering the vector density, in addition to providing an aquatic medium for the mosquitos' life cycle, increased humidity, and thus vector longevity [8,15]. Although rainfall plays an important role in malaria, its effect and intensity can vary with the circumstances in certain geographic regions [8].

Another relevant element is understanding the hydrological patterns in relation to malaria cases. Seasonal variations in hydrological levels contribute to the formation of potential breeding sites, with a significant impact on malaria fluctuation and incidence [14,16].

Since environmental and climatic characteristics ensure favorable environments for this endemic's perennial transmission [2], understanding the relations between rainfall and river water level and their effects on malaria is important for understanding the heterogeneous epidemiological profile and differences in variability in the Amazon Region.

Even in a region where malaria is considered endemic, the transmission dynamics can vary depending on the interaction with environmental sociocultural, economic, and political factors [17]. According to Confalonieri [18], the environmental and social characteristics of the Brazilian Amazon are relevant to the determination of epidemiological patterns. The region's geographic and ecological characteristics also substantially determine potential habitats for the vector's reproduction.

Since malaria displays complex interaction between the parasite, vector, human population, and environment, the disease also shows a complex spatial and temporal distribution. In addition to the influence of public policies, various studies point to non-homogeneity as a function of different forms of land occupation and distinct epidemiological conditions due to landscape characteristics and climatic conditions [19,20,21].

Studies aimed at shedding light on the disease dynamics, with differences at the local level, and identifying spatial differences based on the river basin's hydrological variability and local rainfall conditions provide relevant backing for the implementation of prevention and control strategies based on distinct malaria patterns. The current study thus aimed to aimed to analyze the statistical covariance in local rainfall and river water levels and malaria cases in order to demonstrate how these relations vary in the same endemic space.

Methodology

Study area

The state of Amazonas is located in the North of Brazil, with an area of 1,559,161.682km^2. The state's climate is humid equatorial, with high temperatures and high mean rainfall. The region basically has two well-defined seasons, from November to March (rainy season) and from May to September (dry season), with the high river flooding season from May to August and the low river level season from September to October [22].

Data

Data on total malaria cases and rainfall and water level anomalies for each municipality included the historical series from 2003 to 2010 on a monthly scale. Since the data from the Global Historical Climatology Network (GHCN) at the time of the data collection provided a historical series up to the year 2010, we opted to standardize the size of the historical data series based on the availability of data on total malaria cases from the Epidemiological Information System on Malaria (SIVEP-Malaria), from 2003 to 2010, contained in the GHCN database. The water level data were obtained for this same period.

The municipalities were selected randomly among those with complete hydrological data, providing a representative sample of the state of Amazonas, as well as municipalities located in different river basins. The municipalities analyzed in the study were Barcelos, Borba, Canutama, Carauari, Coari, Eirunepé, Humaitá and São Gabriel da Cachoeira (Figure 1).

• Malaria cases

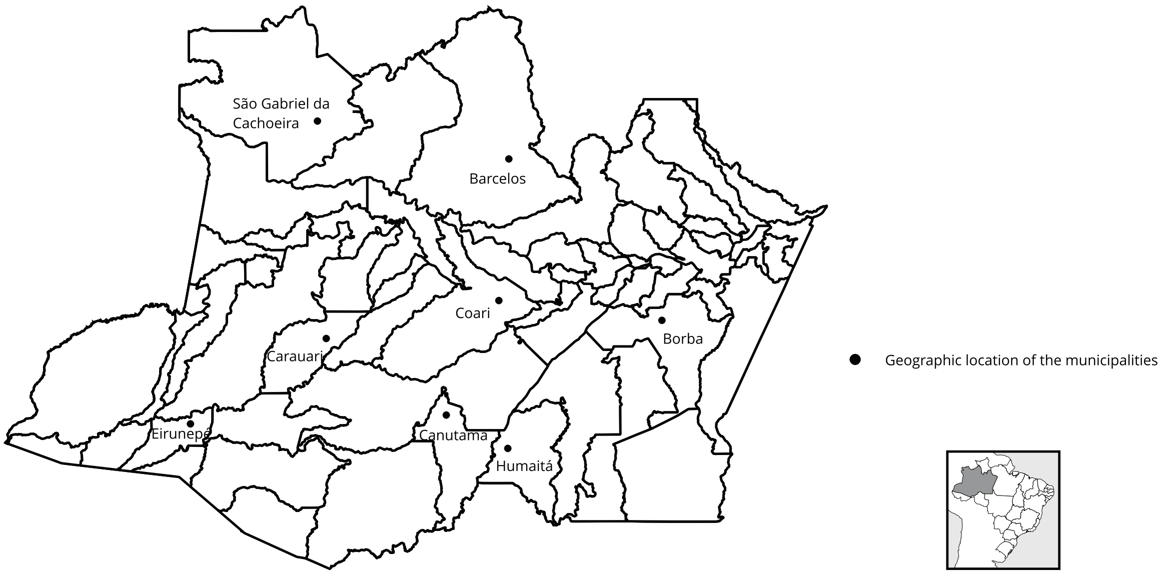
Data on total malaria cases were obtained by processing crude data in dbf files, available in SIVEP-Malaria, using only total new and autochthonous cases.

• Water levels

Water level data (hydrometric station measurements) were obtained from the database of the Brazilian National Water Agency (ANA) and SO HYBAM (Observation Service “Geodynamical, Hydrological and Biogeochemical Control of Erosion/Alteration and Material Transport in the Amazon,

Figure 1

Location of the study area in the state of Amazonas, Brazil. The eight municipalities analyzed were São Gabriel da Cachoeira, Barcelos, Eirunepé, Carauari, Coari, Canutama, Humaitá, and Borba.



Orinoco and Congo Basins”). When choosing the target municipalities, the hydrometric stations were selected on the basis of criteria including data comprehensiveness and consistency.

- **Rainfall**

Monthly rainfall data were used for global continental areas from 1948-2010, with a horizontal resolution of 0.5º latitude and 0.5º longitude referring to latitudinal and longitudinal points in the municipality, available through GHCN in the 2B and CAMS version. First, we calculated mean rainfall and total mean for the series, and next, for the years 2003-2010, we calculated the monthly rainfall anomalies. The rainfall anomalies allowed assessing the degree of rainfall variability and its relationship to extreme events.

Data analysis

The study used the procedures and calculations proposed by Torrence & Compo [23]. Coherence and wavelet phase analysis allows determining the dominant modes of variability between the variables and how these modes vary over time [24], i.e., breaking down and describing the function f(t) in the frequency domain in order to analyze this function on different frequency and time scales. This technique is important for investigating non-stationary phenomena.

Coherence values can be viewed based on the chromatic scale from blue to red. Coherence values of one (red) represent a strong relationship between the variables. Coherences from yellow to blue represent weaker relations and without statistical significance. Statistically significant coherences are demarcated by a black line, where the level of significance using the Monte Carlo method is 95% confidence. Low and statistically non-significant coherence values indicate that the variables were independent in the years. However, significant and high coherence values suggest that the series presents a degree of interrelationship with variations on the same frequency.

Phase or lagged analysis between the series is characterized and illustrated by the vectors’ slope angle. Horizontal arrows pointing to the right (0º) result in series in the same phase (joint relationship); arrows pointing left (180º) reflect series in opposite phases (inverse relationship). Arrows pointing down (-45º, -90º, or -135º) suggest that the first series analyzed is lagged, occurring before the second series; arrows pointing up (45º, 90º, or 135º) indicate that the first series is lagged, occurring after the second phase.

For this study’s analyses and to understand the time lags (how much one variable antecedes or precedes the other), the independent variables were rainfall and water level, and the dependent variable was malaria cases. Calculation of the lag is based on the vector’s slope angle.

The abscissa represents the annual period, subdivided into fractions of a year, i.e.: levels 0.25, 0.5, 1.0, and 2.0, which appear standardized on the axes and correspond to periods of 3 months, 6 months, 1 year, and 2 years, respectively. The results for this type of analysis frequently vary in the intervals at these levels.

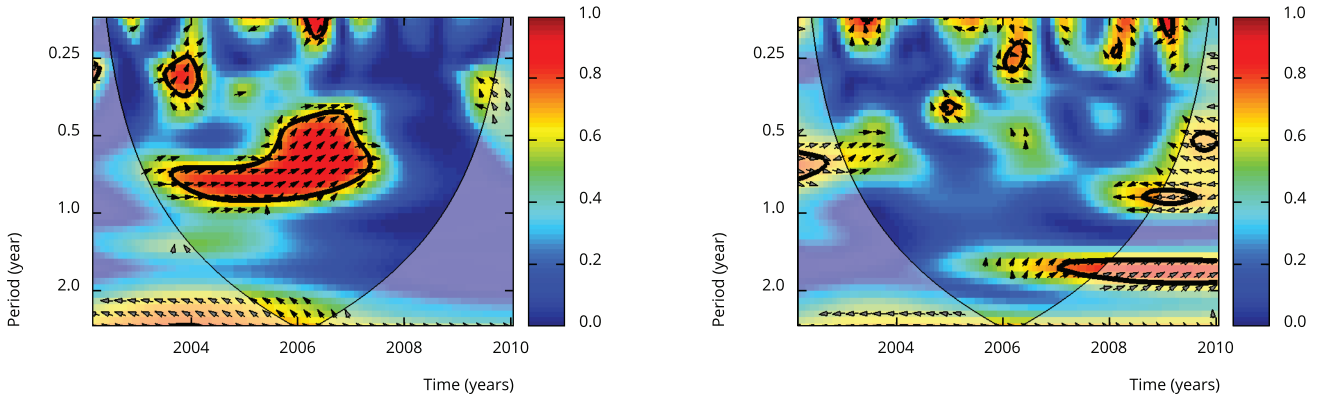
Results

The results of coherence analysis generally indicate relations on an annual scale of variability (one year), but smaller scales of 0.25-0.9 years (corresponding to 3-9 months) and on a biennial scale (two years) were also observed. In relation to rainfall and malaria cases, the results vary in phase coherences (relations between variables occurring at the same time) and lagged coherences (variables occurring at different moments). For water level and malaria, the coherences were mainly lagged, with variability of 1-4 months, according to the municipalities.

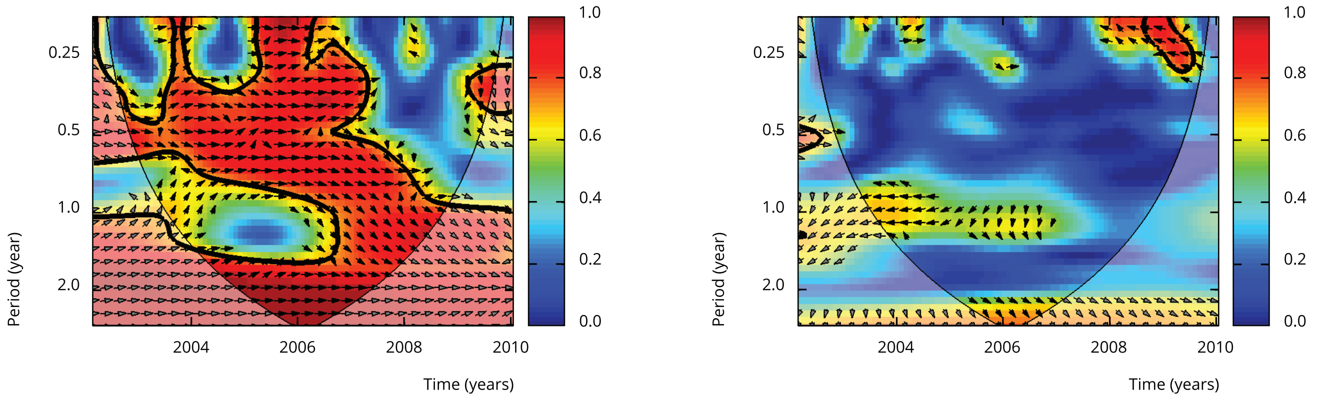
The variables rainfall and malaria cases in the municiplaty of São Gabriel da Cachoeria (Figure 2) feature phases coherences in the years 2004-2006 on a scale of variability of 0.6-0.8 years (corresponding to eight to 10 months). Lagged coherences on a scale of variability of 0.25-0.33 years (3-4 months) for the year 2004 and 0.41-0.66 years (5-8 months) for 2006 and 2007 indicate that the peaks in malaria cases anteceded the peaks in rainfall by 20-30 days. In the year 2007, on the scale of

Figure 2

Coherence (hatching from red to blue) and difference in wavelet phase (arrows) in the series "rainfall-malaria cases" and "water level-malaria cases" for the municipalities of São Gabriel da Cachoeira and Barcelos, Amazonas State, Brasil, 2003-2010.


2a) São Gabriel da Cachoeira: rainfall – malaria cases

2b) São Gabriel da Cachoeira: water level – malaria cases


2c) Barcelos: rainfall – malaria cases

2d) Barcelos: water level – malaria cases

0.08-0.41 years (1-5 months), lagged coherences suggest that the peak rainfall anteceded the peak in malaria cases by 10-20 days. For the variables water level and malaria cases (Figure 2), no coherences were observed on the annual scale (one year), except for late 2009, while on the biennial scale (two years) significant coherences were observed for the year 2008. Minor coherences were observed at smaller scales.

For the municipality of Barcelos, the variables rainfall and malaria cases showed quite important coherences (Figure 2). On the annual scale, starting in the year 2007 until early 2009, lagged coherences occurred in which rainfall anteceded malaria cases by approximately a month and a half. On scales of variability of 0.08-0.83 years (1-10 months) and on a biennial scale, phase coherences were observed in which rainfall and malaria cases displayed strong interdependence. As for the variables water level and malaria cases (Figure 2) on the annual scale, in the first half of the series (the same period in which no coherence was seen with rainfall), the relationship occurred in the opposite phase to water level, but without statistical significance. Significant coherence was only observed in 2009 on the scale of variability of 0.08-0.25 years (1-3 months), and in the opposite phase.

For the municipality of Eirunepé, analyzing rainfall and malaria cases (Figure 3), lagged coherences were observed on the annual scale for the years 2005 and 2006, in which the rainfall peaks occurred a month and a half after the peaks in malaria cases. On the biennial scale, the variables showed phase coherences between 2006 and 2008. On the annual scale, phase coherences were observed between 2007 and 2009. In relation to the variables water level and malaria cases (Figure 3) on the annual scale, lagged coherences were observed in which the peak water levels anteceded the malaria peaks by 3-4 months. On the scale of variability of 0.08-0.41 years, there were opposite phase coherences between the years 2004 and 2006.

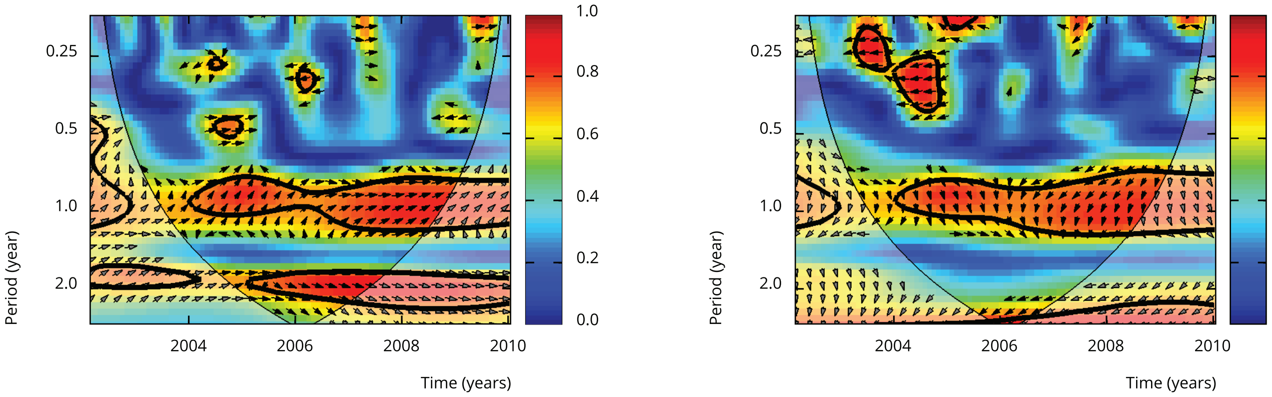
For the municipality of Carauari, a strong relationship was observed for all the years in the series. On the annual scale, lagged coherences were observed between 2007 and 2009 in which the peaks in malaria cases anteceded the rainfall peaks by a month and a half (Figure 3). On the scale of 0.25 to 0.33 years for 2009, lagged coherence was seen in which the peak in malaria anteceded the peak rainfall by 10 to 15 days. In relation to water level and malaria cases (Figure 3) on the annual scale, relations of moderate to strong dependence were observed for practically all the years with lagged coherences, in which the water level series anteceded by 45 days in the initial years of the series (2004-2006) and by three months for the rest of the years (2008-2010).

Figure 3

Coherence (hatching from red to blue) and difference in wavelet phase (arrows) in the series "rainfall-malaria cases" and "water level-malaria cases" for the municipalities of Eirunepé and Carauari, Amazonas State, Brasil, 2003-2010.

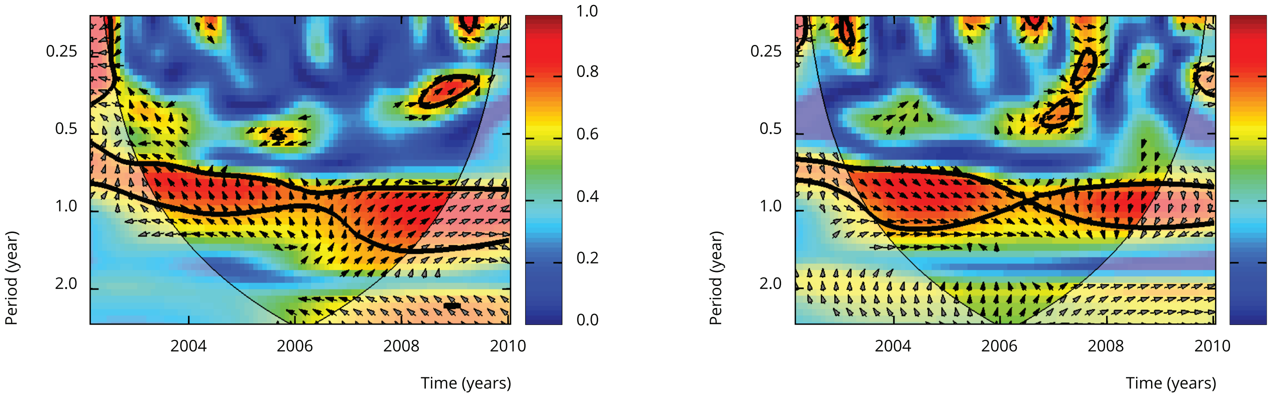
3a) Eirunepé: rainfall – malaria cases

3b) Eirunepé: water level – malaria cases



3c) Carauari: rainfall – malaria cases

3d) Carauari: water level – malaria cases

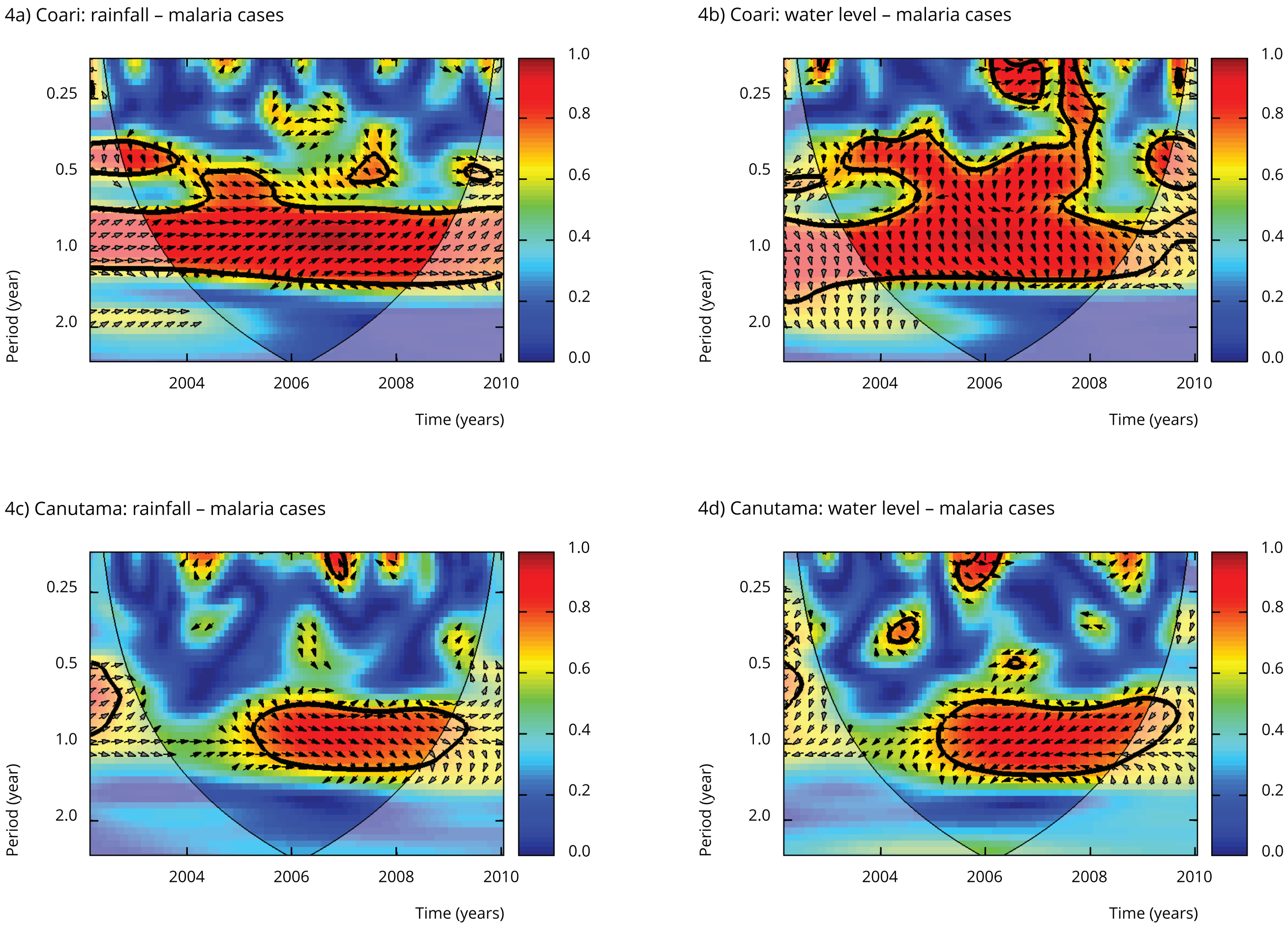


For the municipality of Coari, phase coherences were observed between rainfall and malaria cases (Figure 4). The phase coherences generally occurred on an annual scale, but lagged coherences were observed between the years 2005 and 2007. For 2004 and 2008, lagged coherences were shown on the scale of variability of 0.33-0.5 years (4-6 months), indicating that the peaks in rainfall anteceded the peaks in malaria cases by 20-45 days. As for water level and malaria cases, the coherences were much stronger. On an annual scale, lagged coherences were seen in which in the peak water levels anteceded the peaks in malaria cases by three months (Figure 4). On the scale of variability of 0.33-0.66 years (4-8 months), in the years 2004-2008, lagged coherences were observed in which the peak water levels anteceded the peaks in malaria cases by 1-2 months. On a scale of variability of 0.08-0.25 years, phase coherences were observed for the years 2007 and 2008.

The municipality of Canutama displayed near-phase coherences between rainfall and malaria cases from 2006 to 2009 on the annual scale (Figure 4). Although there were phase coherences between rainfall and malaria cases, inverse relations (opposite phase) were seen between water levels and malaria cases in the same period during which the relationship with rainfall was significant (Figure 4).

Figure 4

Coherence (hatching from red to blue) and difference in wavelet phase (arrows) in the series "rainfall-malaria cases" and "water level-malaria cases" for the municipalities of Coari and Canutama, Amazonas State, Brasil, 2003-2010.



For the municipality of Humaitá, the relationship between rainfall and malaria cases was only observed on the scales of variability of 0.08-0.5 years (1-6 months) and in phase, from 2003 to 2007 (Figure 5). For the year 2009, on the scale of variability of 0.08-0.16 years (1-2 months), lagged coherence was seen in which the peak in malaria cases anteceded the peak rainfall by seven to 15 days. As for the variables water level and malaria cases on an annual scale, lagged coherences were seen in practically the entire series, where peak water levels anteceded the peak in malaria cases by a month and a half (Figure 5).

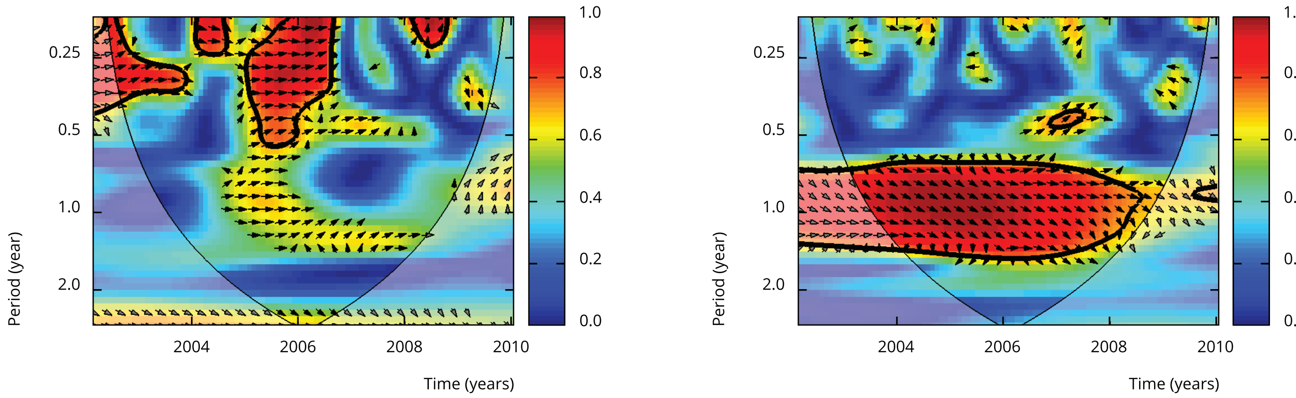
In the municipality of Borba, on the annual scale, lagged coherences were seen, where the peaks in malaria cases anteceded the peak rainfall by a month and a half in practically the entire series (Figure 5). As for water level and malaria cases on the annual scale, there were significantly strong lagged coherences in which the peak water levels anteceded the peaks in malaria cases by up to three months in the entire series (Figure 5).

Figure 5

Coherence (hatching from red to blue) and difference in wavelet phase (arrows) in the series "rainfall-malaria cases" and "water level-malaria cases" for the municipalities of Humaitá and Borba, Amazonas State, Brasil, 2003-2010.

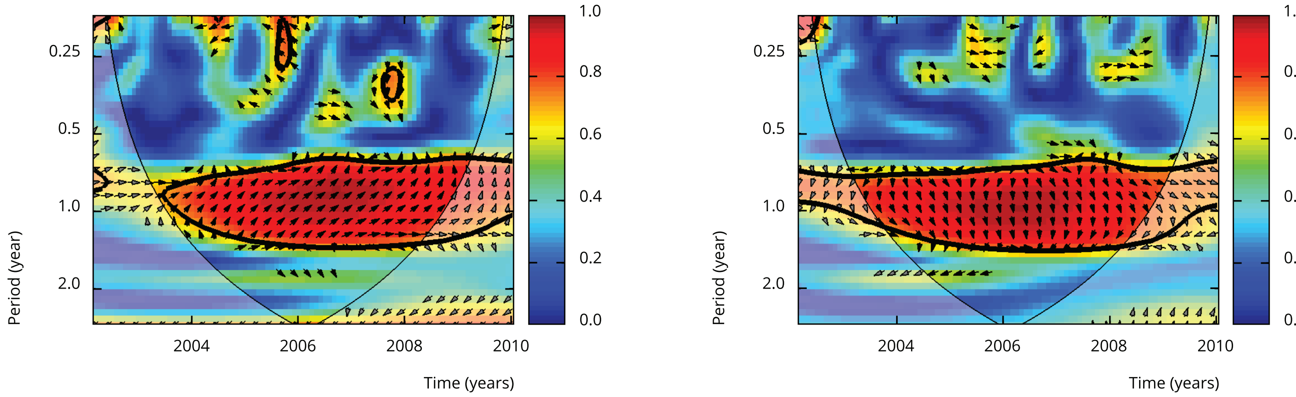
5a) Humaitá: rainfall – malaria cases

5b) Humaitá: water level – malaria cases



5c) Borba: rainfall – malaria cases

5d) Borba: water level – malaria cases



Discussion

In Amazonia, rainfall variability and its influence on the hydrological regime are frequently associated with the dynamics of vector development and malaria transmission. Although these associations are closely interrelated, factors pertaining to climatic and environmental conditions and epidemiological surveillance activities establish distinct spatial scenarios for malaria.

The study showed that the relationship between rainfall and malaria cases resulted in phase coherences, in which the frequency of peaks in the variables occurred at the same time, and lagged coherences, in which cases of the disease occurred on average one and a half months before or after the peaks in rainfall. According to Gurgel [6], peaks in malaria cases that antecede or precede the peaks in rainfall characterize peaks in the disease at the start of the rainy season or in the dry season. This variation is linked to the existence of ecological niches that allow the vector's development and reproduction in these periods.

In many parts of Amazonia, peaks in malaria cases occur mainly during the dry season, following the peak rains [6,25,26]. In the post-rainy periods, high transmission rates are often reported, when the environment becomes more favorable for the vector's reproduction [27,28,29].

The municipalities that showed malaria peaks during the dry season (second half of the year) were Coari and Canutama (mean yearly peak in August), São Gabriel da Cachoeira (mean yearly peak in October), and Barcelos (meanly yearly peak in December). On the other hand, the municipalities of Humaitá and Carauari (with mean yearly peaks in April) and Borba and Eirunepé (meanly yearly peaks in May) showed peaks in malaria cases in the first half of the year. Wolfarth-Couto et al. [30] explain that peaks in malaria cases can also occur before August in regions where the rainfall and hydrological regime are anticipated naturally, thus leading to different seasonality patterns in malaria cases.

Although the highest reports of malaria cases in the literature are in the dry season, right after the peak there is a decrease in the number of cases. Due to the low relative humidity and lack of temporary vector breeding sites caused by the low rainfall and high temperatures. the vector rates fall, thus impacting disease transmission and case reporting. During this period, the mosquitos reproduce in perennial bodies of water, mainly along the riverbanks [31], which play the role of year-round breeding sites, even in the dry season.

The lags we observed between rainfall and malaria cases in the eight municipalities showed similar characteristics to those reported by Grillet et al. [32]. Lighter rainfall plays a critical role in the annual variation in cases, directly impacting the peaks in malaria [6,32,33].

Local observations reveal the existence of different seasonal patterns for malaria in Amazonia, which is not environmentally uniform, given the huge differences in topography, drainage patterns, and economic and social development [25,34]. Despite the importance of rainfall for malaria in the Amazon Region and the fact that this relationship varies throughout the Amazon Basin [15,32], biological, geographic, ecological, social, cultural, and economic factors can act synergistically in the production, distribution, and especially control of vector-borne diseases [35]. According to Barreto et al. [36], geographic, economic, and social factors facilitate transmission and limit the application of standard control measures.

Rainfall in Amazon does not display spatially and temporally uniform behavior [37]. Analogously, malaria itself is not homogeneous. Although the results showed relations between rainfall and malaria, phase coherences and lagged coherences express differences that may be related to the local environmental characteristics and reflect the influence of epidemiological surveillance activities in each location.

Another element that cannot be ruled out is that in the majority of the endemic areas, *Plasmodium vivax* coexists with *Plasmodium falciparum*, and its recurrences follow a different temporal pattern [38]. Since *P. vivax* is more difficult to control and eliminate than *P. falciparum* due to its tendency to relapse after the primary infection [38,39,40], this may affect the total number of malaria cases and the relations between the variables, since the number of cases involving *P. vivax* (the principal etiological agent of malaria in the region) is related more to relapses than to environmental determinants.

Coherence and wavelet phase analysis shows that local environmental conditions play an important role in the vector's seasonal cycle [41]. Consistent with the findings by Hurtado et al. [42], the relations between the variables indicated a strong annual pattern, in addition to significant coherences on the scale of variability less than one year and on the biennial scale. According to Chowell et al. [43], a strong annual pattern can be followed by biennial cycles, but differing by region and by type of malaria. Since rainfall acts as a modulator of vector dynamics, interannual rainfall variability may have effects on this relationship [31,43,44].

The scale of biennial oscillation, which appears heterogeneously between the municipalities, was observed in the relationship between malaria cases and rainfall (Barcelos and Eirunepé) and water level (São Gabriel da Cachoeira). Poveda & Mesa [45] suggest that biennial rainfall variability is associated with interference by ENOS (El Niño-Southern Oscillation), with responses in hydrological variability. Interannual oscillations in rainfall lead to responses in the Amazon Basin's rivers, decreasing (or increasing) the water discharges during El Niño/La Niña events [46].

According to Ferreira de Souza et al. [41], the biennial scale of ENOS is the principal phenomenon that modulates climatic variability in Amazonia, as reflected mainly by the rainfall anomalies. In the tropics, El Niño/La Niña heavily modulate the interannual changes in the predominant environmental variables. According to Rasmusson et al. [47], biennial oscillation is a fundamental element in the variability of ENOS and evolves typically over the course of two years.

Studies on climatic influences on infectious diseases focus mainly on ENOS in public health and malaria control. The malaria vector is susceptible to meteorological changes, which directly affect the mosquito's life cycle [10]. Information on the potential impact of climatic factors on malaria incidence can be useful for orienting disease prevention programs, aimed at the ultimate elimination of the disease [42].

In relation to the scale of variability less than one year, the study showed an association between malaria cases and water level. Hydrological phenomena on this scale may be associated with the increase in the mosquito vector.

Consistent with Wolfarth [25] and Xavier [48], the data from rainfall series can display unusual hydrological variability. Known as "repiquete", characterized as an atypical hydrological phenomenon with an oscillation outside the annual variability pattern, it consists of sudden variations in the water level (in a mean period of one to three months) until the standard hydrological regime is established. According to Wolfarth [25], the causes of repiquete are unknown, but the phenomenon may be associated with processes of climatic variability and have effects on the peaks in malaria cases.

Lagged coherences on the annual scale of variability in which malaria cases occur on average one to four months after the peak river water levels are consistent with Wolfarth-Couto e al. [30], who state that distinct hydrological regimes are important in the variable seasonality of malaria cases by shifting the river water flooding.

Studies have shown that like rainfall, hydrological variability influences the fluctuation in vector density [16,49,50]. Rainfall not only provides larval habitats, but is also responsible for the rising river levels that creates permanent breeding sites.

The findings comparing water levels and malaria cases suggest a better description of the dependence between the study's variables. According to Stefani et al. [14], malaria incidence receives a relevant impact from water level variation. The rivers of the Amazon Basin and their hydrological variability have a major influence on vector density [16,27,50], expressing year-round relations.

The independent variables and malaria cases may or may not present significant relations. Girod et al. [21] explain the variation in these relations based on the characteristics of each location's landscape. In addition, the climatic conditions in a given region are relevant for understanding the distinct (or similar) dynamics of the disease [20].

Regardless of significant associations between the variables, the relationship between malaria and climate is complex and indirect, especially when using data on malaria cases and not on the vector (number of anopheline mosquitos). Despite this limitation, malaria cases serve as an excellent health indicator and measure of epidemiological surveillance in the region, besides serving to back planning, interventions, and control by health services [51]. Grillet et al. [32] contend that better understanding of temporal patterns in malaria would allow developing more effective surveillance and early warning systems to prevent cases in response to climatic variations.

Environmental factors are not the only elements that determine malaria transmission. A better understanding of the impacts of climate changes, hydrological variation, and ecological and epidemiological factors are still necessary to assess the true local risk of malaria [26]. Terrazas et al. [50] emphasize the importance of socioeconomic policies to be implemented jointly with strategic environmental protection and epidemiological surveillance measure for the population in the state of Amazonas.

Importantly, factors not assessed such as species-specific malaria cases, local temperatures, and ENOS have distinct responses in association with malaria and can contribute to more robust conclusions. Although environmental and climatic factors have a certain influence on malaria dynamics, surveillance, prevention, and control issues should not be overlooked. Government measures in health may (or may not) act effectively, masking possible relations with hydrological and climatic conditions.

Coherence and wavelet phase analysis has become an increasingly useful and significant tool for interpreting natural phenomena in different fields of study [32,41,42,43]. The technique provides a robust mathematical base that encourages scientific research aimed at analyzing physical signs with complex variabilities. It is thus possible to simply and quickly determine the covariance of variables and their interrelations [52].

Conclusion

The statistical analyses show that malaria cases are strongly associated with rainfall and river water levels as climatic factors. Significant coherences were thus demonstrated, mainly on the scale of annual variability, in addition to displaying coherences on scales smaller than one year and on the biennial scale. The analyses show that peaks in malaria cases are reported approximately one month and a half before or after peaks in rainfall, and on average one to four months after the peak river water levels in most of the municipalities studied here.

Importantly, each environmental variable displayed a distinct local behavior in time and space, suggesting that other local variables (such as topography) may control the environmental conditions and favor different behavior in each municipality. However, when the analyses are performed jointly it is possible to see a non-random order in these relations.

The study suggests that intervention and control plans that contemplate each location's environmental and climatic reality, together with lagged conditions in the hydrological and rainfall regimes, are fundamental elements for monitoring and helping to control the disease, with the potential to assist in mitigating the burden caused by malaria in the state of Amazonas.

Contributors

B. Wolfarth-Couto participated in the study conception and design, statistical analysis, data interpretation, and writing of the manuscript. R. A. Silva participated in the statistical analysis and data interpretation. N. Filizola participated in the study's orientation, data interpretation, and critical revision of the manuscript.

Additional informations

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Acknowledgments

The study was financed by the Amazonas State Research Foundation (FAPEAM) and the Brazilian National Research Council (CNPq). The authors wish to acknowledge the support received from the Institut de Recherche pour le Développmente (IRD; France), Maison de la Télédétection (Montpellier, France), Potamology Laboratory of the Amazon (LAPA), Federal University of Amazonas (UFAM), State University of Amazonas (UEA) (especially MSc. Igor Oliveira for the technical support), and the Graduate Studies Program in Climate and the Environment, National Institute of Amazonian Research (PPG-CLIAMB/INPA).

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Resumo

O entendimento das relações entre as variáveis de precipitação e nível d'água dos rios com os casos de malária podem fornecer indícios importantes da modulação da doença no contexto da variabilidade climática local. No intuito de demonstrar como essas relações variam no mesmo espaço endêmico, realizou-se a análise de coerência e fase de ondeletas entre as variáveis ambientais e epidemiológica no período de 2003 a 2010 para 8 municípios do Estado do Amazonas (Barcelos, Borba, Canutama, Carauari, Coari, Eirunepé, Humaitá e São Gabriel da Cachoeira). Os resultados indicam coerências significativas principalmente na escala de variabilidade anual, contudo, escalas menores que 1 ano e bienal também foram encontradas. As análises mostram que casos de malária apresentam pico com aproximadamente 1 mês e meio antes ou depois dos picos de chuva, e em média 1-4 meses após o pico dos rios para grande parte dos municípios estudados. Foi notado que cada variável ambiental apresentou atuação local distinta no tempo e no espaço, sugerindo que outras variáveis locais (a topografia é um exemplo) possam controlar as condições ambientais favorecendo uma atuação diferenciada em cada município, porém, quando as análises são feitas em conjunto é possível ver uma ordem não aleatória destas relações acontecerem. Embora os fatores ambientais e climáticos denotem certa influência sobre a dinâmica da malária, questões de vigilância, prevenção e controle não devem ser desprezadas, significando que as atuações governamentais de saúde podem mascarar possíveis relações com as condições hidrológicas e climáticas locais.

Malária; Precipitação Atmosférica; Hidrologia

Resumen

La comprensión de las relaciones entre las variables de precipitaciones y el nivel de agua de los ríos con los casos de malaria pueden proporcionar indicios importantes sobre la modulación de la enfermedad en el contexto de la variabilidad climática local. Con el fin de demonstrar cómo varían esas relaciones en el mismo espacio endémico, se realizó un análisis de coherencia y fase de ondeletas entre las variables ambientales y epidemiológicas, durante el período de 2003 a 2010, en 8 municipios del estado de Amazonas (Barcelos, Borba, Canutama, Carauari, Coari, Eirunepé, Humaitá y São Gabriel da Cachoeira). Los resultados indican coherencias significativas, principalmente en la escala de variabilidad anual, sin embargo, también se detectaron escalas menores de 1 año y bienal. Los análisis muestran que los casos de malaria presentan un pico con aproximadamente 1 mes y medio antes o después de la pluviosidad más alta, y de media 1-4 meses tras el pico de los ríos para gran parte de los municipios estudiados. Se observó que cada variable ambiental presentó una actuación local distinta en el tiempo y en el espacio, sugiriendo que otras variables locales (la topografía es un ejemplo) puedan controlar las condiciones ambientales, favoreciendo una actuación diferenciada en cada municipio, no obstante, cuando los análisis se realizan en conjunto es posible ver un orden no aleatorio de estas relaciones para que se produzcan. A pesar de que los factores ambientales y climáticos denoten una cierta influencia sobre la dinámica de la malaria, cuestiones de vigilancia, prevención y control no se deben despreciar, lo que significa que las actuaciones gubernamentales de salud pueden enmascarar posibles relaciones con las condiciones hidrológicas y climáticas locales.

Malaria; Precipitación Atmosférica; Hidrología

Submitted on 01/Feb/2018
Final version resubmitted on 04/Jul/2018
Approved on 05/Sep/2018