Flowing with the River: Health Impacts of Seasonal Changes in the Brazilian Amazon

Lucas Falcão*[1]

[1]FGV-EAESP

22 July 2024

Abstract

This study examines the impact of seasonal variations in river levels of the Brazilian Amazon on health outcomes and healthcare provision. Although environmental factors directly impact health, the literature often overlooks indirect effects, such as barriers to accessing healthcare services. The seasonality of Amazonian rivers presents an interesting case for analyzing these mechanisms. It is expected that the flood and dry seasons lead to different challenges in healthcare provision. I rely on the fact that the Amazon basin is the largest in the world and presents a high heterogeneity across its rivers to identify the river seasonality. I assess the effect of river seasonality using panel data regressions with fixed effects. I also use two-stage least squares regression, using upstream precipitation as an instrumental variable. The results indicate an increase in mortality rates during the flood season, even in non-communicable diseases. This increase is not attributed to waterborne diseases but to the impact of water levels on healthcare provision. It is possible to observe a decrease in the distribution of chronic medications during floods. In the drought season, there is a higher mortality due to emergency conditions not accompanied by hospitalizations, thus indicating limited access to emergency care during this season. These findings suggest that the environmental risk factor could be higher than expected in developing regions that depend on seasonal environmental elements.

Keywords: : Seasonality; Health impact; Amazon.

JEL codes: I10, I12, I18, Q54.

*Corresponding author: lucas.silva.11@fgv.edu.br

1 Introduction

Individuals rely on seasonal environmental fluctuations to shape expectations and drive adaptive behaviors. This phenomenon is evident in health contexts, particularly concerning communicable diseases such as respiratory infections during winter (Chew et al., 1998) and malaria outbreaks in summer (Bomblies, 2012). However, the implications of seasonal variations extend beyond immediate health threats, potentially leading to restrictions and behavioral changes that can exacerbate chronic illnesses. Environmental factors influence health not only through direct consequences but also through indirect mechanisms. Therefore, it is imperative to identify potential seasonal impacts of environmental factors.

In this article, we investigate how the seasonality of rivers affects mortality in the Brazilian Amazon and identify potential mechanisms. The Amazon rivers are relevant for four reasons. First, they are crucial for the population, serving as transportation routes, sources of food, and means of transmitting waterborne diseases (Parry et al., 2018; Tregidgo et al., 2020). Second, there is clear seasonal variability that impacts various dimensions, such as navigability, fishing, and disease transmission. Third, river levels in a particular location are influenced by meteorological variations in distant areas, resulting in fluctuations independent of local meteorological and epidemiological conditions. Lastly, the Amazon region, with the world's largest hydrographic basin and the highest water discharge into oceans (Milliman and Farnsworth, 2011), has rivers originating from vastly different locations in the northern and southern hemispheres. This allows us to explore variations among river branches independently of common regional seasonality.

I investigated the impact of river seasonality on health outcomes and healthcare services by compiling a database integrating health information with river-related variables. The primary dependent variables included standardized mortality rates by gender and age for various causes, place of death, and hospitalizations for 555 municipalities in the Brazilian Amazon biome. The study covered January 2008 to December 2019, and georeferencing methods were used to establish a monthly water level indicator for all rivers in the region. For the analysis, I identified the month marking the transition between flood and drought periods and used models with fixed effects for time and municipality to capture the temporal dynamics around this neutral month. I also explored upstream precipitation as an instrumental variable for river levels at the municipality level.

The results reveal a concentration of deaths from noncommunicable causes during flood months and emergency conditions during dry months, indicating that river seasonality impacts health beyond communicable diseases. Environmental factors influence various aspects of residents' lives, adversely affecting health, particularly during floods when mitigating factors for chronic diseases are disrupted. There is a decrease in the availability of medications during these periods. While literature often focuses on the direct impact of rivers on health, such as waterborne diseases during extreme floods (Levy et al., 2016), I demonstrate that river seasonality also affects chronic diseases through indirect mechanisms, specifically by impacting access to healthcare. This issue is not unique to the Amazon but is also relevant in other developing regions facing similar problems due to environmental factors like precipitation and unpaved roads (Alegana et al., 2012; Blanford et al., 2012; Otu, 2019). Understanding these effects is crucial for sustainable development and human capital.

In the context of the Amazon, significant socioeconomic vulnerability and anthropogenic events in areas dependent on river transportation (Parry et al., 2018), exacerbate challenges in accessing healthcare (Garnelo et al., 2020). The increasing frequency of extreme weather events due to climate change further impacts river seasonality (Duffy et al., 2015; Gomes et al., 2020).

In the following sections, I provide the background in the Section 2, followed by data description in the Section 3. Section 4 methods for empirical analysis. In Section 5, I provide the results, and then the conclusion in the Section 6.

2 Background

2.1 Environment and health

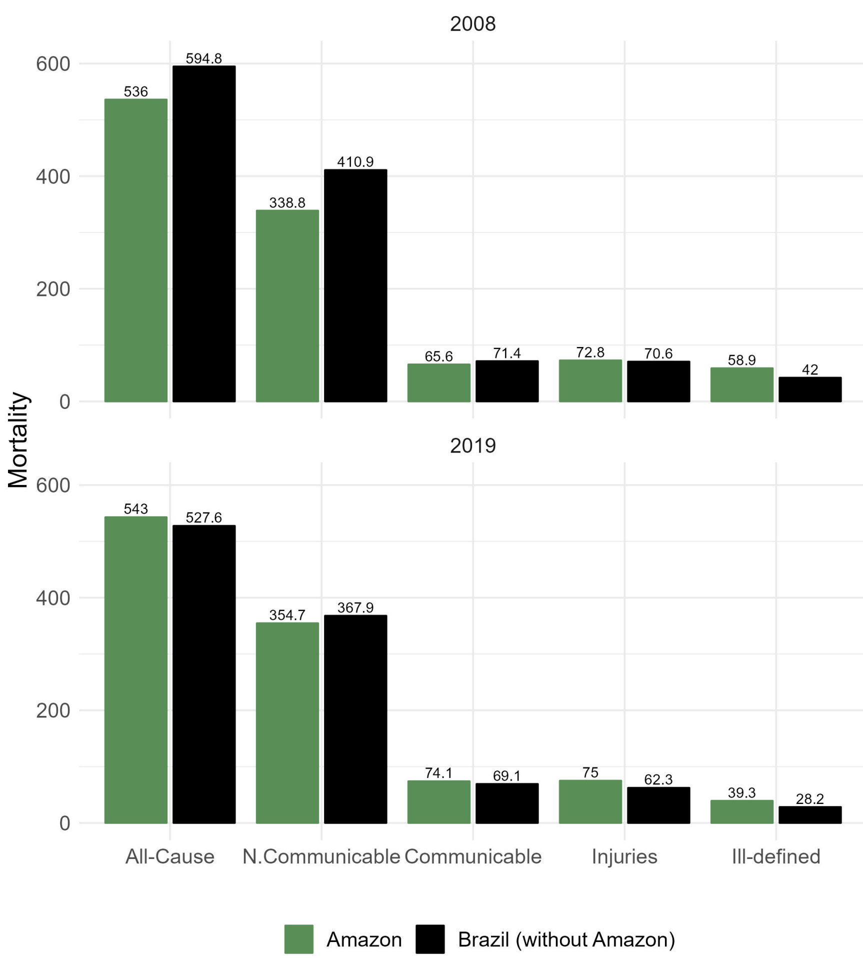
Existing literature categorizes the effects of meteorological and climatic changes on health into direct physical impacts (e.g., drowning), indirect impacts (e.g., vector propagation), and those mediated through social and sociodemographic factors such as migration (Haines and Ebi, 2019; Patz et al., 2000). A key indirect mechanism involves accessibility, as meteorological events can significantly impact mobility by altering travel modes and duration (Changnon, 1996; Lepage and Morency, 2020).

In developing countries, adverse weather conditions exacerbate challenges due to weakened transport infrastructure, particularly in rural areas. About 39% of rural populations lack access to all-season roads (Roberts et al., 2006). Limited research on climate impacts on geographical accessibility often groups dry and rainy seasons together, affecting travel time for health services (Alegana et al., 2012; Blanford et al., 2012; Otu, 2019). Increased travel time during rainy seasons is common in areas with poor infrastructure (Blanford et al., 2012; Otu, 2019; Stone et al., 2020). Consequently, environmental adversities can raise transportation costs for healthcare, influencing travel decisions and potentially leading to delays in medical care, especially with unpredictable climate patterns.

2.2 Health in Amazon

The Amazon struggles with the interaction between a vulnerable population, unique environmental characteristics, and inadequate health policies for these conditions (e.g., higher costs and lack of institutional capacity, including a shortage of healthcare professionals) (Rocha et al., 2021). All these elements, along with the possible influence of river seasonality, contribute to an age-sex adjusted mortality rate that is increasing at a faster pace compared to the rest of Brazil, as shown in Figure 1. The main factor driving this trend is the rise in deaths due to non-communicable diseases. In 2008, the Amazon had fewer deaths from these conditions, but by 2019, there was a 4.7% increase, while the rest of the country experienced a 10.5% decrease. This might indicates that health policies in the region are not as effective as those in the rest of the country. We argue that river seasonality and its significance to the region is one of the factors undermining public health.

Figure 1: Age-sex adjusted mortality rate in 2008 and 2019

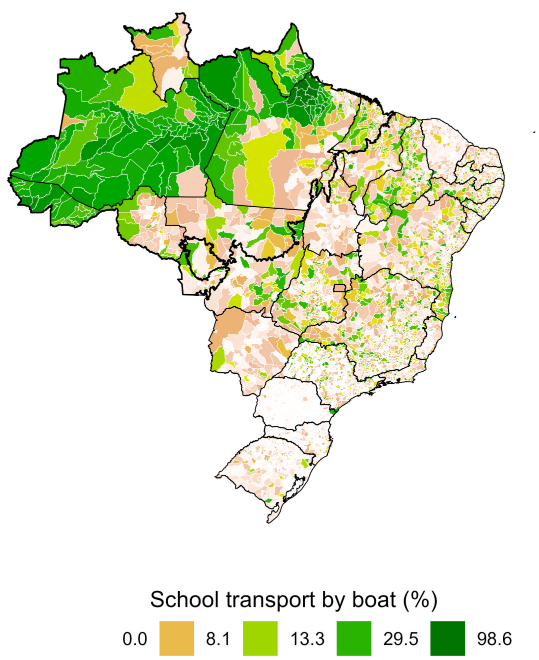


Note: Age-sex adjusted mortality rate in 2008 and 2019 considering WHO classification.

2.3 River importance

Among the main characteristics of the region that differ from the rest of the country are the vast distances and modes of transport. As illustrated in Figure 2, in the Amazon biome, there is a higher proportion of municipalities where the population relies on rivers for transportation (using school transportation as a proxy). Given the poor road infrastructure and the high environmental and monetary costs of building new highways, residents in more forested areas use rivers as their primary means of transportation. Qualitative research often highlights that droughts pose a challenge to navigation by increasing travel time or even making access to healthcare services impossible (Garnelo et al., 2020). Conversely, during floods, especially with river overflow, homes and urban centers along the riverside become submerged, leading to the disruption of public services (da Franca and Mendonça, 2015).

Figure 2: Percentage of school transportation by boats

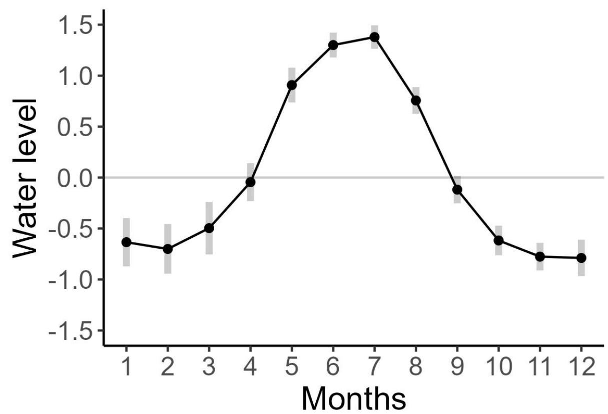


Note: average proportion of regular education students using boat transportation among the total using school transportation between 2011 and 2019 based on the School Census. Thin black lines represent the federal units, and the highlighted area with a bold line represents the Amazon Biome

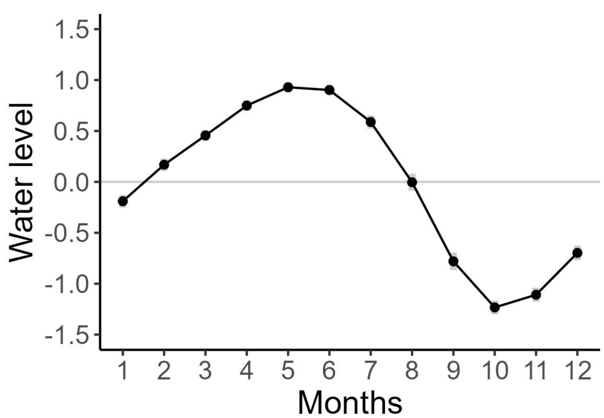
2.4 River seasonality variation

The Amazon basin, with its sources and subbasins spread across the Americas, exhibits significant variability in climatic conditions that influence its hydrological processes. This variability results in heterogeneous patterns of river level seasonality both within and between municipalities. Figure 3 illustrates this heterogeneity by showing the mean water levels for each panel month. For instance, the Negro River reaches an intermediate level in April and September, while the Amazonas/Solimões River has an average level in February and August. In contrast, the Juruá River remains at intermediate levels from December to May. This variation in river seasonality enables us to analyze the effects of river level changes on health outcomes.

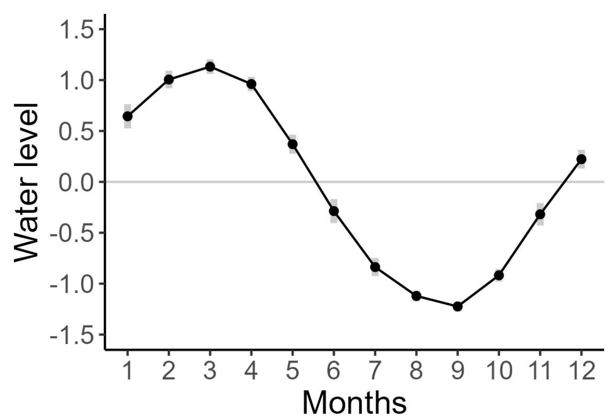
Figure 3: Average river level by month)



(a) Negro



(b) Amazonas/Solimões



(c) Jurua

Note: Average river level for each month considering all ANA gauging stations for each river.

3 Data

3.1 River level

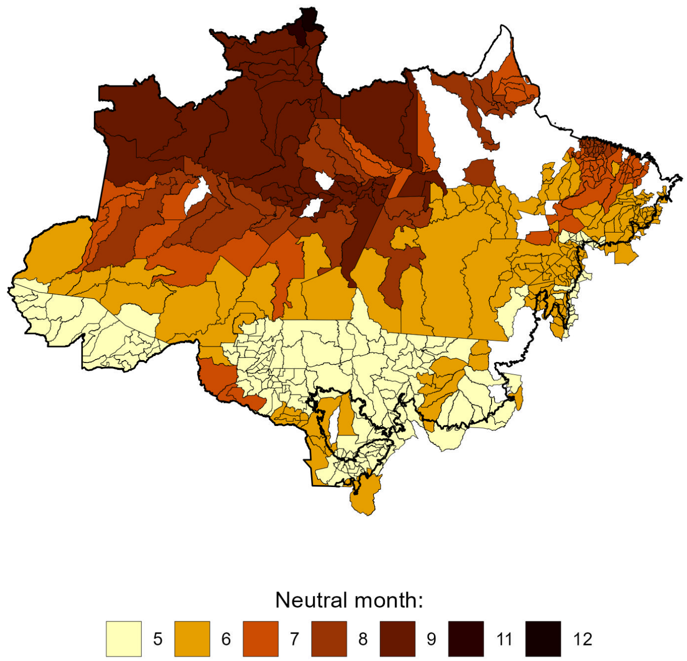
To estimate the river level for each municipality, we extracted data from river gauge stations in the Legal Amazon with records between 2007 and 2019 from the API of the Hidroweb information system of the National Water Agency (ANA). We restricted the stations to those with at least 80% valid daily observations. To represent the municipalities, we used the centroids of census tracts from the 2010 Census, thus identifying the stations closest to each centroid (typically the area with the highest population concentration in the municipality). We considered only stations in the same ottocoded level 3 hydrographic basin as the census tract to perform this procedure. Subsequently, we calculated the weighted average of river levels between all the stations closest to each census tract, based on their proportion of inhabitants. Using this procedure, the indicator was calculated as the z-score of the monthly average river level. Through these methods, we have estimates for 467 municipalities in the Amazon Biome, corresponding to 84.1% of the municipalities.

3.2 River seasonality

To capture the effect of seasonality, we identified the month in each municipality when the river is at a neutral level, that is, neither in flood nor drought, more specifically, the moment when the river begins to decline. The criteria adopted to identify the neutral month were: (i) based on the values of the average river level for each calendar month (1 to 12), selecting the month with the value closest to zero, given that the series is in z-score; and (ii) since there are two possible moments in the year when the river reaches intermediate height levels, we restricted it to the decreasing moment of the level. Therefore, we defined a binary variable resulting from this process that indicates the neutral month preceding droughts. The months before this received values of -5 to -1, representing the flood period, and the subsequent months, 1 to 6, representing the dry periods. Appendix X illustrates this definition.

An essential factor for the effects of seasonality to be independent of other seasonal phenomena common to the entire region is the variation of the neutral month between municipalities. As the Amazon basin is vast and receives river inflows from different distant locations, there are different seasonal patterns in climatic conditions and, consequently, in river heights. This can be observed in Figure 4, where municipalities further south experience the neutral month around the middle of the year, while those further north experience it toward the end of the year.

Figure 4: Map of neutral month by municialities



Note: Neutral month is the month that typically is between the flood and drought seasons.

3.3 Health indicators

The main source of mortality data in Brazil is the Mortality Information System (SIM - *Sistema de Informação sobre Mortalidade*), containing information such as age, place of residence, and ICD codes. This allows me to calculate monthly mortality rates for various causes according to the World Health Organization (WHO) categories defined in 2013, using the annual population projection provided by the Ministry of Health. As the age composition influences local epidemiology, I used age standardization of mortality rates using the 5-year age groups of the Brazilian population from 2010 as a reference. I also performed the same standardization for hospitalization rates based on the Hospital Information System data. The initial analysis period is from 2008 (beginning of information collection regarding patient's place of residence) to 2019 (the year preceding the COVID-19 pandemic, which disrupted the regular provision of various services).

The main database on the execution of health services in Brazil is the Ambulatory Information System (SIA - *Sistema de Informações Ambulatoriais*), containing microdata related to SUS procedures. Despite being limited to the public service, around 90% of the population in the Legal Amazon does not have private health plans (Rocha et al., 2021), so the data covers most of the Amazonian population. There are incentives to avoid underreporting since resource allocation is tied to this information.

I also considered control variables associated with socioeconomic factors and health supply indicators in the municipalities, including the annual municipal GDP at 2008 values (IBGE, adjusted based on inflation indicator IPCA), the number of Bolsa Família beneficiaries (MDS), the number of hospital beds, and the number of health teams (CNES/Datasus).

4 Methods

4.1 Dynamic effects of river seasonality

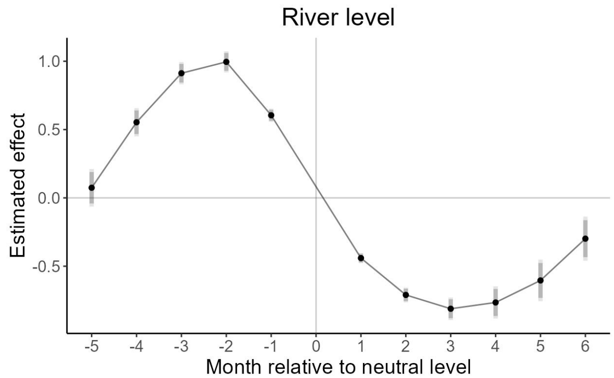
To estimate the effects of seasonality, I use the following equation:

$$Health_{it} = \sum_{n=-5}^{6} \beta_n Neutral_{i(t+n)} + \phi_i + \delta_t + \phi_i : \omega_t + \epsilon_{it} \quad (1)$$

Where *Health* represents the variable related to health outcomes in municipality i in month t. The binary variable *Neutral* takes the value 1 if in municipality i, month t is the neutral month. The other terms in the summation indicate the other months before and after the neutral month, which will be used as the reference month in the regressions (-5 to -1 represent the flood season, and 1 to 6 represent the drought). Therefore, β represents the expected effect of river seasonality. I include fixed effects for municipalities ϕ, time fixed effects δ, and a municipality interacted with the panel month ω. Therefore, I am also controlling for the specific seasonality of the municipality. The factor that makes the regression possible is the presence of other municipalities with the same neutral month. In all estimations, I consider robust standard errors clustered at the subbasin level and weight the regression for the log of population.

To understand and interpret the results appropriately, Figure 5 shows the estimation 1 against the river level indicator. We observe that during the period with typical seasonality, the months preceding the *Neutral* month correspond to the flood period, with maximum height around months -3 and -2. The months following the *Neutral* month correspond to the drought period, generally reaching a minimum between months 2 and 4. In months 6 and -5, the river approaches intermediate levels again.

Figure 5: Effect of river seasonality on water level indicator



Note: Coefficients of the estimation 1 on water level indicator. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

4.2 Average effects of river seasonality

I also considered alternative versions in which I aggregate the months that represents the flood and drought season:

$$Health_{it} = \beta_1 FloodSeason_{it} + \beta_2 DroughtSeason_{it} + Controls_{it} + \phi_i + \delta_t + \phi_i : \omega_t + \epsilon_{it} \quad (2)$$

Where *Health* represents the variable related to health outcomes in municipality i in month t. The binary variable *FloodSeason* takes the value 1 if in municipality i, month t is before the neutral month (-5 to -1) and *DroughtSeason* indicates the months after the neutral month (1 to 6). Therefore, I'm capturing the average effect of the each season in relation to the neutral month. In this version, I add the controls. Specifically, I controlled for socioeconomic factors (per capita Bolsa Família beneficiary families, per capita GDP, and population) and healthcare service availability (number of beds and primary health care teams), in addition to local precipitation. It include the same set of fixed effects (municipalities, time, and a municipality interacted with the panel month) and use the same cluster level and weights.

4.3 IV: upstream precipitation

I use the fact that the local river level is explained by the upstream precipitation to adopt the following two stage estimation:

$$Health_{it} = \beta_1 Flood\hat{S}easonit + \beta 2 Drough\hat{t}Seasonit + Controlsit + \phi_i + \delta_t + \phi_i : \omega_t + \epsilon_{it} \quad (3)$$

Where $Flood\hat{S}eason$ and $Drough\hat{t}Season$ are the predicted values from the first-stage regression:

$$FloodSeason_{it} = \gamma_1 UpstreamRain_{it} + \gamma_2 UpstreamRain_{i(t-1)} + Controls_{it} + \phi_i + \delta_t + \phi_i : \omega_t + \nu_{it} \tag{4}$$

$$DroughtSeason_{it} = \gamma_3 UpstreamRain_{it} + \gamma_4 UpstreamRain_{i(t-1)} + Controls_{it} + \phi_i + \delta_t + \phi_i : \omega_t + \xi_{it} \tag{5}$$

Where $Health$ represents the variable related to health outcomes in municipality i in month t. The binary variable $FloodSeason$ takes the value 1 if in municipality i, month t is before the neutral month (-5 to -1), and $DroughtSeason$ indicates the months after the neutral month (1 to 6). To address potential endogeneity, both $FloodSeason$ and $DroughtSeason$ are instrumentalized using upstream precipitation and its lag (log) in the furthest subbasin. This IV approach helps to isolate the exogenous variation in flood and drought seasons due to upstream precipitation patterns, providing more reliable estimates of their impact on health outcomes. I also use the same controls, fixed effects, clusters, and weights as in equation 2. Municipalities in the most upstream subbasins (16.7% of the sample of municipalities) and in subbasins that are tributaries of the main river of the basin (42%) were excluded. This procedure leads to a sample with only 189 municipalities, thus it might not be representative of the whole Amazon region. I also consider a version excluding municipalities that are 1,000 km or less from the most upstream subbasin to ensure that the precipitation is not correlated with local weather conditions. However, this procedure reduces the number of municipalities to 108.

The results from the first stage are displayed in the Table 1. The estimated coefficients for $UpstreamRain$ have the expected sign and significance. All F-statistics are significant and exceed the threshold of 10.

Table 1: First stage results

	Drought (1)	Flood (2)	Drought (3)	Flood (4)
Upstream Rain	-0.364 ***	0.305 ***	-0.379 ***	0.341 ***
	(0.038)	(0.035)	(0.055)	(0.063)
Upstream (lag)	-0.035	0.023	-0.030	0.045
	(0.029)	(0.029)	(0.017)	(0.024)
F:	72.2	67.6	37.1	22.2
N	28356	28356	15012	15012

*Note: **** p <0.01; ** p <0.05; * p <0.1. All F are significant. All estimations with controls and municipality, date and month:municipality fixed effects. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

4.4 Descriptive statistics

Table 2: Summary Statistics

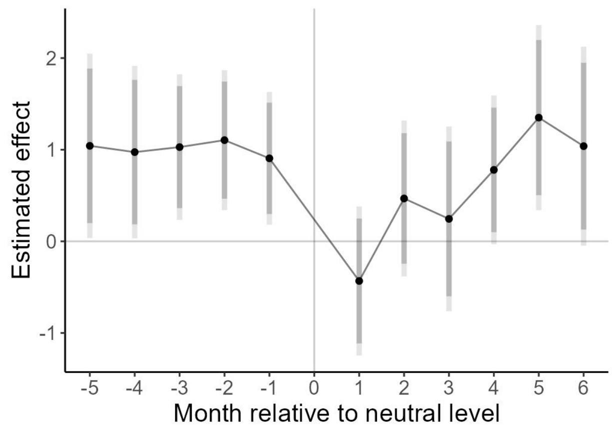
Statistic	Mean	St. Dev.	Min	Max
Water level	0.01	0.9	-2.9	8.4
Mortality Rate (/100,000 inhabitant, adj.)	39.1	23.7	0.0	387.9
Waterborne diseases	0.2	1.7	0.0	127.7
Non-communicable	24.3	18.9	0.0	387.9
In hospitals	21.7	17.7	0.0	312.4
Outside hospitals	17.4	15.7	0.0	330.2
Dispensed medications (/1000)	35.4	272.2	0.0	30,105.2
Outpatiant procedures (/1000)	53.9	214.5	0.0	8,601.4

5 Results

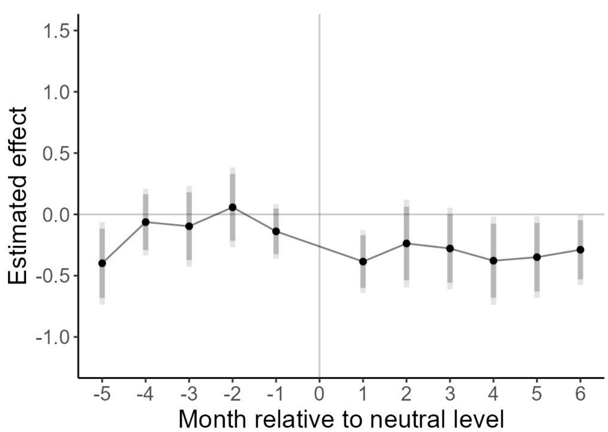
5.1 Effects of seasonality on mortality

For a better understanding of the results of the main estimate, we present them graphically, as shown in Figure 6, where the results for the mortality rate per 100,000 inhabitants are displayed. Values represent marginal effects for each binary variable in relation to the neutral month (negative months represent the flood period, and positive months represent the dry period). We observe that the seasonality of the river has an impact on the most vital health outcome. During periods of elevated river levels, the mortality rate remains higher than in the neutral month, with one additional death per 100,000 inhabitants. However, in the dry season, the effects are not statistically different from zero, except for the last months when the rivers start to rise again.

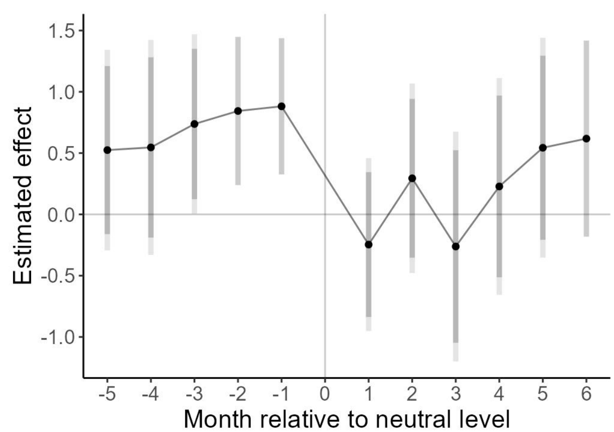
Figure 6: Effect of river seasonality on mortality (per 100,000 inhabitants)



(a) General



(b) Communicable



(c) Non-Communicable

Note: Coefficients of the estimation 1 on (a) overall mortality, (b) communicable, and (c) non-communicable. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

When I estimate the joint effect of the dry and flood seasons in relation to the neutral month using different controls and fixed effects, as shown in Table 3, we confirm that the flood season has a higher mortality rate (0.7 average effect) than both the neutral month and the dry season (not significant). This evidence shows that river seasonality is associated with the most vital health outcome: mortality.

However, when using precipitation in upstream subbasins as an instrumental variable (IV), there is no significant effect, as shown in Table 4. As discussed in Section 4, due to limitations imposed by the lack of an upstream subbasin, the sample size for the IV analysis is 58.7% smaller than the sample size for the fixed effects estimation. We can see how this affects the estimations by analyzing estimation 1 in Table 4, where the IV is not used. Although the result is significant for the whole sample (Table 3), it is not significant for the subsample used in the IV analysis. For this reason, I use the estimations for 1 and 2 as the main results for the remainder of the paper.

Table 3: Effects on mortality

	(1)	(2)	(3)
Flood season	0.709 **	0.709 **	0.698 **
	(0.287)	(0.287)	(0.288)
Drought season	0.287	0.287	0.295
	(0.322)	(0.322)	(0.321)
Time and mun. FE:	Yes	Yes	Yes
Month:Mun. FE:	No	Yes	Yes
Controls:	No	No	Yes

*Note: **** p <0.01; ** p <0.05; * p <0.1. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

Table 4: Effects on mortality using IV

	Mortality				
	(1)	(2)	(3)	(4)	(5)
Drought season	0.260	4.535	3.802	18.348	14.014
	(0.411)	(53.244)	(30.997)	(15.317)	(11.035)
Flood season	0.585	5.434	4.761	18.885	15.512
	(0.414)	(56.047)	(37.138)	(15.985)	(12.333)
IV:	No	Yes	Yes	Yes	Yes
Only >1,000 km.:	No	No	No	Yes	Yes
Controls:	No	No	Yes	No	Yes

*Note: **** p <0.01; ** p <0.05; * p <0.1. IV: precipitation on the further upstream subbasin. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

Before understanding what leads to this association between deaths and the flood period, it is important to understand which health conditions are responsible for this pattern. Figure 6 also shows the results for the main mortality categories according to the WHO ICD classification, communicable and non-communicable diseases. Despite the same pattern for communicable diseases (lower mortality during the dry period), it is evident that the higher mortality during floods is largely due to non-communicable diseases (reaching 0.7 additional deaths per 100,000 inhabitants). This indicates an association between seasonality and mortality from chronic diseases, with greater effects than for communicable diseases, which are usually more susceptible to environmental risks.

The results for the joint impact of the flood and dry seasons, shown in Table 5, also confirm these findings. While there is no significant effect during the drought, the flood season shows an average effect of 0.58 deaths per 100,000 inhabitants due to non-communicable diseases. Most of these deaths are due to cardiovascular diseases. As we argue in the following sections, we believe that the mechanism behind this increase in mortality during the flood season is related to the lack of access to proper health care.

Table 5: Effects on mortality by burdens

	Communicable (1)	Waterborne (2)	Non-Communicable (3)	Cardiovascular (4)
Flood season	-0.128	0.017	0.580 **	0.426 **
	(0.114)	(0.022)	(0.280)	(0.208)
Drought season	-0.276 **	-0.012	0.166	0.130
	(0.123)	(0.027)	(0.318)	(0.193)

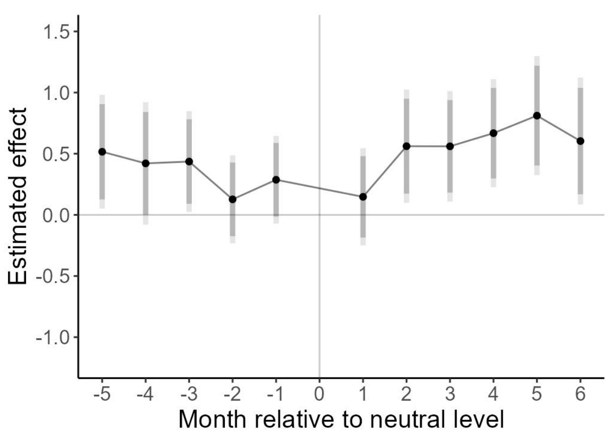
*Note: **** p <0.01; ** p <0.05; * p <0.1. All estimations with controls and municipality, date and month:municipality fixed effects. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

Mortality due to emergency conditions

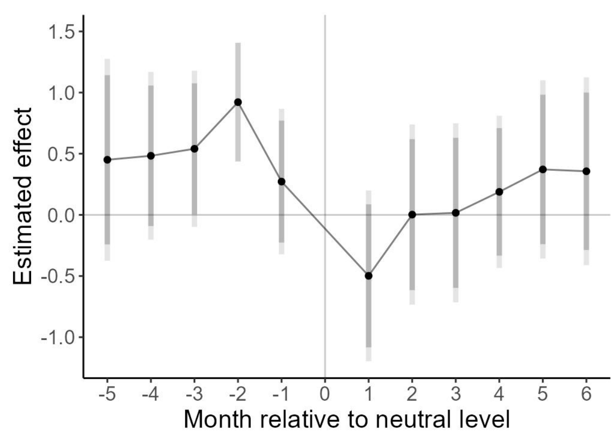
Mortality due to emergency conditions is indicator of access to healthcare. High mortality rates from conditions that typically require urgent medical attention, such as heart attacks, strokes, severe infections or traumas, may suggest delays or barriers in accessing timely healthcare services. If patients cannot reach healthcare facilities promptly or if there are deficiencies in emergency response and treatment capabilities, the likelihood of fatal outcomes increases. Therefore, examining these mortality patterns can highlight systemic issues in healthcare accessibility. I use the classification of burdens sensible to emergency care from Chang et al. (2016).

The results for estimation 1, showing the adjusted mortality rate for non-emergency and emergency conditions per 100,000 inhabitants, are displayed in Figure 7. During the flood season, there is an increase of up to 0.5 deaths per 100,000 inhabitants due to emergency conditions, but non-emergency deaths peak at 0.9 deaths. In the dry season, there are more emergency deaths, reaching 0.8 deaths per 100,000 inhabitants. Table 6 displays the results for the joint seasonal effects on non-emergency and emergency conditions, segregating them by type. It is clear that the higher number of deaths due to emergency conditions is caused by injuries during the dry season, while the mild increase during the flood season is likely caused by non-communicable conditions in the flood season. If we look for the mortality due to injuries in the appendix A1, it is possible to affirm that the positives values in the main estimation for the general mortality (Figure 6) is lead by the injuries. This means that especially during the flood season there is more challenging to provide adequate emergency care, thus leading to a higher a mortality. However, another possibility is the increase in the prevalence of these type of burdens. Hospitalization analysis can help to discern this scenarios.

Figure 7: Effect of river seasonality on emergency conditions mortality



(a) Emergency



(b) Non-Emergency

Note: Coefficients of the estimation 1 on adjusted mortality rate per 100,000 inhabitants due to (a) emergency conditions, and (b) non-emergency conditions. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

Table 6: Effects on mortality due to emergency conditions by burdens

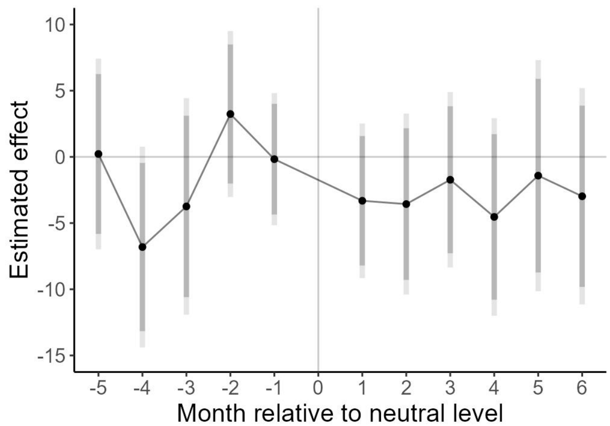
	Non-Emergency	Emergency			
		General	Non-Communicable	Communicable	Injuries
	(1)	(2)	(3)	(4)	(5)
Flood season	0.349	0.243 *	0.229 *	-0.040	0.054
	(0.239)	(0.141)	(0.125)	(0.039)	(0.101)
Drought season	-0.069	0.396 **	0.166	-0.094 **	0.325 ***
	(0.274)	(0.168)	(0.114)	(0.040)	(0.111)

*Note: **** p <0.01; ** p <0.05; * p <0.1. All estimations with controls and municipality, date and month:municipality fixed effects. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

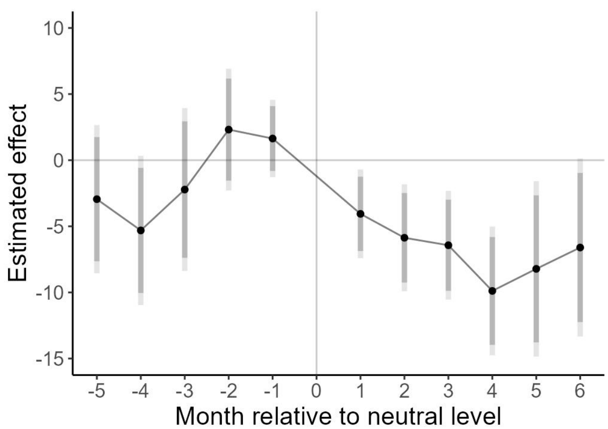
5.2 Effects of seasonality on hospitalizations

Hospitalization rates, in comparison to mortality rates, can provide insights into access to health care, particularly in developing regions. High hospitalization rates alongside lower mortality rates indicate that individuals have access to medical facilities and are receiving the necessary treatment for their conditions. Conversely, lower hospitalization rates paired with higher mortality rates may suggest barriers to accessing healthcare services. This scenario is evident in the Brazilian Amazon. In Figure 8, I show the results for general, communicable, and non-communicable adjusted sex-age hospitalization rates. There is no clear pattern for the general hospitalization outcome. Although there is a significant increase in hospitalizations due to non-communicable diseases in one specific month during the flood season (-5), a clear pattern is observed only for communicable diseases. These results are corroborated by the effects of the joint season analysis provided in the Table 7. During the flood or drought season, there is no significant effect on overall hospitalizations or chronic diseases. Therefore, the peak in mortality during the flood season due to non-communicable diseases is not accompanied by a higher hospitalization rate, indicating possible health care access problems.

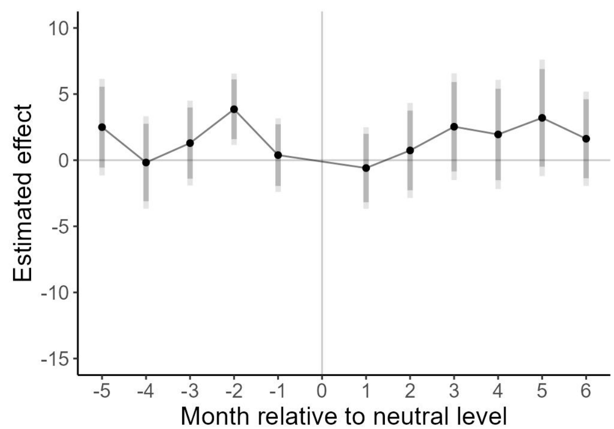
Figure 8: Effect of river seasonality on hospitalization (per 100,000 inhabitants)



(a) General



(b) Communicable



(c) Non-Communicable

Note: Coefficients of the estimation 1 on (a) overall age-sex adjusted hospitalizations, (b) communicable, and (c) non-communicable. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

Table 7: Effects on hospitalizations by burdens

	General (1)	Communicable (2)	Non-Communicable (3)	Emergency (4)	Non-Emergency (5)
Flood season	-1.013	0.140	0.967	2.831 ***	-3.459 ***
	(2.186)	(1.538)	(1.006)	(0.794)	(1.036)
Drought season	-2.547	-4.780 ***	0.809	-2.841 ***	-0.948
	(2.458)	(1.654)	(1.256)	(0.999)	(0.728)

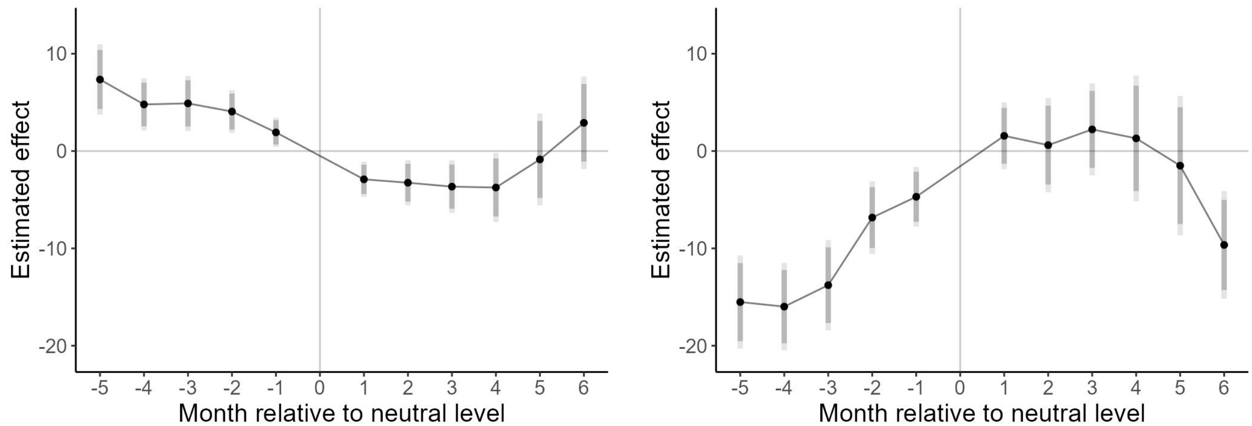
*Note: **** p <0.01; ** p <0.05; * p <0.1. Hospitalizations per 100,000 inhabitants. All estimations with controls and municipality, date and month:municipality fixed effects. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

Hospitalization due to emergency conditions

In Figure 9, the results for the hospitalization rate for emergency and non-emergency conditions are displayed. In this case, the existence of higher mortality without a corresponding increase in hospitalization rates is a more noticeable indicator of challenges in accessing adequate healthcare. During the drought season, when there is a higher number of deaths due to emergency conditions, there is not a relatively higher hospitalization rate. In fact, by analyzing the joint season effects in Table 7, there is a decrease of 2.8 hospitalizations per 100,000 inhabitants due to emergency burdens. Therefore, even with a higher prevalence of emergency conditions during the drought season, emergency policies are not effectively providing adequate care. As explained in Section 2, navigation in the rivers becomes challenging during the drought season, thus increasing the difficulty in providing emergency care.

On the other hand, a similar process occurs for non-emergency conditions during the flood season. Although there is an increase in mortality for these conditions during the flood season, there is a relatively lower hospitalization rate as shown in Figure 9. The results for the whole season in Table 7 reveal that during the flood season there are 3.6 fewer hospitalizations per 100,000 inhabitants compared to the neutral month. Therefore, even for non-emergency conditions, there are shortcomings in the provision of care. However, the mechanisms that explain these barriers differ from those in the drought season, as discussed in the following sections.

Figure 9: Effect of river seasonality on emergency conditions mortality



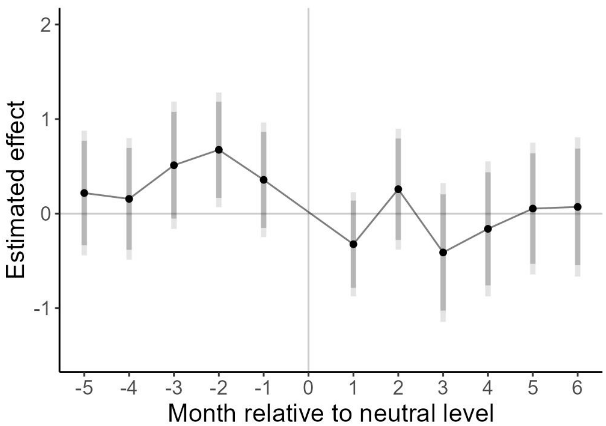
(a) Emergency (b) Non-Emergency

Note: Coefficients of the estimation 1 on adjusted hospitalization rate per 100,000 inhabitants due to (a) emergency conditions, and (b) non-emergency conditions. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

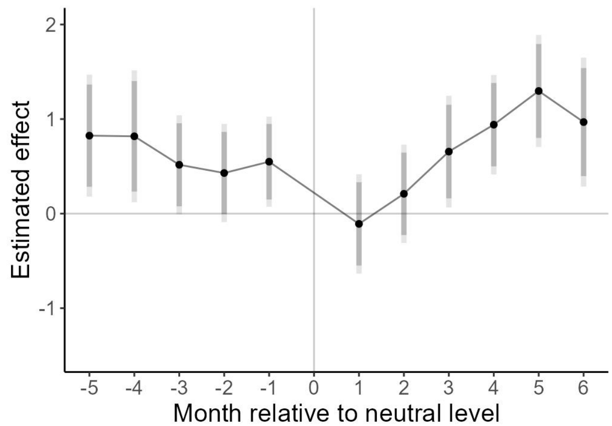
5.3 Effects of seasonality on place of death

The place of death can be a significant indicator of access to health care, particularly in developing regions. In these areas, a higher proportion of deaths occurring at home or in non-medical settings often reflects inadequate access to health facilities, lack of transportation, financial barriers, and insufficient availability of medical resources. Conversely, a higher proportion of deaths in hospitals or clinics may suggest better access to healthcare services and emergency care. In Figure 10, I present the results for deaths in hospitals and non-hospitals (mortality rate minus the mortality rate of deaths in hospitals). Although there is higher mortality in hospitals during the flood season, there is also a higher number of deaths outside hospitals throughout this period. When comparing all places of death accounted for in the data, as shown in Table 8, there is a higher mortality rate during floods primarily in homes (0.44 deaths per 100,000 inhabitants), indicating a suboptimal scenario for health care provision.

Figure 10: Effect of river seasonality on mortality by place of death (per 100,000 inhabitants)



(a) Hospital



(b) Non-Hospital

Note: Coefficients of the estimation 1 on adjusted mortality rate by place of death: (a) hospital, and (b) non-hospital (home, street, another health facilities, others). Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

Table 8: Effects on mortality rate by place of death

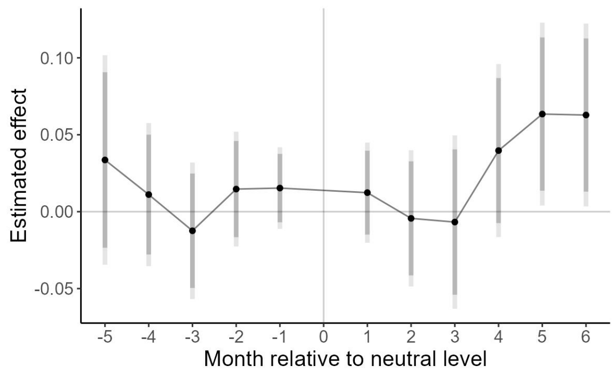
	Hospitals (1)	Other health f. (2)	Home (3)	Street (4)	Others (5)
Flood season	0.340	-0.054	0.442 ***	-0.019	0.003
	(0.212)	(0.079)	(0.163)	(0.078)	(0.078)
Drought season	-0.058	0.007	0.103	0.170 **	0.074
	(0.245)	(0.086)	(0.165)	(0.080)	(0.076)

*Note: **** p <0.01; ** p <0.05; * p <0.1. All estimations with controls and municipality, date and month:municipality fixed effects. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

5.4 Effects of seasonality on outpatient procedures

Outpatient procedures, which include diagnostic tests, minor surgeries, and routine check-ups, are critical for maintaining public health and preventing more serious conditions. A low number of outpatient procedures indicates barriers to accessing healthcare services. Figure 11 shows the effect of river seasonality on the number of outpatient procedures (log.). In this case, we can see that there is no peak during the flood season, a period in which I have already identified higher mortality. The estimation using joint season effect (Table 9) also show the same result. Therefore, this result, alongside the data on hospitalizations and place of death, indicates that there is a demand for healthcare that is not being met.

Figure 11: Effect of river seasonality on outpatient procedures



Note: Coefficients of the estimation 1 on log of the total number of outpatient procedures. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

Table 9: Effects on outpatient procedures by level of care

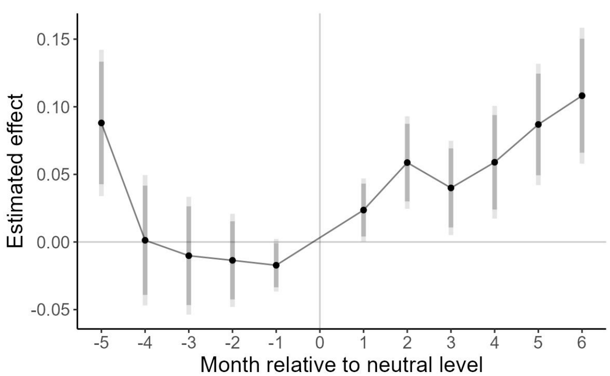
	Procedures (1)	Primary (2)	Secondary (3)	Tertiary (4)	Others (5)
Flood season	0.001	0.009	0.019	-0.011	-0.010
	(0.013)	(0.018)	(0.024)	(0.008)	(0.020)
Drought season	0.020	0.000	0.051 **	0.009	-0.005
	(0.017)	(0.022)	(0.023)	(0.007)	(0.022)

*Note: **** p <0.01; ** p <0.05; * p <0.1. Effects on log. of outpatient procedures. All estimations with controls and municipality, date and month:municipality fixed effects. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

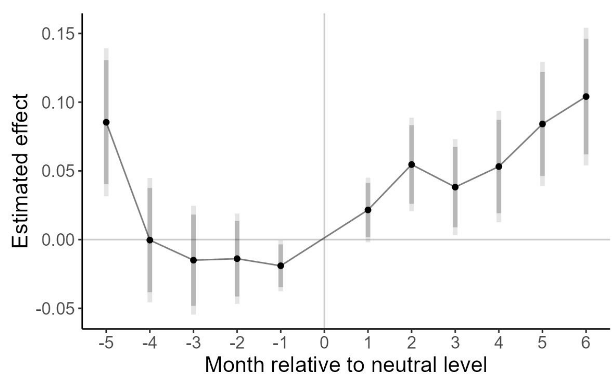
5.5 Effects of seasonality on dispensed medications

Analyzing the number of dispensed medications, particularly for chronic conditions like hypertension, can provide crucial insights into access to healthcare. Hypertension requires ongoing management and consistent access to medication to prevent severe health complications such as heart attacks or strokes. A low number of dispensed hypertension medications may suggests that patients do not have reliable access to the healthcare system and are not able to manage their condition effectively. Based on this set of evidence, the Brazilian government provides subsidized or free medications to the population through the *Farmácia Popular* program [Popular Pharmacy]. The main type of medication provided is for chronic diseases (diabetes, asthma and cardiovascular diseases), contraceptives, and common infections. Figure 12 shows the result of the main estimation for the total number of dispensed medications and for hypertension (log.). The pattern is the same for the both of them. During the flood season the number of dispensed medications is similar to the neutral month, but during the dry season there, using the estimated overall effect of Table 10, there is an increase of 4.6% in the number of dispensed medications. Therefore, this another evidence about the indirect mechanism that explain a higher mortality during the flood season, specially for chronic diseases. Although the consequence of not taking the medication in time can take a while for have a effect on health outcomes, it is a proxy for health accessibility.

Figure 12: Effect of river seasonality on dispensed medications



(a) Total



(b) Hypertension

Note: Coefficients of the estimation 1 on (a) total number of dispensed medications (log.) by Popular Pharmacy program, and (b) hypertension medications. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).

Table 10: Effects on dispensed medications

	Total (1)	Hypertension (2)
Flood season	0.004	0.001
	(0.012)	(0.012)
Drought season	0.046 ***	0.043 ***
	(0.013)	(0.013)

*Note: **** p <0.01; ** p <0.05; * p <0.1. Total number of dispensed medications (log.) by Popular Pharmacy program, and hypertension medications. All estimations with controls and municipality, date and month:municipality fixed effects. Controls: per capita Bolsa Família beneficiary families (log.), per capita GDP (log.), and population (log.), number of beds per capita, and primary health care teams, and local precipitation. Grouped errors by subbasin. Weighted by population (log.).*

6 Conclusion

The objective of this research is to identify the possible effects of the seasonality of an environmental factor on health outcomes. Given the relevance of certain factors for life in developing regions, seasonal variations may have repercussions for health that go beyond the variation in communicable diseases. This has important implications given the scenario of worsening climate change. I used econometric methods to disentangle the effect of river seasonality in the Brazilian Amazon on health outcomes from other seasonal events. The results show that there is indeed higher mortality from non-communicable causes during the flood period, when there is evidence of discontinuous care, and higher mortality due to emergency conditions in the dry season, when accessibility is more difficult due to the depth of the rivers.

Although cardiorespiratory diseases are impacted by temperature (Burkart et al., 2014) and air pollution (Al-Kindi et al., 2020), I present evidence that the observed pattern in the Amazon may be explained by indirect mechanisms, such as disruption of health services during floods. This disruption of the system can be observed in four dimensions: lower dispensation of subsidized medications, reduced production of ambulatory care, higher mortality in homes, and lower hospitalization rates. In other words, the population does not access subsidized continuous-use medications, and there is a significant lack of access to health services.

This is an alarming result, as climate change is expected to lead to more frequent extreme droughts and floods in the Amazon (Gomes et al., 2020). Considering that the Amazon has a younger population (Rocha et al., 2021) and recognizing the substantial economic impact of premature deaths (Carter et al., 2017), there is a pressing need for awareness and the implementation of appropriate public health policies to adapt to environmental factors and build resilience in the context of climate change.

Based on these results, we highlight that health-related environmental risks should encompass elements that not only directly impact the human body but also have the potential to disrupt healthcare provision. In future research, it is crucial to investigate whether the increase in mortality attributable to floods represents premature and preventable deaths. It is important to recognize that methodological aspects of the research need improvement, particularly the IV approach and heterogeneity with dimensions regarding river use. A necessary topic for further exploration is how seasonal patterns are disrupted or not by extreme events.

References

Al-Kindi, S. G., Brook, R. D., Biswal, S., and Rajagopalan, S. (2020). Environmental determinants of cardiovascular disease: lessons learned from air pollution. *Nature Reviews Cardiology*, 17(10):656–672.

Alegana, V. A., Wright, J. A., Pentrina, U., Noor, A. M., Snow, R. W., and Atkinson, P. M. (2012). Spatial modelling of healthcare utilisation for treatment of fever in Namibia. *International Journal of Health Geographics*, 11:1–13.

Blanford, J. I., Kumar, S., Luo, W., and MacEachren, A. M. (2012). It's a long, long walk: accessibility to hospitals, maternity and integrated health centers in Niger. *International Journal of Health Geographics*, 11:1–15.

Bomblies, A. (2012). Modeling the role of rainfall patterns in seasonal malaria transmission. *Climatic Change*, 112(3-4):673–685.

Burkart, K., Khan, M. M. H., Schneider, A., Breitner, S., Langner, M., Krämer, A., and Endlicher, W. (2014). The effects of season and meteorology on human mortality in tropical climates: A systematic review. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 108(7):393–401.

Carter, H. E., Schofield, D., and Shrestha, R. (2017). The long-term productivity impacts of all cause premature mortality in Australia. *Australian and New Zealand Journal of Public Health*, 41(2):137–143.

Chang, C. Y., Abujaber, S., Reynolds, T. A., Camargo, C. A., and Obermeyer, Z. (2016). Burden of emergency conditions and emergency care usage: new estimates from 40 countries. *Emergency Medicine Journal*, 33(11):794–800.

Changnon, S. A. (1996). Effects of summer precipitation on urban transportation. *Climatic Change*, 32(4):481–494.

Chew, F. T., Doraisingham, S., Ling, A. E., Kumarasinghe, G., and Lee, B. W. (1998). Seasonal trends of viral respiratory tract infections in the tropics. *Epidemiology and Infection*, 121(1):121–128.

da Franca, R. R. and Mendonça, F. d. A. (2015). A CHEIA HISTÓRICA DO RIO MADEIRA NO ANO DE 2014: RISCOS E IMPACTOS À SAÚDE EM PORTO VELHO (RO). *Hygeia - Revista Brasileira de Geografia Médica e da Saúde*, 11(21):62–79.

Duffy, P. B., Brando, P., Asner, G. P., and Field, C. B. (2015). Projections of future meteorological drought and wet periods in the Amazon. *Proceedings of the National Academy of Sciences of the United States of America*, 112(43):13172–13177.

Garnelo, L., Parente, R. C. P., Puchiarelli, M. L. R., Correia, P. C., Torres, M. V., and Herkrath, F. J. (2020). Barriers to access and organization of primary health care services for rural riverside populations in the Amazon. *International Journal for Equity in Health*, 19(1):1–14.

Gomes, W. d. B., Correia, F. W. S., Capistrano, V., Veiga, J. A. P., Vergasta, L. A., Chou, S. C., Lyra, A. d. A., and Rocha, V. M. (2020). Avaliação dos Impactos das Mudanças na Cobertura da Terra e Cenário de Emissões (RCP 8.5) no Balanço de água na Bacia do Rio Madeira. *Revista Brasileira de Meteorologia*, 35(4):689–702.

Haines, A. and Ebi, K. (2019). The Imperative for Climate Action to Protect Health. *New England Journal of Medicine*, 380(3):263–273.

Lepage, S. and Morency, C. (2020). Impact of Weather, Activities, and Service Disruptions on Transportation Demand. *Transportation Research Record*, 2675(1):294–304.

Levy, K., Woster, A. P., Goldstein, R. S., and Carlton, E. J. (2016). Untangling the Impacts of Climate Change on Waterborne Diseases: A Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Drought. *Environmental Science and Technology*, 50(10):4905–4922.

Milliman, J. D. and Farnsworth, K. L. (2011). River discharge to the coastal ocean: A global synthesis. *River Discharge to the Coastal Ocean: A Global Synthesis*, pages 1–384.

Otu, E. (2019). *Seasonal geographical access to healthcare in Cross River State*. PhD thesis, University of Sheffield.

Parry, L., Davies, G., Almeida, O., Frausin, G., de Moraés, A., Rivero, S., Filizola, N., and Torres, P. (2018). Social Vulnerability to Climatic Shocks Is Shaped by Urban Accessibility. *Annals of the American Association of Geographers*, 108(1):125–143.

Patz, J. A., Engelberg, D., and Last, J. (2000). The Effects of Changing Weather on Public Health. *Annual Review of Public Health*, 21(1):271–307.

Roberts, P., KC, S., and Rastogi, C. (2006). Rural Access Index : A Key Development Indicator. *Word Bank*.

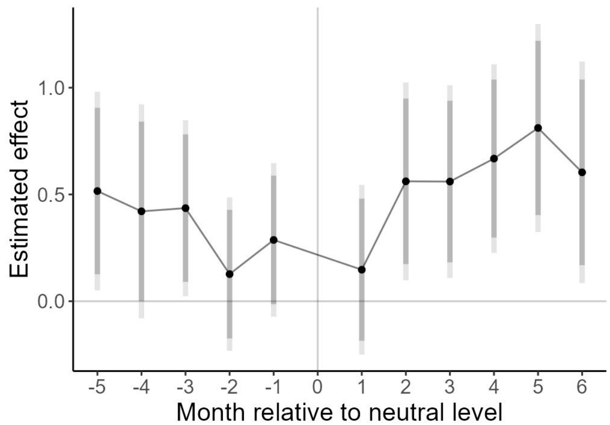
Rocha, R., Camargo, M., Falcão, L., Silveira, M., and Thomazinho, G. (2021). A Saúde na Amazônia Legal: Evolução Recente e Desafios em Perspectiva Comparada. *Amazonia 2030*.

Stone, B., Sambo, J., Sawadogo-Lewis, T., and Roberton, T. (2020). When it rains, it pours: detecting seasonal patterns in utilization of maternal healthcare in Mozambique using routine data. *BMC Health Services Research*, 20(1):1–10.

Tregidgo, D., Barlow, J., Pompeu, P. S., and Parry, L. (2020). Tough fishing and severe seasonal food insecurity in Amazonian flooded forests. *People and Nature*, 2(2):468–482.

A Appendix

Figure A1: Effect of river seasonality on mortality due to injuries



Note: Coefficients of the estimation 1 on mortality due to injuries per 100,0000 inhabitants. Coefficients -5 to -1 represent the flood season, and 1 to 6, drought season. Darker shaded line represents the 95% confidence interval, lighter, 90%. Municipality, date, and month: municipality fixed effects. Grouped errors by subbasin. Weighted by population (log.).